申报	系列：教师（教学科研并重型）
	专业：林学
	职称：教授

业绩成果材料

（申报人的业绩成果材料包括论文、科研项目、获奖以及其他成果等）

单　位（二级单位）：林学与风景园林学院

姓　名　秦新生

材料核对人：　　单位盖章：

核对时间：

华南农业大学制

目　录

一、教学研究业绩

1.教学研究项目 ••

①《广州高校校园植物通识教育手册》编研

② 树木学课程思政示范课程

③ 华南农业大学2023年度在线开放课程（《树木学》）

④ 《风景园林植物应用》国家级一流本科课程（线上）

2.教改论文 ••

3.教学成果奖证书 ••••••••••••••••••••••••••••

4.编写教材 ••

①《园林树木学（华南本 第三版）》

② 国家林业和草原局普通高教育“十四五” 规划教材《古树导论》

③ 全国高等农林院校“十二五”规划教材《树木学（南方本第三版）》

④ 普通高等院校风景园林类专业“十二五”规划教材《园林树木学》

⑤ 教育部首批特色专业资助教材《观赏植物种质资源学》

二、科研项目

1.主持（项目的立项通知（合同）及有关佐证材料）••••••••••

① 国家自然科学基金.中国鹅绒藤属（萝藦科）的分类学研究

② 横向.《海南吊罗山野生植物彩色图鉴》编研

③ 横向.广东罗坑鳄蜥国家级自然保护区古茶树资源普查

④ 横向.坪山新区古树资源普查（古树志编辑）服务项目

⑤ 广州市科技局.《广州市中小学校园常见植物识别手册》专著编研

⑥ 其他纵向.深圳宝安区城市道路园林植物资源及其景观调研

⑦ 其他纵向.深圳宝安区城市道路园林植物及其景观提升导则编研

⑧ 其他纵向. 深圳市宝安区绿化管养监管评价及绿化管养精细化指引编制

⑨ 深圳市宝安区城管局.特大台风“山竹”对宝安区城市道路行道树树木破坏情况的调查及基于抗风性的宝安区行道树树种安全评价、筛选与管护标准体系研究

⑩ 横向.广东省翁源青云山省级自然保护区科研监测体系建设

⑪ 其他纵向. 深圳市宝安区石岩街道主要道路和公园绿化问题调研与应对策略分析

⑫ 国家其他.第四次全国中药资源普查-广东省汕尾市城区、陆丰市中药资源普查

⑬ 横向.广东乳源大峡谷省级自然保护区植物调查监测项目

⑭ 横向.植物标本翻新制作

⑮ 横向.东莞市大岭山森林公园生态公益林道路植物科普展示服务

⑯ 横向.东莞市自然保护区植物多样性固定样地监测

⑰ 横向.人才公园-广东乡土树种博物馆项目技术咨询及方案设计

⑱ 广东省林业局.广东省河源市第二次全国重点保护野生植物资源调查（河源市重点保护野生植物资源调查）

⑲ 国家自然科学基金. 基于古树资源综合评价的高密度城市行道树树种选择指引研究——以澳门为例

⑳ 广东省林业局.狗牙花属药赏两用树种种质资源评价与繁育技术研究

㉑ 横向.古树大树移植和智慧养护关键技术研究

2.主参••••••

的谱系地理学研究

③ 国家自然科学基金.苦楮和钩锥的基因组异质性分化和渗透研究

④ 国家其他.第四次全国中药资源普查-广东省汕头南澳县中药资源普查

⑤ 广东省林业局.林木种质资源调查

⑥ 广东省林业局.碳中和背景下广东省典型优势树种组大径材林培育关键技术体系构建与示范

⑦ 广东省林业局.紫薇属树种种质创新与产业化利用研究

三、论文、著作等

1.检索证明 ••••••

⑥ 东莞园林植物及其应用现状研究. 广东园林，2011. 5：59-65.

⑦ 中国鹅绒藤属（萝藦科）植物研究进展.中国野生植物资源，2011.30(5)：7-13.

⑧ 海南特有野生花卉资源及其利用.中国园林，2011.27（187）：72-78.

⑨ 适合园林应用的三种乌桕属乡土观赏植物. 广东园林,2011. 2: 71-73.

⑩ 2 种石灰岩特有植物的特性及园林应用价值. 广东园林，2011. 1：52-54.

3.以通讯作者发表本专业论文情况 ••••••••••••••••••••••••••••

① Delineating the Area for Sustainable Cultivation of *Morinda officinalis* Based on the MaxEnt Model. Agronomy, 2024. 14, 1134.

② Research progress on Brassicaceae plants: a bibliometrics analysis. Frontiers in Plant Science, 2024.15:1285050.

③ *Ophioglossum hongii* (Ophioglossaceae), a new species from Xizang, China. Phytotaxa,2024. 676 (2): 169-180.

④ 基于 CiteSpace 文献计量分析的红豆属植物研究进展. 安徽农学通报,2024. 30 (15): 59-63.

⑤ 广东省封开县野生林木种质资源调查研究. 中国野生植物资源,2024. 43 (8): 112-119.

⑥ Vein hierarchy mediates the two-dimensional relationship between leaf size and drought tolerance across subtropical forest tree species. Tree Physiology, 2023. tpad141.

⑦ Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in *Phyllostachys propinqua* McClure across Northern

China. Forests, 2023. 14, 2243.

⑧ Statistics and Analysis of Digital Information on Vascular Plant Specimens and the History of Plant Collecting in Guangzhou, China. Plants, 2023. 12, 3325.

⑨ 基于CiteSpace的萝芙木属植物研究知识图谱可视化分析. 北京大学学报（自然科学版），2023. 59(6)：1011-1024.

⑩ 海丰县野生林木种质资源研究.中国野生植物资源，2023. 42(3)：9-14.

⑪ Species characteristics and cultural value of stone wall trees in the urban area of Macao. Scientifc Reports, 2022. 12:1562.

⑫ 广东陆丰市豆科野生药用植物资源调查分析.福建林业科技，2022. 49(2):116-121.

⑬ Purification Efficiency of Three Combinations of Native Aquatic Macrophytes in Artificial Wastewater in Autumn. International Journal of Environmental Research and Public Health, 2021. 18(11):6162.

⑭ 澳门地被植物资源. 广东园林，2021. 43(4)：79-84.

⑪ 广东汕尾城区捷胜镇野生药用植物资源初步研究. 中国野生植物资源，2021. 40(12)：80-84.

⑮ 澳门药用植物资源. 广东园林，2021. 43(1)：60-63.

⑯ 海南夹竹桃科植物园林应用分析与评价. 环境生态学，2019. 1(5):47-56.

⑰ *Gomphogyne hainanensis* (Cucurbitaceae), a New Species from Hainan Island, China. Ann.Bot.Fennici,2017. 54:7-11.

⑱ 海南尖峰岭热带山地雨林2种夹竹桃科植物的空间分布格局与关联性. 生物多样性，2017，25 (10)：1065-1074

⑲ 广州市广雅中学植物造景特点浅析.广东园林，2015. 37（6）：66-69.

⑳ 广州市培正中学园林植物及其应用现状研究. 广东园林，2015. 37（5）：56-58.

㉑ 9 种鹅绒藤属(萝藦科)植物种子微形态特征研究.西南农业学报，2014. 27(2)：797-800.

㉒ 石灰岩特有植物圆叶乌桕土壤与叶片化学元素含量特征. 西南农业学报，2013. 26(3)：1195-1200.

㉓ 中国鹅绒藤属（萝藦科）植物叶表皮微形态扫描电镜研究. 西南农业学报，2013. 26(2)：742-749.

㉔ 17 种 1 亚种鹅绒藤属植物花粉器形态学研究. 西北植物学报，2012. 32(9)：1758-1762 .

㉕ 石灰岩特有植物圆叶乌桕叶表皮形态特征及其生态适应性研究.西北植物学报，2012. 32（4）：0709-0715.

㉖ 12 种鹅绒藤属（萝藦科）植物花粉器形态学研究. 植物研究，2012. 32(2)：137-142.

㉗ 海南浆纸林林下维管植物区系研究. 中南林业科技大学学报，2011. 31（9）：91-96.

4.学术专著 ••

① 第一主编. 2024. 广东大径材树种. 中国林业出版社

② 副主编. 2024. 中国中药资源大典（广东卷 7-8）. 北京科学技术出版社

③ 副主编. 2022. 广东翁源青云山省级自然保护区植物区系与植被. 中国林业出版社

④ 编委. 2022. 中国中草药志（1-5 卷）. 化学工业出版社

⑤ Associate editor. 2021. Flora of Canary Island(Volume 1,2). Science press.

⑥ 副主编. 2020. 中药原植物鉴定图典. 福建科学技术出版社

⑦ 第二主编. 2020. 连山森林康养植物. 中山大学出版社

⑧ 副主编. 2017. 深圳市园林绿化计价标准苗木图鉴（上下册）. 中国计划出版社

⑨ 第二主编.2019. 深圳坪山古树.中国林业出版社

⑩ 副主编. 2019. 中国非粮生物柴油植物. 中国林业出版社

⑪ 第三主编. 2017. 中国喀斯特地区种子植物名录. 科学出版社

⑫ 第三主编. 2014.中国热带雨林地区植物图鉴—海南植物（1-3卷）.华中科技大学出版社

⑬ 编委. 2013. 广东森林植物. 华中科技大学出版社

⑭ 主编. 2013. 海南吊罗山野生植物彩色图鉴. 中国林业出版社

⑮ 编委. 2013. 乐昌植物. 华中科技大学出版社

⑯ 副主编. 2012. 海南植物物种多样性编目. 华中科技大学出版社

四、科研成果

1.科技奖励证书 ••

① 广东省农业技术推广奖 二等奖.广东省石灰岩山区造林树种选择和造林技术推广.2017

② 广东省科学技术奖一等奖.中国南海岛屿植物多样性研究及产业化.2017

2.标准 ••

广东省地方标准. 2019. 黄花风铃木栽培技术规程

五、其他业绩

1.指导学生学科竞赛 ••

① 首届全国植物生产类大学生实践创新论坛（南京农业大学）《中国鹅绒藤属植物叶表皮微形态扫描电镜研究》论文获二等奖.2013.

② 第二届全国植物生产类大学生实践创新论坛暨成果展（西北农

林科技大学）《9 种鹅绒藤属(萝藦科)植物种子微形态特征研究》论文获二等奖.2014.

③ 首届全国植物生产类大学生实践创新论坛“学生最喜欢的实践创新项目作品”.2013

④ 第二届全国植物生产类大学生实践创新论坛暨成果展“学生最喜欢的实践创新项目作品”.2014

2.其他

① 广东园林学会2022年优秀论文征集评选活动一等奖. 朱槿品种资源与分类探讨

② 华南农业大学 2019-2021 年部门工会工会工作积极分子

③ 粤港澳大湾区生态保护与生态系统治理高端学术研讨会优秀论文二等奖（中国林学会）

④ 华南农业大学第八届（2018-2020 年）本科教学督导

项目编号：JG14 0 4 4

华南农业大学教育教学改革与研究项目

申　报　书

项目名称：《广州高校校园植物通识教育手册》编研

申 请 人：秦新生

工作单位：林学院（盖章）

职　　称：副教授

移动电话：13416164982

电子邮箱：qinxinsheng@scau.edu.cn

申请日期：2014 年 4 月 17 日

华南农业大学 教务处 制

001

一、简表

<table>
<tr><td rowspan="3">项目简况</td><td>项目名称</td><td colspan="6">《广州高校校园植物通识教育手册》编研</td></tr>
<tr><td>项目类别</td><td colspan="6">□攻关项目　□非攻关项目√　（评审后确定资助类别）</td></tr>
<tr><td>起止时间</td><td colspan="6">2014 年 7 月 —— 2016 年 7 月</td></tr>
<tr><td rowspan="11">项目申请人</td><td>姓名</td><td>秦新生</td><td>性别</td><td>男</td><td>出生年月</td><td colspan="2">1979 年 8 月</td></tr>
<tr><td>专业技术职务</td><td colspan="2">副教授</td><td>行政职务</td><td colspan="2">无</td></tr>
<tr><td>学历</td><td colspan="2">研究生</td><td>最终学位</td><td colspan="2">博士</td></tr>
<tr><td rowspan="3">所在单位及联系方式</td><td>单位名称</td><td colspan="5">华南农业大学林学院</td></tr>
<tr><td>办公电话</td><td colspan="2">无</td><td>手机</td><td colspan="2">13416164982</td></tr>
<tr><td>E—mail</td><td colspan="5">qinxinsheng@scau.edu.cn</td></tr>
<tr><td rowspan="5">主要教学工作简历</td><td>时间</td><td>课程名称</td><td colspan="2">授课对象</td><td>学时</td><td>所在单位</td></tr>
<tr><td>2014 年上半年</td><td>树木学</td><td colspan="2">12 城市林业 1</td><td>64+1 周</td><td>林学院</td></tr>
<tr><td>2013 年上半年</td><td>树木学</td><td colspan="2">11 城市林业 1</td><td>48+1 周</td><td>林学院</td></tr>
<tr><td>2013 年下半年</td><td>观赏树木学</td><td colspan="2">13 旅游管理 2、3</td><td>32+1 周</td><td>林学院</td></tr>
<tr><td>2013 年下半年</td><td>园林树木学</td><td colspan="2">12 园林 3</td><td>48+0.5 周</td><td>林学院</td></tr>
<tr><td rowspan="5">主要教学改革和科学研究工作简历</td><td>时间</td><td colspan="4">项目名称</td><td>获奖情况</td></tr>
<tr><td>2009-2010</td><td colspan="4">《树木学校园实习手册》编研</td><td>无</td></tr>
<tr><td>2008-2013</td><td colspan="4">海南非粮柴油能源植物资源的调查、收集与保存</td><td>无</td></tr>
<tr><td>2010-2013</td><td colspan="4">中国鹅绒藤属植物分类学研究</td><td>无</td></tr>
<tr><td></td><td colspan="4"></td><td></td></tr>
<tr><td rowspan="7">项目组</td><td>总人数</td><td>高级</td><td>中级</td><td>初级</td><td>博士后</td><td>博士</td><td>硕士</td><td>本科</td></tr>
<tr><td>5</td><td>1</td><td>2</td><td></td><td></td><td></td><td>2</td><td></td></tr>
<tr><td rowspan="5">主要成员（不含申请者）</td><td>姓名</td><td>性别</td><td>出生年月</td><td>职称</td><td>工作单位</td><td colspan="2">分工</td><td>签名</td></tr>
<tr><td>郑明轩</td><td>男</td><td>1981-9</td><td>实验师</td><td>林学院</td><td colspan="2">实地调查</td><td></td></tr>
<tr><td>姜春宁</td><td>女</td><td>1980—5</td><td>讲师</td><td>林学院</td><td colspan="2">实地调查</td><td></td></tr>
<tr><td>何增丽</td><td>女</td><td>1990—12</td><td>硕士生</td><td>林学院</td><td colspan="2">实地调查、图文编撰</td><td></td></tr>
<tr><td>申凯歌</td><td>女</td><td>1988—3</td><td>硕士生</td><td>林学院</td><td colspan="2">实地调查、图文编撰</td><td></td></tr>
</table>

二、立项依据：（项目的意义、现状分析）

通识教育（general education）是对所有学生的教育，是造就具备远大眼光、通融识见、博雅精神和优美情感人才的高层文明教育和完备的人性教育，目的在于培养健全的个人和自由社会中健全的公民。通识教育是是一种大学理念，即整个大学的办学思想，其实质就是对自由与人文传统的继承。

通识教育的思想，源远流长，早在《中庸》中就已主张做学问应“博学之，审问之，慎思之，明辨之，笃行之”。19 世纪初美国帕卡德（A.S.parkard）教授第一次将它与高等教育联系起来，目前已是世界各大学普遍接受的国际化议题，应当引起中国教育界的充分重视，应作为一项重要任务贯穿在学生日常学习和生活中。校园是广大师生学习、生活的重要场所，优雅的校园环境是学生健康成长的基本保障，一个干净、舒适、美观的校园环境，使人产生美的感受，学生置身其间，能够感受到“随风潜入夜，润物细无声”那样一种潜移默化的教育。良好的校园环境能够培养学生发现美、欣赏美、热爱美并且创造美的高尚情操，达到人与自然的和谐统一。校园同时也是高校自然科学课程，特别是生物课程教学与实习的主要场所，校园内的野生和栽培植物都是很好的生物教学资源，因为它们看得见、摸得着，便于观察、取材和探究，是学生最容易亲近的生物，它们为学生识别和观察植物提供了良好素材。

校园植物是学校环境绿化、美化不可或缺的重要组成部分，也是校园精神文明建设的重要标志之一，它对绿化校园生态环境、美化学习环境以及优化育人环境等都起到了重要作用。随着我国教育改革的深入发展，通识性教育课程的比重明显在上升，校园植物很多种类具有丰富的生物学和人文知识，因而具有通识性教育的潜在价值。如果能让学生全面了解校园植物的分类学知识、经济价值和相关的人文知识，文科学生能够从中了解植物的分类学知识及经济价值等，理科学生则能从中了解植物的人文知识，这样既开阔了他们的视野，又培养了他们的探究意识和审美情趣。广州市自然地理条件优越，是我国改革开放的前沿阵地，其经济、政治、科技、文化都取得了令人瞩目的成就，其中高等教育也走在了全国的前列。广州市很多高等学校具有悠久的办学历史，校园环境优雅，得天独厚的气候条件非常适合南亚热带和热带北缘植物的生长，植物种类丰富，其中不乏建

校初期保存下来的古树名木，它们是学校历史、环境变迁最好的见证，也是学校宝贵的物质和文化遗产。据我们了解，很多高校师生对身边的植物很感兴趣，却苦于少有通俗易懂的资料可供查询,因目前很多工具书过于专业化而难以使用。近年来，随着广州市高校办学规模的日益扩大以及校园改扩建工程的实施，校园面貌日新月异，校园园林绿化也陆续引进不少国内外的园林植物，同时校园内一些不为人关注的“杂草”也在悄然消失。

为了让广大师生更快地识别校园内与自己朝夕相处的植物，更好地服务于教学实践工作，适应新时代人才培养的要求，当前有必要对广州市高校的校园植物进行全面调查，编撰一本介绍广州高校校园植物内容全面、图文并茂、通俗易懂的科普读物。编撰“通识教育手册”这类工作国外做的很多，但国内仍处于起步阶段，特别是针对高校学生这一特殊而重要的读者群体，国内此类读物至今仍未见正式出版。本手册的编研、出版将是广州市高校素质教育发展的重要标志，它也将为广州市高校的生物教学和校园绿化提供重要基础资料。

三、项目实施方案及实施计划

1.具体改革内容、改革目标和拟解决的关键问题

项目改革内容：

本项目主要是通过实地调查，拍摄精美彩色植物照片，编撰《广州高校校园植物通识教育手册》专著。主要内容包括以下两个方面：

（1）植物现状实地调查

应用实地调查与历史资料相结合的方法，在不同季节到广州代表性高校校园进行调查，拍摄彩色照片，系统记载校园植物种类、分布、数量及人文知识等，采集、制作校园植物腊叶标本，并对植物标本、照片进行全面整理、鉴定，进行广州高校校园植物编目，确定编写种类名单。

（2）植物专著编撰

编撰《广州高校校园植物通识教育手册》专著 1 部，收录广州高校校园植物约 700 种维管束植物（蕨类和种子植物），内容包括每种植物的名称（中文正名、别名、英文名、学名）、形态、产地、生境、分布、用途及主要鉴别要点，并配以精美的花、果、树形彩色照片，每种植物至少有 3 张彩色照片。

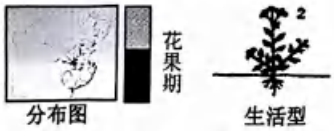
正文范本：

凤凰木（火树、红花楹、金凤）
Delonix regia (Boj.) Raf.
Flame tree
苏木科 Caesalpiniaceae

主要特征 落叶乔木。二回羽状复叶有羽片15-23对，羽片有小叶20-40对①；小叶长圆形，长4-8mm。花冠鲜红色至橙红色，具黄色斑②。荚果微呈镰开形，扁平③。花期5-8月，果期8-10月。花红叶绿，满树如火，犹如蝴蝶飞舞其上。“叶如飞凰之羽，花若丹凤之冠”，故名“凤凰木”。

分布 原产地马达加斯加及热带非洲。中国台湾、海南、福建、广东、广西、云南等省区有引种栽培。

用途 株型优雅，花色艳丽，具较高观赏价值，可用做庭院或行道树。



凤凰木与南洋楹（*Falcataria moluccana*）的区别：前者顶端枝条常扭曲；小叶长圆形且两侧对称，长不足1cm，小叶20-40对①；花大，红色②；果长达60cm③。后者顶端枝条通直；小叶菱状长圆形且两侧不对称，长超过1cm，小叶仅6-26对④；花小，白色⑤；果长不足15cm⑥。



2.实施方案、实施方法、具体实施计划（含年度进展情况）及可行性分析

实施方案：

本项目主要采用实地调查与资料查阅、点与面相结合的方法，选取广州市具有代表性的高等学校开展校园植物实地调查，初步选定的调查范围包括华南农业大学、中山大学、华南理工大学、华南师范大学、暨南大学、广州中医药大学、广州大学、广东外语外贸大学、南方医科大学及广东工业大学等人口集中、植物丰富、建校历史悠久的校园。调查的内容包括记录校园植物种类、分布、数量及人文知识等，采集、制作校园植物腊叶标本，同时每种植物均拍摄景观、全株、花和果特写彩色照片，并进行 GPS 定位。

在开展外业调查工作的同时进行室内标本、照片的整理与鉴定，确定编写种类名单后，开始收录种类的文字编写和部分补点调查。照片、文字审校达至出版要求。

年度进展：

本项目拟在 2014 年 7 月至 2016 年 7 月开展，历时两年，具体安排如下。

2014.7—2015.12　深入广州高校校园调查植物、拍摄照片；整理、鉴定照片；

2016.1—2016.7　补充调查、拍摄照片；完成《广州高校校园植物通识教育手册》专著的图文编写、通稿和审校等工作；撰写结题报告。

可行性分析：

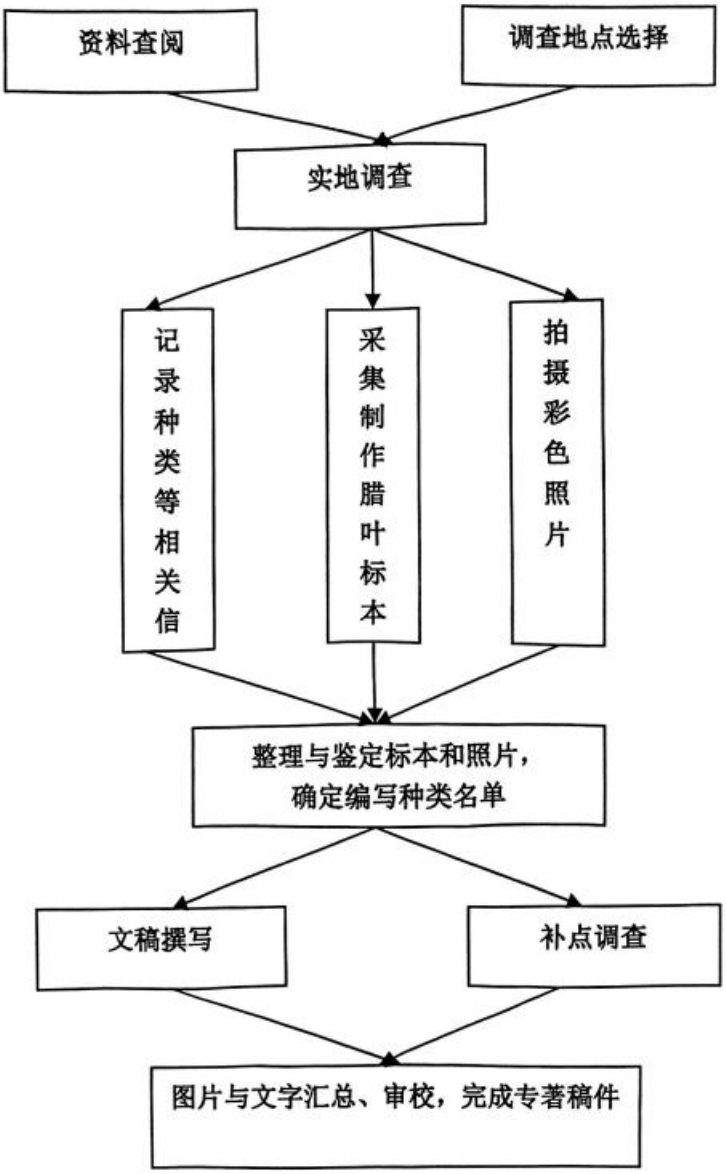
本项目申报单位华南农业大学是广东省和农业部共建“211 工程”的全国重点大学。拥有开展教学和科学研究的良好条件，华南农业大学林学院是该校最早设立的一个学院，也是广东省高校中唯一具有林学本科办学资格的单位，林学院建还有馆藏 10 万余份标本（其中 200 多份模式标本）的植物标本馆（ 国际代码为 CANT），有占地面积约 300 亩、引种 1100 多种的树木园以及专业图书资料室，完全满足本项目的要求。

申请人所在的华南农业大学林学院树木学教研室具有良好的植物分类学研究基础，项目组成员具有丰富的野外植物调查和教学科研经验，熟悉植物摄影技巧和图片处理方法。

申请人和项目组成员已主编或参编出版与本项目相关的专著与教材近 15 部，积累了大量文图素材和成功编辑经验，可以确保本专著的编研质量。

校园植物调查、拍摄较为便利，不受时间和空间的限制，申请人及项目组成员多年来已拍摄了大量校园植物照片，故在经费有限的情况下可以保证本项目能按时按质完成。

项目实施的技术路线图：



3.项目预期的成果和效果（包括成果形式，预期推广、应用范围、受益面等）

项目预期成果形式：

编撰完成《广州高校校园植物通识教育手册》专著 1 部。

项目预期推广、应用范围及受益面：

本书的编写力求集科学性、趣味性、实用性为一体，区别于现有的植物志书及彩色图谱。

读者群主要是高校广大师生，但对于小学、中学师生及林业、园艺工作者和植物爱好者等也具有较高的参考价值。相信出版后会取得社会良好反响并能起到示范作用。

4. 本项目的特色与创新之处

（1） 本手册的编写区别于一般的专业丛书，主要致力于植物分类学知识的普及，其定位既考虑到专业性、知识性，也考虑到一定的趣味性；

（2） 本手册编写体例以方便携带、检索为基本原则，以花色、叶序等特征来编排植物顺序，使非专业读者也能够快捷检索到相应植物；

（3） 本手册全面收录广州市高校校园植物，是首部以广州市高校广大师生为主要读者对象的植物学专著，具有非常重要的科学普及价值，也必将成为广大师生认识植物、了解大自然的重要工具书。

四、现有研究基础

1. 与本项目有关的研究积累或已取得的教学改革工作成绩

项目申请人长期从事植物分类、区系地理方面的研究与树木学、园林树木学、观赏植物学、药用植物学等本科生和研究生课程教学工作。主持和参加的科研项目有 18 项，其中国家级 8 项（1 项主持，7 项参加），省部级 5 项（1 项主持，4 项参加），厅局级 5 项（4 项主持，1 项参加）。已主持完成国家自然科学基金、国家科技部基础性工作专项重点项目专题、广东省自然科学基金及华南农业大学教育与教学改革研究重点项目各 1 项，熟悉华南尤其是广东、海南的植物种类以及植物地理学、植物分类和植物生态学的研究方法。现已发表科研和教改论文共 35 篇，其中 15 篇为第一作者（5 篇被 SCI 期刊收录）；主编和参编的植物学学术专著有 14 部，其中 2 部为主编，2 部为副主编。

申请人参编的《中国的珍稀植物》专著曾获 2007 年“第二届国家图书馆文津图书奖”及 2006 年“新闻出版总署向全国青少年推荐的百种优秀图书”。已发表教学改革论文“如何提高高等农林院校学生识别植物的能力”。

已发表的科研论文和参与编写的专著如下（部分）：

XIN-SHENG QIN, RONG-JING ZHANG AND FU-WU XING *. 2012. A STUDY ON THE FLORA AND VEGETATION OF CAT DUA ISLAND, NORTHEASTERN VIETNAM. *Parkistan Journal of Botany*, 44(4): 1229-1232.

XIN-SHENG QIN, RONG-JING ZHANG and FU-WU XING*. 2008. A new species of *Maytenus* sect. *Gymnosporia* (Celastraceae) from Hainan Island, China. *Botanical Journal of the Linnean Society*, 158:534-538.

Xin-Sheng Qin, Hong-Feng Chen and Fu-Wu Xing*. 2007. A new species of *Drypetes* (Putranjivaceae) from China. *Nordic Journal of Botany*, 25: 38-40.

秦新生. 如何提高高等农林院校学生识别植物的能力. 时代教育. 2009，1：90

秦新生，何科稣，刘立武，孙君梅，齐旭明，施浩. 2012. 海南俄贤岭石灰岩山地海南凤仙花所在群落植物区系及生态特征. 华南农业大学学报（自然科学版），33(3):361-367

秦新生(主编). 海南吊罗山野生植物彩色图鉴. 中国林业出版社. 2013

秦新生(主编). 海南浆纸林林下植物彩色图鉴. 化学工业出版社. 2010

秦新生(副主编). 邢福武等主编. 中国景观植物（上、下册）. 华中科技大学出版社. 2009

秦新生(编委). 广州野生植物. 中国科学院华南植物园和广州市林业局编著. 百通集团贵州科技出版社. 2008

秦新生(编委). 中国的珍稀植物. 湖南教育出版社. 2005

秦新生(编委). 广东植物名录. 世界图书出版社. 2005

秦新生（副主编）. 身边的植物. 中国林业出版社. 2005

2.单位已具备的教研基础和环境及项目的支持情况，尚缺少的条件和拟解决的途径

华南农业大学林学院是广东省高校中唯一具有林学本科办学资格的单位，目前林学院下设4个系，有3个博士学位授予点，7个硕士学位授予点，2个专业硕士点，有林业规划设计院、风景园林设计研究院、森林经理研究室、华南植物研究室、岭南园林规划设计研究室、森林生态研究室、热带园林研究中心、经济林研究中心、高新技术木质复合材料工程中心以及广东省自然保护区研究中心等研发机构，设有广东省木材与木材制品产品质量监督检测站。林学院建还有馆藏10万余份标本（其中200多份模式标本）的植物标本馆，该馆得到了国际植物学会正式承认（ 国际代码为CANT），有占地面积约300亩的树木园，园内已引种1100多种植物，包括约62种珍稀濒危植物。林学院研究成果显著，曾有多项研究成果获得国家、省市的科技进步奖。

华南农业大学具备本项目研究所需的植物标本室、鉴定室以及文献资料室，拥有编研常用网络数据库及专业工具书，如中国期刊网、Wiley-Blackwell期刊、Species 2000、《中国植物志》、《中国高等植物》、《中国高等植物图鉴》、《广东植物志》、*Flora of China* 等。申请人及项目组成员均配备有植物摄影专业相机。上述条件完全可以满足本项目的要求。

3.申请者和项目组成员所承担的教学改革和科研项目情况

申请人及项目组主要成员自2006年7月入校工作以来，就一直承担树木学、园林树木学、观赏植物学、药用植物学及其实习课程教学任务，2009年成功申报1项校级教育教学改革与研究重点项目“《树木学校园实习手册》编研”（2008-2010），该项目已顺利结题，已发表相关教改论文。

五、经费预算

支出科目	金额（元）	计算根据及理由
合计	10,000	
1. 差旅费	4,500	分不同季节到校园调查植物、拍摄照片所需的交通、住宿费等。
2. 材料费	4,000	购置、打印文献资料、调查及摄影、图文编辑等所需用具。
3. 人员费	1,500	参加项目调研研究生及本科生劳务费。

六、申请者所在单位评审、推荐意见

单位意见

同意申报

（公章）

单位领导签字：

二〇一四 年 四 月 二十 日

七、评审小组意见

同意立项

评审小组长签字：

二〇一四 年 四 月 二十五 日

八、学校意见

同意立项

签章：

二〇一四 年 四 月 二十五 日

华南农业大学文件

华南农教〔2023〕1号

关于公布华南农业大学2022年度课程思政示范项目认定名单的通知

各学院、部处、各单位:

根据《华南农业大学课程思政实施方案》(华农党发〔2022〕26号)精神和《关于开展2022年度校级课程思政示范项目遴选认定工作的通知》要求，学校组织开展了2022年度课程思政示范项目遴选认定工作。

经项目负责人申请、所在单位遴选推荐、学校组织专家评审、校内公示等程序，现认定华南农业大学2022年度课程思政示范项目共177个,其中包括资源环境学院等课程思政试点学院3个、“动物生物化学与饲料生物技术教学团队”等课程思政示范团队19个、《动物组织学与胚胎学》等课程思政示范课程43门、“微观经济学-第八章第三节”等课程思政示范课堂54个、《概率论

与数理统计》等课程思政典型案例 58 个，现予以公布（名单详见附件）。

本次认定的试点学院建设期至 2024 年 9 月，其他示范项目的有效期至 2026 年 12 月 31 日；有效期内，示范项目原则上不允许更换负责人或变更项目团队成员。获评为课程思政示范课程的，将同时认定为 2022 年度校级一流本科课程（课程思政）。试点学院要按照项目建设任务及要求，及时开展各项工作，加快推进课程思政改革，确保高质量完成建设目标。

请各学院充分认识课程思政改革的重要意义，认真贯彻《华南农业大学课程思政实施方案》，加强对教师的相关培训、指导、引领和支持，带动教师全员积极参与课程思政教学改革，持续深入抓典型、树标杆、推经验，全面提升本科人才培养质量。

附件：华南农业大学 2022 年度课程思政示范项目认定名单

华南农业大学

2023 年 1 月 8 日

公开方式：主动公开

华南农业大学党政办公室　　2023 年 1 月 12 日印发

附件

华南农业大学2022年度课程思政示范项目认定名单

一、试点学院

序号	建设单位
1	资源环境学院
2	经济管理学院
3	兽医学院

二、示范团队

序号	建设单位	示范团队名称	负责人
1	动物科学学院	动物生物化学与饲料生物技术教学团队	习欠云
2	数学与信息学院、软件学院	数学建模课程思政示范团队	房少梅
3	电子工程学院（人工智能学院）	电子信息工程专业基础课程思政教学团队	宋淑然
4	食品学院	食品微生物学课程思政示范团队	钟青萍
5	材料与能源学院	无机及分析化学课程思政示范团队	刘英菊
6	园艺学院	压花艺术教学团队	陈国菊
7	人文与法学学院	刑事法实践教学团队	杜国明
8	海洋学院	水产专业基础课程思政教学团队	王梅芳
9	数学与信息学院、软件学院	数字电路与逻辑设计教学团队	黄　琼
10	园艺学院	果树学课程思政教学团队	黄旭明

		学改革探索	
35	外国语学院	国际商务谈判	尹静媛
36	海洋学院	《鱼类生理学》	赵会宏
37	兽医学院	兽药残留分析	陈　红
38	林学与风景园林学院	树木学	秦新生
39	材料与能源学院	有机化学	李春远
40	人文与法学学院	《婚姻家庭与继承法》	李艳梅
41	数学与信息学院、软件学院	复变函数与积分变换	刘　丹
42	外国语学院	扎根中国 融通中外 学以致用 《大学基础英语》课程思政	梁红梅
43	水利与土木工程学院	地下工程计算机软件应用	张　巍

四、示范课堂

序号	建设单位	示范课堂名称	负责人
1	经济管理学院	微观经济学-第八章第三节	申津羽
2	数学与信息学院、软件学院	数学建模-第十一章回归分析第一节	朱艳科
3	兽医学院	兽医流行病学-第一章绪论第一节	曹伟胜
4	人文与法学学院	美学导论-美学的研究对象	李　飞
5	资源环境学院	测量学-水准测量原理与外业工作	姚朝龙
6	数学与信息学院、软件学院	高等数学	林利云
7	海洋学院	《海洋生物学基础》课程示范课堂	严慕婷
8	经济管理学院	农林产品国际贸易	张奕婧
9	植物保护学院	知农药残留，保食品安全，守环境健康	刘家莉

附件 1：

华南农业大学 2023 年度在线开放课程建设项目名单

编号	课程名称	负责人	所属单位
Zxkc202301	跨文化交际	刘傲冬	外国语学院
Zxkc202302	情商训练	吴琪	人文与法学学院
Zxkc202303	动物组织学与胚胎学	梁晓欢	兽医学院
Zxkc202304	应用统计学	张建桃	数学与信息学院、软件学院
Zxkc202305	理论力学	胡圣荣	水利与土木工程学院
Zxkc202306	瑜伽——身心疗愈，共创美好	何灵捷	体育教学研究部
Zxkc202307	会计学原理	陈晓敏	经济管理学院
Zxkc202308	森林培育学	邱权	林学与风景园林风学院
Zxkc202309	民族服饰传承与传播	陈金怡	艺术学院
Zxkc202310	动物营养学	张世海	动物科学学院
Zxkc202311	社会调查理论与方法	廖杨	公共管理学院
Zxkc202312	树木学	秦新生	林学与风景园林风学院
Zxkc202313	《红楼梦》里的哲学	李飞	人文与法学学院
Zxkc202314	工程热力学与传热学	张烨	工程学院
Zxkc202315	园艺产品营养与功能	王惠聪	园艺学院
Zxkc202316	媒介概论	赵娜	艺术学院
Zxkc202317	复变函数	刘丹	数学与信息学院、软件学院
Zxkc202318	统计学原理	谭莹	经济管理学院
Zxkc202319	种子加工与贮藏学	张亚锋	农学院
Zxkc202320	新能源材料	胡航	材料与能源学院

附件

第二批国家级一流本科课程公示名单

一、线上一流课程（1095门）

序号	课程名称	课程负责人	课程团队其他主要成员	主要建设单位	主要开课平台
1	欧盟经济	吴侨玲		北京大学	学堂在线
2	投资银行学	冯科		北京大学	爱课程(中国大学 MOOC)
3	宏观经济学	唐遥		北京大学	爱课程(中国大学 MOOC)
4	新结构经济学	林毅夫	付才辉	北京大学	爱课程(中国大学 MOOC)
5	逻辑导论	陈波	冯雪松	北京大学	爱课程(中国大学 MOOC)
6	运动健身原理与方法	赫忠慧	袁睿超、车磊、花琳、邢衍安	北京大学	爱课程(中国大学 MOOC)
7	刘伟教你打乒乓	刘伟		北京大学	爱课程(中国大学 MOOC)
8	中国当代文学	陈晓明		北京大学	爱课程(中国大学 MOOC)
9	汉语修辞学	陈汝东	赵蕾、邹漫云、姜保红、蒋雪颖	北京大学	爱课程(中国大学 MOOC)
10	神话与神话研究	王娟		北京大学	爱课程(中国大学 MOOC)
11	《孟子》精读	吴国武		北京大学	爱课程(中国大学 MOOC)
12	生理学（上、下）	王世强	罗冬根、柴真、白书农	北京大学	爱课程(中国大学 MOOC)
13	遗传学实验	张文霞	辛广伟	北京大学	爱课程(中国大学 MOOC)
14	地球与人类文明	陈斌	郭艳军	北京大学	爱课程(中国大学 MOOC)
15	数学物理方法	吴崇试	高春媛	北京大学	爱课程(中国大学 MOOC)
16	力学	刘树新	田光善、孟策、颜莎、张国辉	北京大学	爱课程(中国大学 MOOC)
17	神经系统疾病病人的护理	江华	李明子、张英爽、刘献增、周宝华	北京大学	爱课程(中国大学 MOOC)
18	常见消化系统疾病病人的围手术期护理	庞冬	路潜、杨萍、金三丽	北京大学	爱课程(中国大学 MOOC)
19	传染病病人的护理	孙玉梅	杨滢、刘春梓、张洁利、韩晶	北京大学	爱课程(中国大学 MOOC)
20	医学免疫学原理	王月丹	初明	北京大学	学堂在线
21	走进护理	王艳	周宇彤、李葆华	北京大学	爱课程(中国大学 MOOC)
22	知识产权法	姚欢庆		中国人民大学	融优学堂

序号	课程名称	课程负责人	课程团队其他主要成员	主要建设单位
1505	病理学	苏敏	刘淑慧、张国红、李晓昀、林润华	汕头大学
1506	感染与免疫	辛岗	苏芸、李春燕、姚芬、刘卫东	汕头大学
1507	汉英翻译	钟书能	朱献珑、巫喜丽	华南理工大学
1508	摄像基础	周煜	陈映、郑重	华南理工大学
1509	化工原理	郑大锋	江燕斌、马四朋、龙新峰、易聪华	华南理工大学
1510	数学物理方程	朱长江	金海洋、刘青青、季善明、温焕尧	华南理工大学
1511	数字系统设计	徐向民	青春美、姜小波、王前、邢晓芬	华南理工大学
1512	射频电路	陈付昌	章秀银、谢泽明、孔永丹、马自龙	华南理工大学
1513	工程制图	王枫红	陈亮、熊巍、张瑞秋、姜立军	华南理工大学
1514	数字逻辑	俞鹤伟	毕盛、冼进、罗荣华、梅登华	华南理工大学
1515	公共管理学方法论	张玉	戴育滨、唐斌、张雯闻、石玲玲	华南农业大学
1516	林业经济管理学	高岚	李怡、周伟、段伟、张奕婧	华南农业大学
1517	市场营销学（双语教学）	张蓓	张光辉、文晓巍、贾莉、王晛	华南农业大学
1518	新制度经济学	罗必良	仇童伟、胡新艳、钟文晶、谢琳	华南农业大学
1519	社会工作导论	卓彩琴	贾昕珊、唐晓容、马林芳、张兴杰	华南农业大学
1520	风景园林植物应用	翁殊斐	冯志坚、冼丽铧、秦新生、姜春宁	华南农业大学
1521	兽医免疫学	陈金顶	琚春梅、易琳、范双旗、郭霄峰	华南农业大学
1522	植物化学保护学	徐汉虹	钟国华、张志祥、刘家莉、林菲	华南农业大学
1523	农业生态学	章家恩	王建武、蔡昆争、舒迎花、赵本良	华南农业大学
1524	农业昆虫学	陆永跃	岑伊静、冼继东、黄振、潘慧鹏	华南农业大学
1525	轮机自动化	贾宝柱		广东海洋大学
1526	急诊医学	陈晓辉	江慧琳、李敏、朱永城、林珮仪	广州医科大学
1527	中医学	王新华	夏鑫华、黄婉怡、张志敏、武志娟	广州医科大学
1528	卫生应急	李芳健	周芸、周泉、唐杰、周小彦	广州医科大学
1529	影像诊断学	谭理连	利晞、李新春、陈淮、宋亭	广州医科大学
1530	临床基础检验学技术	邓小燕	彭亮、陶爱林、杜晶春、吴红	广州医科大学

CSCD来源期刊 中国中文核心期刊 中国科技核心期刊

ISSN 1000-5471
CN 50-1045/N

西南師範大學學報

JOURNAL OF SOUTHWEST CHINA NORMAL UNIVERSITY

自然科学版
NATURAL SCIENCE EDITION

XINAN SHIFAN DAXUE XUEBAO
ZIRANKEXUEBAN

11
2014
第39卷 第11期
中国·重庆
CHONGQING CHINA

西南师范大学学报

（自然科学版）

第39卷　第11期　　总第212期　　2014年11月20日出版

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期刊基本参数：CN50－1045/N＊1957＊b＊A4＊248＊zh＊P＊￥20.00＊1000＊43＊2014－11

DOI:10.13718/j.cnki.xsxb.2014.11.041

农业院校校园植物资源在教学实践中的充分利用

——以华南农业大学为例①

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摘要:校园植物与学校师生学习、生活关系密切,是植物学等相关课程教学的重要素材.该文以百年老校华南农业大学为例,结合近年来的教学体会,就如何充分发挥校园植物资源优势,做好课程实践教学活动进行探讨.

关 键 词:校园植物;教学应用;植物学

中图分类号:G642.0 文献标志码:A 文章编号:1000-5471(2014)11-0229-05

中国是农业大国,以农为本,农业人口占全国人口的绝大多数,因此农村、农业和农民形成的"三农"问题也是历届党和国家政府部门关注的重点.我国以农业研究和人才培养为主的高校众多,除中国香港、中国台湾、中国澳门地区外,基本上每省都有一所农业本科院校,广东省就有华南农业大学和仲恺农业工程学院两所.农业院校涉农专业的研究对象有植物,开设的植物学、园林植物学、观赏植物学、药用植物学以及树木学、园林树木学、观赏树木学、花卉学等是相关专业必修的基础课程,它们多安排在大一或大二,以便为后续课程的学习奠定基础.上述课程实践性非常强,因此平常除理论教学外,一般会安排到校园或周边开展实践教学,理论课程结束后还有 0.5~1 周的实践教学环节.

校园是师生学习、生活的重要场所,也是相关课程教学与实习的主要场所,校园内的野生和栽培植物都是很好的教学资源,因为它们看得见、摸得着,便于观察、取材和探究,是学生最容易亲近的植物,它们为学生识别和观察植物提供了良好素材.此外,校园植物很多种类具有丰富的生物学和人文知识,具有通识性教育的潜在价值.如果能让学生全面了解校园植物的分类学知识、经济价值以及相关的人文知识,文科学生能够从中了解植物的分类学知识及经济价值等,理科学生则能从中了解植物的人文知识,这样既开阔了他们的视野,又培养了他们的探究意识和审美情趣.目前有关校园植物的研究多集中在植物区系、生态设计等方面[1-7].本文以笔者所在的华南农业大学为例,结合多年的实践教学经验,探讨植物学等相关课程的实践教学中如何充分发挥校园植物资源的优势.

1 研究地概况

华南农业大学是广东省和农业部共建"211 工程"的全国重点大学,校园坐落在素有"花城"美誉的广州市天河区五山,占地约 550 万 m^2,校舍总建筑面积约 137 万 m^2,办学历史可追溯至始创于 1909 年的广东全省农事试验场暨附设农业讲习所,现有 23 个学院(部),88 个本科专业,12 个博士学位授权一级学科,

① 收稿日期:2013-12-04

基金项目:华南农业大学林学院院级教改课题资助[华农大(林)字 2011-8 号];国家高等学校本科特色专业建设点——林学课题资助(教高函 201015 号).

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23个硕士学位授权一级学科，52个博士学位授权点，103个硕士学位授权点；教职工2 900多人，全日制在校生4万余人. 全校分为茶山区、华山区、嵩山区、六一区、燕山区、启林区、泰山区和东区等.

2 结果与分析

华南农业大学历经百余年的发展，校园植物丰富. 据现有资料统计，校园分布有维管束植物约1 479种，包含近200科[8-10]；随着校园绿化工程的不断推进以及调查的深入，预计校园植物的数量将可达到1 800种左右. 按照生长习性、分布区域、功用等，华南农业大学校园植物大致可以分为以下几种类型.

2.1 景观植物

此类植物主要分布于校园内各教学区、行政区和生活区，起到遮荫、造景等作用. 常见的植物包括白兰 *Michelia alba*、蝴蝶果 *Cleidiocarpon cavaleriei*、人面子 *Dracontomelon duperreanum*、尖叶杜英 *Elaeocarpus rugosus*、高山榕 *Ficus altissima*、黄葛树 *Ficus virens*、蒲桃 *Syzygium jambos*、白千层 *Melaleuca quinquenervia*、非洲楝 *Khaya senegalensis*、麻楝 *Chukrasia tabularis*、阴香 *Cinnamomum burmannii*、柠檬桉 *Eucalyptus citriodora*、团花 *Neolamarckia cadamba*、海南红豆 *Ormosia pinnata*、大花紫薇 *Lagerstroemia speciosa*、凤凰木 *Delonix regia*、南洋楹 *Falcataria moluccana*、大王椰子 *Roystonea regia* 和假槟榔 *Archontophoenix alexandrae* 等. 2008年以来，学校致力于打造“五湖四海一片林的紫荆校园”环境，在校园里陆续种植了近5 000株苏木科羊蹄甲属 *Bauhinia* 植物，包括洋紫荆宫粉羊蹄甲 *Bauhinia variegata*、白花洋紫荆 *Bauhinia variegata* var. *candida*、红花羊蹄甲 *Bauhinia blakeana*、羊蹄甲 *Bauhinia purpurea* 等，其中种植最多的是洋紫荆和白花洋紫荆.

2.2 野生乡土植物

校园内除了人工栽培的景观植物外，在空旷荒地、房前屋后、路旁、树木园等人为干扰较少之处生长着众多乡土植物. 常见种类包括芒萁 *Dicranopteris pedata*、乌毛蕨 *Blechnum orientale*、构树 *Broussonetia papyrifera*、榕树 *Ficus microcarpa*、对叶榕 *Ficus hispida*、粗叶榕 *Ficus hirta*、野牡丹 *Melastoma malabathricum*、地茶 *Melastoma dodecandrum*、桃金娘 *Rhodomyrtus tomentosa*、岗梅 *Ilex asprella*、地桃花 *Urena lobata*、刺蒴麻 *Triumfetta rhomboidea*、海芋 *Alocasia odora*、淡竹叶 *Lophatherum gracile* 和露籽草 *Ottochloa nodosa* 等. 这类植物中部分种类人们常称之为“杂草”而被铲除，但它们对维持生物多样性以及水土保持等具有不可替代的作用，建议保留.

2.3 野生外来植物

外来植物的来源较为多样化，主要是自然扩散或人为无意带入等方式所致. 这类植物多生长在校园荒地、路旁、林缘等，包括含羞草 *Mimosa pudica*、巴西含羞草 *Mimosa invisa*、无刺含羞草 *M. invisa* var. *inermis*、光荚含羞草 *Mimosa bimucronata*、野茼蒿 *Crassocephalum crepidioides*、鬼针草 *Bidens pilosa*、红花酢浆草 *Oxalis corymbosa*、薇甘菊 *Mikania micrantha*、羽芒菊 *Tridax procumbens*、马缨丹 *Lantana camara*、翼茎阔苞菊 *Pluchea sagittalis*、阔叶丰花草 *Borreria latifolia* 和象草 *Pennisetum purpureum* 等. 外来植物的引入与人类活动密切相关，但也可以作为教学素材，不过对一些入侵性较强的种类，如薇甘菊等需加以管控以防其蔓延.

2.4 迁地保育植物

在树木园迁地保育稀有濒危和国家重点保护植物共计88种1亚种2变种，隶属于46科75属，其中国家重点保护植物58种1亚种2变种，包括国家一级重点保护植物15种，国家二级重点保护植物43种[8]. 目前长势较好、常见的包括水松 *Glyptostrobus pensilis*、鸡毛松 *Dacrycarpus imbricatus* var. *patulus*、长叶竹柏 *Nageia fleuryi*、土沉香 *Aquilaria sinensis*、坡垒 *Hopea hainanensis*、青梅 *Vatica mangachapoi*、蝴蝶果、降香黄檀 *Dalbergia odorifera*、见血封喉 *Antiaris toxicaria* 和樟 *Cinnamomum camphora* 等. 另外，在行政楼前木兰园引种有较多木兰科珍稀濒危植物，包括乐东拟单性木兰 *Parakmeria lotungensis*、合

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果木 *Michelia baillonii*、焕镛木 *Woonyoungia septentrionalis*、观光木 *Michelia odora* 和华盖木 *Pachylarnax sinica* 等.

2.5　实验材料植物

主要见于林学、园艺、农学、生命科学、资源环境等学院温室和室外苗木种植基地，用于开展生物学特性与栽培繁殖、引种驯化等研究实验，包括速生树种团花、红椿 *Toona ciliata* 和壳菜果 *Mytilaria laosensis*，早期造林树种马尾松 *Pinus massoniana*、湿地松 *Pinus elliottii*、桉属植物 *Eucalyptus* spp. 以及各类花卉.

2.6　果树

园艺学院果园主要引种热带亚热带果树，种类近百种，包括荔枝 *Litchi chinensis*、龙眼 *Dimocarpus longan*、波罗蜜 *Artocarpus heterophyllus*、杨梅 *Myrica rubra*、火龙果 *Hylocereus undatus*、人心果 *Manilkara zapota*、蛋黄果 *Lucuma nervosa*、鸡蛋果 *Passiflora edulis*、番石榴 *Psidium guajava*、余甘子 *Phyllanthus emblica*、黄皮 *Clausena lansium*、蒲桃、洋蒲桃 *Syzygium samarangense*、中华猕猴桃 *Actinidia chinensis* 和番木瓜 *Carica papaya* 等.

2.7　杀虫植物

资源环境学院杀虫植物园由赵善欢院士创建，目前引种有具杀虫功效、可制作生物农药的植物近百种，主要包括蝶形花科、楝科、芸香科以及樟科植物，如楝 *Melia azedarach*、川楝 *Melia toosendan*、印楝 (*Azadirachta indica*)、米仔兰 *Aglaia odorata*、桃花心木 *Swietenia mahagoni*、灰毛豆 *Tephrosia purpurea*、鱼藤属植物 *Derris* spp.、臭茉莉 *Clerodendrum chinense* var. *simplex*、猪屎豆 *Crotalaria pallida*、博落回 *Macleaya cordata*、九里香 *Murraya exotica*、夹竹桃 *Nerium indicum*、狗牙花 *Tabernaemontana divaricata* 和羊角拗 *Strophanthus divaricatus* 等.

2.8　药用植物

兽医学院药圃盆栽有近百种常用入药的植物，包括小槐花 *Ohwia caudata*、穿心莲 *Andrographis paniculata*、两面针 *Zanthoxylum nitidum*、三桠苦 *Evodia lepta*、粗叶榕、薏米 *Coix lacryma*、木芙蓉 *Hibiscus mutabilis*、龙脷叶 *Sauropus spatulifolius*、叶下珠 *Phyllanthus urinaria*、鱼腥草 *Houttuynia cordata*、何首乌 *Fallopia multiflora* 和香茅 *Hierochloe odorata* 等.

2.9　湿生植物

“五湖四海一片林”中“五湖”是指校内五大湖体，即鄱阳湖、宁荫湖、洪泽湖、西湖和昭阳湖，此外校园内还有新增一个由足球场改造成的湿地公园. 校园内围绕水体种植有较多湿生植物，包括香蒲 *Typha orientalis*、芦竹 *Arundo donax*、再力花 *Thalia dealbata*、梭鱼草 *Pontederia cordata*、睡莲类 *Nymphaea* spp.、荷花 *Nelumbo nucifera*、水石榕 *Elaeocarpus hainanensis* 和水翁 *Cleistocalyx operculatus* 等.

3　结　　语

校园丰富的植物资源为植物学相关课程教学提供了良好的素材，近年来我们充分利用校园植物，尽力采取多种形式开展教学实践活动，取得较好的教学效果.

(1) 教师现场讲授

根据课程进度在校园内沿路进行讲授，主要结合课堂讲解的理论知识，实地分析植物形态特征，推演其所隶属的科属，并介绍其学名来源和功用等. 实习结束需完成实习所见种类的总结，并从其中选取 10～15 种编制检索表. 这种教学方式尽管不完全是“填鸭式”，但经常出现学生一开始积极性很高，但随着介绍的种类越来越多，时间一长学生很容易混淆，从而注意力和积极性有所下降，最终效果不甚理想. 另外，有时班级学生人数过多也会导致实习纪律难以管控.

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(2)发挥学生主观能动性

为充分调动学生学习积极性,化被动为主动,提高学习效率,我们尝试采取以下措施:

1)调查校园植物,编写植物名录.理论课程总论和概论部分结束后,开始讲解各论部分之前,一般是开学1～3周后开始向同学们布置课后作业,即以校园为基地,校园植物为调查对象,2～3人一组,在校园内分区域开展植物调查,对植物种类较多的区域如树木园等安排3～4组.调查前将植物名录格式要求下发到各组,期末统一检查上交.

2)拍摄校园植物照片、制作植物标本,期末集中讲解展示.分组调查的同学每人制作符合标本馆入库要求的植物标本5～8份,提交植物名录中的种类均需有实地拍摄的照片作为凭证.所有植物需小组成员分工合作,独立鉴定,教研室提供《广东植物志》、《广州植物志》、《广州野生植物》、《华南农业大学校园木本植物图鉴》、《华南农业大学校园常见种子植物拉汉英名称手册》、《华南农业大学校园植物名录》等工具书.疑难标本和照片,期末集中时间由教师统一指导鉴定.期末各小组将其负责区域的植物标本、照片向全班同学展示并讲解,这样大家可以互通有无,对校园植物有了更全面和深入的了解.

3)给校园植物挂牌.在学校主干道和人流较多之处,选取一些骨干植物挂牌,标明植物的中文名、学名、科名、原产地、用途等.学生通过亲身挂牌,不仅加深了对植物知识的理解,而且还提高了主人翁意识.目前,学校各区主要道路植物均有铭牌标示.

4)利用现代网络技术,建立数据库和及时交流平台.网络数据库资源丰富,除了向同学们介绍一些常用、权威的数据库和论坛外,建立QQ群和博客,便于大家相互交流,及时解疑答惑.学校目前建有"华南农业大学校园植物古树名木网"(http://xy.scau.edu.cn/tree/default.asp),该网站共收录木本植物223种(包括亚种、变种、品种),隶属于62科125属,其中裸子植物6科7属9种,被子植物56科118属214种,包括国家重点保护植物4种,国家珍稀濒危保护植物9种,并按照经济用途和保护等级进行分类介绍;内容包括植物的名称、形态特征、产地、用途及校园分布,并对每种植物附有彩色照片方便学生对照.

5)成立植物兴趣小组.对植物分类、识别感兴趣的同学自发定期组织校园植物考察与交流活动,并请相关老师现场指导.2007年成立"华南农业大学观赏植物协会",2012年成立"华南农业大学植物分类协会",举办了校园植物摄影大赛、标本制作大赛、植物竞猜大赛、植物知识沙龙、野外认植物、植物知识讲座、植物栽培实践等活动,同学们参与的积极性很高,取得了良好效果,获得一致好评.

6)设立植物鉴定、展览室.利用教研室和标本馆现有资源,学生疑难标本可到院楼指定教室鉴定,室内备有中国植物志、华南各地区植物志等文献资料,以及体式显微镜、解剖工具等.同时将一些华南常见科及其代表植物形态特征与图例做成展板悬挂于墙壁四周,包括大戟科、樟科、壳斗科、茜草科、楝科、无患子科、蝶形花科、苏木科和含羞草科等.这与教研室老前辈蒋英先生早期所用的"陈列辅导"法较为相近,可让学生亲身体验,养成勤于钻研的习惯.

美丽校园的建设离不开植物,具有特色的植物种类和配置是校园对外宣传的名片.丰富的校园植物资源为师生提供了基础素材,灵活多样的教学方式提高了广大学生对植物的兴趣和学习效率,积累了植物识别与分类经验.学生在校园通过亲近自然、认识自然,最终将热爱自然、保护自然,不仅提高了专业能力,道德素养也得到提升.多年的教学实践证明学生经过在校期间的专业熏陶,毕业后从事林学、园林等工作能很快地适应,受到用人单位的好评.

尽管我们努力在校园植物实践教学方面做一些积极探索,但如何深入发掘校园植物资源优势,切实提高植物学相关课程的教学实践效果,仍需要进一步思考,摸索出更好、更高效的教学方式.此外,学校在校园总体规划与绿化中也应从植物学教学整体出发,合理布局,保持物种多样性与专类园结合,多保留自然景观,真正将校园打造成宜学、宜居胜地.

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On How to Use Plant Resources for Teaching Practice in Campus in Agricultural University

——A Case Study of South China Agricultural University

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Abstract：The plant resources in campus are closely relative to the teaching and living of teachers and students，and they are important materials of botanic courses. How to use the plant resources for teaching practice in South China Agricultural University has been discussed.

Key words：plant resources in campus；teaching practice；Botany

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执行编辑 潘春燕
英文审校 孟凡君
封面设计 遥 深

ISSN 1000-5471

11>

9 771000 547000

西南師範大學學報

自然科学版 月刊 1957年创刊

第39卷第11期（总第212期） 2014年11月

主管单位:中华人民共和国教育部
主办单位:西南大学
主 编:李 明
常务副主编:汤兴华 孙 凡
编辑出版:西南大学期刊社
邮编地址:400715 重庆市北碚区天生路2号
电 话:(023)68252540 传 真:(023)68252538
网 址:http://xbbjb.swu.cn
投稿网址:http://xbgjxt.swu.cn
印刷单位:重庆荟文印务有限公司
国内发行:重庆市邮政局
订 购:全国各地邮局
国外发行:中国国际图书贸易总公司
（北京399信箱）
发行范围:公开发行

JOURNAL OF SOUTHWEST CHINA NORMAL UNIVERSITY
Natural Science Edition Monthly Started in 1957

Vol.39 No.11(Sum No.212) November. 2014

Competent Authorities: the Ministry of Education of the People's Republic of China
Sponsor: Southwest University
Editor-in-chief:Li Ming
Deputy Editor:Tang Xinghua Sun Fan
Edited and Published: Journal Press of Southwest University
Postcode and Address:No.2,Tiansheng Road,Beibei Chongqing, 400
Tel:(023)68252540 Fax:(023)68252538
Web: http://xbbjb.swu.cn
http://xbgjxt.swu.cn
Printed:Chongqing Huiwen Printing Co.LTD.
Distributed at Home:Chongqing Post Office
Subscribed and Bought:Each Post Office in China
Distributed Abroad:China International Book Trading Corporation(P.O.Box399,Beijing China)
Issue Areas:Domestic and International Public Offerings

国内发行代号:78-22
国外发行代号:BM4600

ISSN 1000-5471
CN 50-1045/N

国内定价：20.00 元

SCAULIB202519468

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1	农业院校校园植物资源在教学实践中的充分利用	西南师范大学学报（自然科学版） 出版年：2014 卷期：39 11 页码：229-233 文献号： 文献类型：	第一作者	C 类	华南农业大学林学院	北大核心	无	无

说明：论文等级和中科院大类分区按《华南农业大学学术论文评价方案（试行）》划分。

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2025-07-19

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证书编号： JXCG21065

华南农业大学

二〇二一年六月



园林树木学

YUANLIN SHUMU XUE

（华南本 第三版）

主　编　庄雪影　　副主编　冯志坚

华南理工大学出版社
SOUTH CHINA UNIVERSITY OF TECHNOLOGY PRESS

内容简介

本教材内容分为绪论、总论、各论三部分。绪论主要介绍园林树木学的研究内容和学习方法、我国园林树木种质资源特点及园林树木引种驯化概况。总论着重阐述园林树木的分类方法、园林树木在园林中的作用和配植，以及园林树木的调查与规划方法。各论部分重点介绍了华南地区常见栽培的园林树种、应用较多的新优园林树种以及有应用前景的乡土树种的识别特征、习性及其在园林中的应用价值，共收集了园林树木 686 种（含种下单位），分属于 76 科 283 属，附图 287 幅。

图书在版编目（CIP）数据

园林树木学（华南本）/庄雪影主编．—3 版．—广州：华南理工大学出版社，2014.9
ISBN 978-7-5623-4298-4

Ⅰ．①园… Ⅱ．①庄… Ⅲ．①园林树木-高等学校-教材 Ⅳ．①S68

中国版本图书馆 CIP 数据核字（2014）第 204458 号

园林树木学（华南本 第三版）
庄雪影 主编

出 版 人：
出版发行：华南理工大学出版社
（广州五山华南理工大学 17 号楼，邮编 510640）
http://www.scutpress.com.cn E-mail：scutc13@scut.edu.cn
营销部电话：020-87113487 87111048（传真）
责任编辑：欧建岸
印 刷 者：广东省农垦总局印刷厂
开 本：787mm×1092mm 1/16 印张：21 字数：540 千
版 次：2014 年 9 月第 3 版 2014 年 9 月第 14 次印刷
定 价：38.50 元

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古树导论

北京农学院 ◎ 组织编写
方炎明 王文和 ◎ 主编

中国林业出版社
CFPH China Forestry Publishing House



《古树导论》编写人员

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《古树导论》教材共有8章，核心内容概述如下："第1章古树概述"介绍古树概念、定义、价值、保护伦理和保护使命与目标。"第2章木本植物生活史与古树寿命"导入树木生活史过程与生活史对策理论，介绍古树寿命及其与内在、外在因素的因果联系。"第3章古树识别与鉴定方法"引入从形态到分子水平的树种鉴定方法。"第4章古树年龄分析与鉴定方法"介绍常规的和实验的树龄鉴定方法。"第5章古树资源调查与数据处理"介绍古树资源调查技术规范。"第6章古树系统分类、分布与生物学特性"，引入树木分类原理，重点介绍77种常见古树树种，包括古树分类地位、鉴别、分布、生境和生活史等特征，提供古树案例和实景图。"第7章中国古树资源"介绍中国古树树种的多样性及其空间分布特征。"第8章国外古树资源"介绍国外古树树种的多样性及其空间分布特征。教材力求理论与实践紧密结合，继承与创新有机结合，民族的与世界的古树文化交融，图文并茂、通俗易读，成为一本真正的古树保护入门教材。

本教材可作为高等农林院校林学和园林类相关专业的本科生教材，也可作为研究生、教师、农林科技工作者、古树爱好者的参考用书。

图书在版编目（CIP）数据

古树导论/北京农学院组织编写；方炎明，王文和主编. —北京 ：中国林业出版社，2023.10

国家林业和草原局普通高等教育"十四五"规划教材　高等院校古树保护专业方向系列教材

ISBN 978-7-5219-1945-5

Ⅰ.①古…　Ⅱ.①北…②方…③王…　Ⅲ.①树木-植物保护-高等学校-教材　Ⅳ.①S76

中国版本图书馆CIP数据核字（2022）第205973号

策划编辑：康红梅

责任编辑：康红梅

责任校对：苏　梅

封面设计：北京点击世代文化传媒有限公司

封面摄影：张子威

出版发行：中国林业出版社

（100009，北京市西城区刘海胡同7号，电话83223120）

电子邮箱：cfphzbs@163.com

网　　址：www.forestry.gov.cn/lycb.html

印　　刷：北京中科印刷有限公司

版　　次：2023年10月第1版

印　　次：2023年10月第1次印刷

开　　本：787mm×1092mm　1/16

印　　张：18

彩　　插：0.5印张

字　　数：462千字

定　　价：58.00元

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全国高等农林院校“十二五”规划教材

树木学

DENDROLOGY

（南方本）

第3版

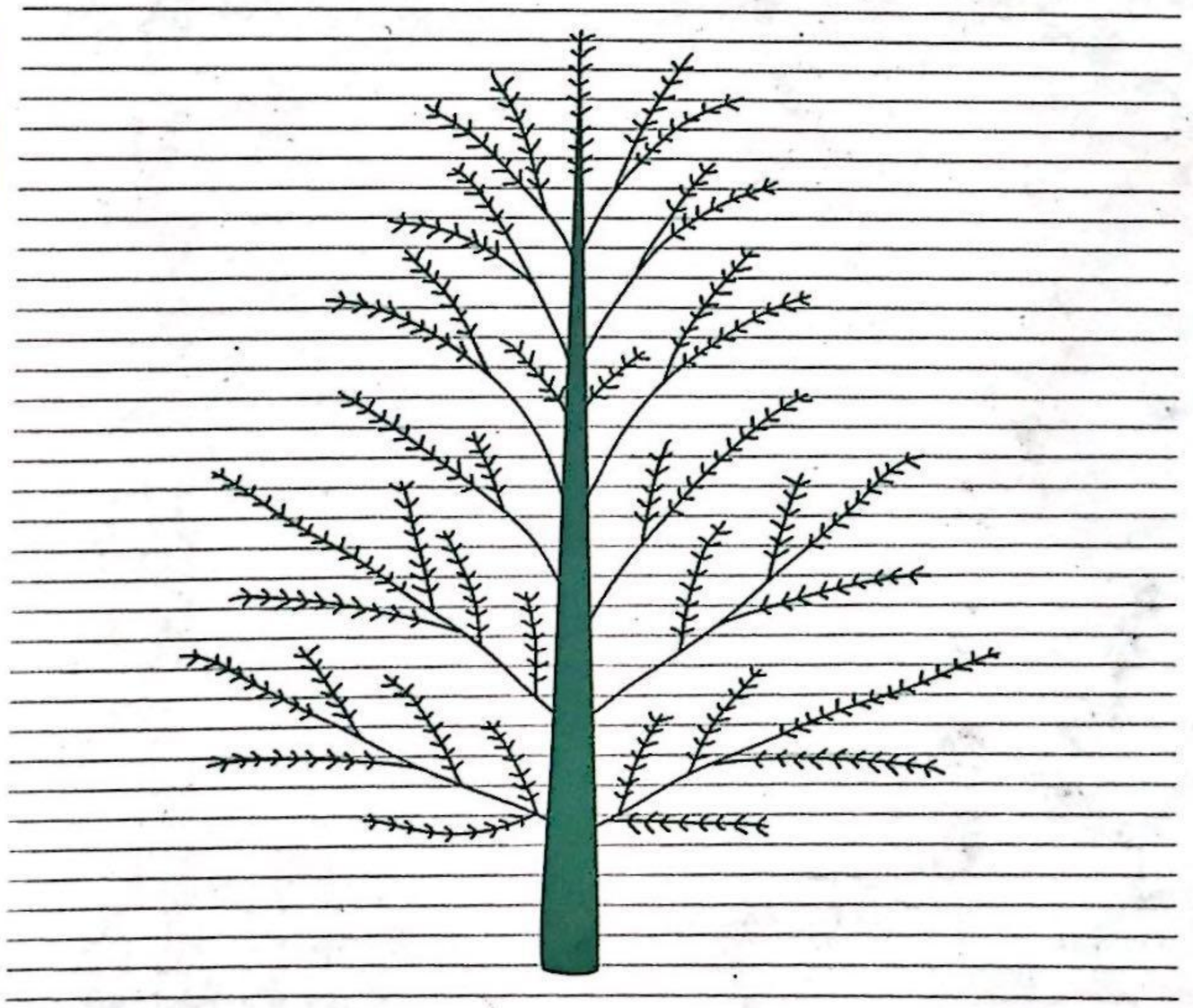
祁承经　汤庚国◎主编











中国林业出版社

图书在版编目（CIP）数据

树木学：南方本/祁承经，汤庚国主编. —3 版. 北京：中国林业出版社，2014.12
全国高等农林院校“十二五”规划教材
ISBN 7-5038-7813-8

Ⅰ.①树… Ⅱ.①祁… ②汤… Ⅲ.①树木学—高等学校—教材 Ⅳ.①S68
中国版本图书馆 CIP 数据核字（2014）第 302740 号

中国林业出版社·教育出版分社

策划编辑：牛玉莲 肖基浒
责任编辑：牛玉莲
电 话：83143555

出版发行 中国林业出版社(100009 北京市西城区德内大街刘海胡同 7 号)
E-mail:jiaocaipublic@163.com 电话:(010)83143500
http://lycb.forestry.gov.cn
经 销 新华书店
印 刷 中国农业出版社印刷厂
版 次 1994 年 9 月第 1 版(共印 8 次)
2005 年 2 月第 2 版(共印 10 次)
2015 年 1 月第 3 版
印 次 2015 年 1 月第 1 次印刷
开 本 850mm×1168mm 1/16
印 张 41.75
字 数 989 千字
定 价 76.00 元

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第3版编写分工

中南林业科技大学：

祁承经——总论、木兰科、樟科、壳斗科，全书文稿及图的统稿（修改和审定）

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中名索引 …… (625)

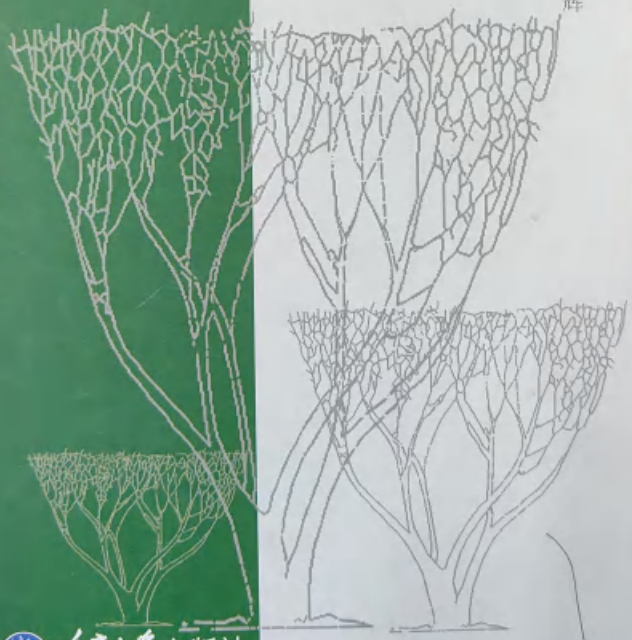
学名索引 …… (636)

普通高等教育风景园林类专业“十二五”规划系列教材

园林树木学

YUANLIN SHUMUXUE

主　编　申晓辉
副主编　李保印　曹基武　李智辉
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重庆大学出版社
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由于编写时间仓促及编者水平有限,教材中难免有错误之处,敬请批评指正。

编 者

2011年12月

内容提要

本教材分总论(第1~3章)和各论(第4章裸子植物门、第5章被子植物门)2个部分。总论首先简要阐述植物分类学研究方法、步骤,重点介绍植物分类的等级、植物双命名法和植物检索表的使用。植物地理学基础在宏观大尺度上概述环境(气候、地形)演变对世界和中国植物区系分区的影响,进而阐述中国植被水平和垂直分布规律。园林树木学基础是衔接总论和各论知识的纽带,重点介绍园林树木的分类、园林树木美学与植物造景,园林树种文化在造园中的应用。

各论共收录82科333属672树种及杂交种(不包括变种、变型、栽培种等种下分级单位),其中裸子植物门采用郑万钧先生(1979年)分类系统,被子植物门采用恩格勒(1964年)分类系统。裸子植物门10科37属81种,被子植物门双子叶植物纲(离瓣花亚纲、合瓣花亚纲)和单子叶植物纲共计72科296属591种。各树种分详细阐述(学名及别名,形态特征,变种、变型及栽培种,产地与分布,习性,繁殖方法,园林应用、树种文化和经济用途10部分)和简要阐述(学名及别名,形态特征,变种、变型及栽培种,产地与分布5项)2个层面,其中详写约480种,并对一些属名的词义进行注释。

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本教材适用于全国各类高等院校、风景园林、园艺及观赏园艺、城市规划与环境设计等本科专业,也可以作为风景园林专业硕士的辅修教材及农林、城市规划部门专业人员的工具书。

图书在版编目(CIP)数据

园林树木学/申晓辉主编. —重庆:重庆大学出版社,2013.5

普通高等院校风景园林类专业"十二五"规划系列教材

ISBN 978-7-5624-6493-8

Ⅰ.园… Ⅱ.①申… Ⅲ.①园林树木—高等学校—教材 Ⅳ.①S68

中国版本图书馆CIP数据核字(2011)第271442号

普通高等院校风景园林类专业"十二五"规划系列教材

园林树木学

主 编 申晓辉

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策划编辑:何 明

责任编辑:何 明 版式设计:莫 西 何 明

责任校对:刘 真 责任印制:赵 晟

*

重庆大学出版社出版发行

出版人:邓晓益

社址:重庆市沙坪坝区大学城西路21号

邮编:401331

电话:(023)88617183 88617185(中小学)

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网址:http://www.cqup.com.cn

邮箱:fxk@cqup.com.cn(营销中心)

全国新华书店经销

重庆升光电力印务有限公司印刷

*

开本:787×1092 1/16 印张:40.75 字数:1042千 插页:16开8页

2013年5月第1版 2013年5月第1次印刷

印数:1—3 000

ISBN 978-7-5624-6493-8 定价:75.00元

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观赏植物种质资源学

GERMPLASM RESOURCES OF ORNAMENTAL PLANTS

主编 宋希强



中国建筑工业出版社

扫描全能王 创建

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扫描全能王 创建

图书在版编目（CIP）数据

观赏植物种质资源学/宋希强主编. —北京：中国建筑工业出版社，2012.2

（热带园艺专业特色教材系列）

ISBN 978-7-112-13729-9

Ⅰ.①观… Ⅱ.①宋… Ⅲ.①观赏植物-种质资源

Ⅳ.①S680.24

中国版本图书馆 CIP 数据核字(2011)第 224564 号

本书以观赏植物种质资源为对象，阐述其研究方法和相关的理论。全书包括绪论、正文和附录。正文首先界定了观赏植物种质资源的概念，概述了世界观赏植物种质资源的地理分布及起源学说；继而在综述观赏植物种质资源研究方法的基础上，分别对观赏植物种质资源的调查、收集、引种、驯化、鉴定、评价和保存等各个环节进行详细介绍。最后结合介绍我国热带地带区域性植被类型与观赏植物资源的关系，重点推荐了草本、灌木、藤本和乔木四大类常见的热带观赏植物资源。为了方便标本检索和物种鉴定，本书附录提供了包括恩格勒系统在内、标本馆通用的分类系统表。本书由海南大学、华南农业大学、福建农林大学、广州中医药大学、漳州师范学院、湛江师范学院和北京林业大学等单位专家共同编写，历时三年。内容丰富翔实，综合国内外先进成果，对观赏植物种质资源的教学和科研具有指导意义。每章后附有思考题和推荐书目，可供读者学习时参考。本书不仅可为我国热带、亚热带地区高等农林院校观赏园艺、园林专业教学用书，也可为其他地区高校园艺类专业学生学习参考书和广大园艺学、风景园林学科研工作者的参考工具书。

责任编辑：郑淮兵

责任设计：董建平

责任校对：肖 剑 赵 颖

热带园艺专业特色教材系列

观赏植物种质资源学

主编 宋希强

*

中国建筑工业出版社出版、发行（北京西郊百万庄）

各地新华书店、建筑书店经销

北京红光制版公司制版

北京市书林印刷有限公司印刷

*

开本：787×1092 毫米 1/16 印张：18¼ 字数：440 千字

2012 年 8 月第一版 2012 年 8 月第一次印刷

定价：35.00 元

ISBN 978-7-112-13729-9

(21498)

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（邮政编码 100037）

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扫描全能王 创建

人才公园-广东乡土树种博物馆项目

技术咨询及方案设计合同

合同编号：SJ80-2023-1640

委 托 人：珠海红宝石建设开发集团有限公司

受 托 人：广州普邦园林股份有限公司（主办方）、
华南农业大学（成员方）

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红土石集团

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委托人(以下简称“甲方”）：**珠海红宝石建设开发集团有限公司**

受托人(以下简称“乙方”）：**广州普邦园林股份有限公司（主办方）、华南农业大学（成员方）**

根据《中华人民共和国民法典》、《中华人民共和国建筑法》、《中华人民共和国城乡规划法》及相关法律、法规、规章的规定，遵循平等、自愿、公平和诚实信用的原则，甲方就委托乙方承担人才公园-广东乡土树种博物馆项目（以下简称“本工程”或“本项目”）技术咨询及方案设计有关事项协商一致，签订本合同。

第一条　工程概况

（1）工程名称：人才公园-广东乡土树种博物馆项目；

（2）工程地点：珠海市洪湾保税十字门片区；

（3）工程立项批准文号：******；

（4）资金来源：财政资金；

（5）工程概况：本项目位于珠海市洪保十片区，马骝洲水道以北、情侣南路以南、东起横琴大桥、西至横琴二桥，绿地全长约 5 公里，总面积约 78 公顷，拟在人才公园基础上打造广东乡土树种博物馆。项目总投资约 4000 万元，其中建安费约 3200 万元。（具体建设内容、规模及投资额以相关政府批复文件为准）

红宝石集团

第二条　合同签订依据

2.1《中华人民共和国民法典》、《中华人民共和国建筑法》、《中华人民共和国城乡规划法》和《建设工程勘察设计管理条例》。

2.2 国家及地方有关建设工程勘察设计管理法规和规章。

2.3 建设项目批准文件。

第三条　技术咨询及方案设计目标

通过规划人才公园的总体植物景观空间，综合场地现状生态修复、滨海生境营造、植物科学选种等方面，科学指引广东乡土树种博物馆的设计建造。

方案总体定位为打造“广东乡土树种博物馆”，同时兼具科普、教育、游憩等综合性功能。要充分发挥空旷地带、开阔场地的优良条件，在广东乡土树种中优选一批有代表性的、符合抗风耐盐碱要求、美观且与公园风格协调的树种，分区域分片科学种植。

为人才公园大树长成、实现绿树成荫奠定基础，满足人才公园后续分阶段建设需要，实施中央绿谷的蹲苗计划。亦为落实“绿美广东”建设发展要求，完成绿美珠海生态建设“百团大战”路线任务，开展全区干部职工和企业代表的“绿美行动”植树活动提供载体。

第四条　技术咨询及方案设计依据

4.1《珠海市国土空间总体规划（2020-2035）》；

4.2《珠海鹤洲新区洪保十片区控制性详细规划》；

4.3《粤港澳园林苗木质量规格规范》；

4.4《珠海经济特区园林绿化条例》；

4.5《广东省城市绿化条例》；

4.6《城市绿地分类标准》CJJ/T85-2017;

4.7《城市绿地设计规范》GB50420-2016;

4.8《公园设计规范》GB51192-2016;

4.9《风景园林工程设计文件编制深度规定》；

4.10 珠海市相关规划及绿化文件;

4.11 国家、广东省、珠海市、其他相关行业及地方政府颁布的有关标准、规范、规程、规定以及设计合同。

以上均以当前最新发布的版本为准。包括但不限于此与设计内容有关的各专业规范及设计标准。

第五条　各阶段工作任务

本项目的技术咨询及方案设计任务为需完成人才公园-广东乡土树种博物馆项目的技术咨询、方案设计工作，包括但不限于植物资源本底调查与土壤检测、引种植物评估报告和推荐引种植物名录、植物景观设计指引、植物景观总体规划及乡土植物种植生境营造规划、方案设计（含估算）等。

5.1 技术咨询工作任务及要求

根据人才公园概念方案、会议纪要、设计任务书及周边项目等资料，在进行充分现场踏勘及调研的基础上，完成本项目的技术咨询工作，主要包括植物资源本底调查与土壤检测、引种植物评估报告和推荐引种植物名录、植物景观设计指引、植物景观总体规划及乡土植物种植生境营造规划等。

5.1.1 深入了解人才公园范围的场地生境条件，开展土壤检测及研究分析，完成本底植物资源和土壤现状调查。

5.1.2 进行南亚热带乡土植物资料收集、整理与资源调查，调研国内优秀植物园种植设计，因地制宜研究适宜地域性植物品种结合优良引种植物种类，形成植物景观设计指引、植物选种引种分名录与评估。

5.1.3 在人才公园概念方案基础上，符合本地域特点，完成“广东乡土树种博物馆”植物景观总体规划、乡土植物种植生境营造规划。

5.1.4 配合人才公园后续开发建设，分阶段提供园林植物选种及引种、植物景观设计及建设等相关技术咨询服务。

5.2 方案设计工作任务及要求

根据人才公园概念方案、会议纪要、设计任务书及周边项目等资料，结合技术咨询的相关工作成果，完成本项目的方案设计（含估算），包括但不限于整体方案设计、其他专项方案及效果图等。

5.2.1 在人才公园概念方案基础上，对设计方案进行深化、优化和完善，形成详细且科学可行的方案文本及图册，应能据以编制工程估算，满足甲方、相关政府部门、项目审批及专家评审的要求，为下一步设计提供依据。

5.2.2 参照植物选种指引、植物总体规划及生境营造等成果，制定植树方案，按照功能搭配合理、景色优美怡人的原则，研究分阶段种植广东乡土树种的种类、数量及片区分布，合理搭配植物设计及微地形塑造。

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第六条 技术咨询及方案设计服务

乙方的技术咨询及方案设计服务应符合国际通用的 ISO—9000 质量管理体系对于技术咨询和工程设计所规定的标准及质量要求。乙方应及时地提供服务，满足甲方在时间上的要求。

6.1 考察服务

为科学推进人才公园-广东乡土树种博物馆建设，针对性指导本项目前期设计及落地实施工作，乙方须结合项目实际情况，组织甲方及相关单位人员前往国内城市进行优秀案例的实地考察。

6.2 汇报、报审、报建配合服务

（1）乙方配合需要，参与向各级职能部门及政府部门的汇报工作。

（2）乙方应在设计过程按照本项目前期报审报建的要求，提交所有必需的文件、图纸及其相应的电子文件（刻制成光盘），并配合报审报建过程中必要的技术协调、送审技术性文件等工作，直至完成前期审批手续。

（3）对乙方提交报审汇报、报建资料的要求：提交的文件、图纸及其相应的电子文件按照相关报审报建职能部门或主管部门的提交要求和份数要求。

第七条 甲方向乙方提交的有关资料、文件、份数及时间

序号	资料及文件名称	份数	提交日期	备注
1	项目前期文件	2	满足设计进度要求	
2	设计任务书	2	满足设计进度要求	
3	与本项目有关规划设计条件	2	满足设计进度要求	

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第八条 乙方向甲方交付的成果文件、份数、地点及时间

8.1 乙方提交技术咨询成果文件的时间及份数如下：

序号	资料及文件名称	份数	提交日期	备注
1	植物资源本底调查与土壤检测报告	6	中标通知书签发后第 2 天起算，15 个日历天内提交。	含可编辑版电子光盘 2 份
2	引种植物评估报告和推荐引种植物名录	12	中标通知书签发后第 2 天起算，25 个日历天内提交初稿。成果文件经汇报认可后，20 个日历天内提交定稿。	含可编辑版电子光盘 2 份
3	植物景观设计指引	12	中标通知书签发后第 2 天起算，25 个日历天内提交初稿。成果文件经汇报认可后，20 个日历天内提交定稿。	含可编辑版电子光盘 2 份
4	植物景观总体规划方案	12	中标通知书签发后第 2 天起算，25 个日历天内提交初稿。成果文件经汇报认可后，20 个日历天内提交定稿。	含可编辑版电子光盘 2 份
5	乡土植物种植生境营造规划	12	中标通知书签发后第 2 天起算，25 个日历天内提交初稿。成果文件经汇报	含可编辑版电子光

	方案		认可后，20 个日历天内提交定稿。	盘 2 份

8.2 乙方提交方案设计成果文件的时间及份数如下：

序号	资料及文件名称	份数	提交日期	备注
1	方案设计（含估算）	12	中标通知书签发后第 2 天起算，25 个日历天内提交初稿。成果文件经汇报认可后，20 个日历天内提交定稿。	含可编辑版电子光盘 2 份
2	其他专项设计文件及效果图	按需提供	满足设计进度要求	

乙方应将各阶段成果文件送至甲方指定的办公地点。除纸质文件外，乙方还需同时提交可读、可编辑的上述成果文件的电子文件光盘 2 张。

乙方必须在上述成果文件审批后 7 个日历天内按照审批部门的要求完成设计文件修改工作。

如甲方要求提供超过合同约定份数的设计成果文件，乙方应按甲方的要求提供且不另行收取任何费用。

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第九条　合同价款

本合同暂定总价为人民币大写玖拾万伍仟元整（￥905,000.00）(含增值税)。

其中：

9.1 技术咨询费

本合同约定的技术咨询费为人民币大写伍拾柒万伍仟元整（￥575,000.00），其中不含税金额为伍拾伍万捌仟贰佰伍拾贰元肆角叁分（￥558,252.43），以税率 3%计算的增值税额为壹万陆仟柒佰肆拾柒元伍角柒分（￥16,747.57）。本合同技术咨询费为合同包干价，结算时不予增减，最终以终审部门的审定价为准。

9.2 方案设计费

本合同工程方案设计费暂定价为人民币大写叁拾叁万元整（￥330,000.00），其中不含税金额为叁拾壹万壹仟叁佰贰拾元柒角伍分（￥311,320.75），以税率6%计算的增值税额为壹万捌仟陆佰柒拾玖元贰角伍分（￥18,679.25）。方案设计费结算价为根据乙方实际完成的工作量并参照国家计委、建设部文件关于发布《工程勘察设计收费管理规定》的通知（计价格[2002]10号文）所规定的标准计算得出的金额×30%×方案设计中标费率（79.19%）（方案中标费率=方案设计费中标总价/方案设计费预算总价*100.00%，方案设计费预算总价为416,728.95元），本合同工程设计费结算价以终审部门的审定价为准，且不得超过本合同工程方案设计费暂定价，超过时按照本合同工程方案设计费暂定价予以结算。

其中方案设计收费计费额为政府批复本工程概算中的乙方实际服务范围内的建安工程费及管线迁改费（若有）之和；如本工程无批复概算则为终审部门审定的预算中的乙方实际服务范围内的建安工程费（不含暂列金额）及管线迁改费（若有，不含暂列金额）之和为工程设计收费计费额；如无审定预算的则以终审部门审定结算中的乙方实际服务范围内的建安工程费及管线迁改费（若有）之和为工程设计收费计费额。

本工程方案设计费计算的专业调整系数为1.1、工程复杂程度调整系数为1.15、附加调整系数为1.0，方案设计阶段工作量比例为30%（占整个设计（即方案设计+初步设计+施工图设计）的比例）。凡是本条款中所确定的各项取费系数及费率（包括但不限于专业调整系数、工程复杂调整系数、附加调整系数、各设计阶段工作量比例、下浮率或中标费率等）均不因实际设计复杂程度与否而作调整，也不得因其他任何因素的发生变化而改变，但合同另有约定的除外。

9.3 按上述方式计算的合同价款包括但不限于乙方完成本合同项下的全部义务所发生的现场勘查费（技术咨询及方案设计工作所需）、人工费、协调费、材料费及递送费、场地办公费、设备费、交通差旅费、管理费、专家评审费用、专题研究费、考察费、专家咨询费、报审报批费、加班费、利润、税金、保险等各项应有费用。除非双方另有约定，上述费用不随国家政策或法规、标准及市场因素的变化而调整，且甲方无需就本合同所述的乙方服务向乙方或其人员或任何第三方支付任何其他费用。

第十条　支付方式

10.1 预付款

☒本项目不设预付款。

☑本合同生效后 15 个工作日内，甲方向乙方支付本合同暂定总价的 10%作为预付款（即￥90,500.00），但所支付的预付款从甲方支付第一笔进度款开始进行抵扣，若第一笔进度款不足以抵扣完预付款的，则从下一笔进度款中继续进行抵扣，直至抵扣完毕为止。

10.2 进度款支付

10.2.1 技术咨询费

（1）乙方向甲方提交甲方要求的土壤检测报告、引种植物评估报告和推荐引种植物名录、植物景观设计指引、植物景观总体规划方案和乡土植物种植生境营造规划方案等成果文件初稿，甲方向乙方支付至本合同技术咨询费的 20%（即￥115,000.00）；

（2）乙方向甲方提交经甲方认可的土壤检测报告、引种植物评估报告和推荐引种植物名录、植物景观设计指引、植物景观总体规划方案和乡土植物种植生境营造规划方案后，甲方向乙方支付至本合同技

术咨询费的50%（即￥287,500.00）；

（3）按照甲方要求提供相关技术咨询服务一年期满（以施工开工之日起计算）后，甲方向乙方支付至本合同技术咨询费的80%（即￥460,000.00）。

10.2.2 方案设计费

乙方完成甲方要求的方案设计成果文件（含估算）以及其他专项设计文件（甲方要求时），并经甲方认可和相关职能部门或审图机构审批通过（如需），且将方案设计文件及其他成果文件全部交给甲方后，甲方按照实际完成情况支付至方案设计费暂定价的80%;

10.2.3 当本合同累计支付的金额达到本合同暂定总价的80%时，暂停本合同费用的申请、审核及支付。

10.2.4 本合同费用结算金额经终审部门审定（或备案）后，乙方办理支付申请，并经甲方审核确认后支付至本合同终审部门审定（或备案）结算价款的100%。如已付合同费用金额超出终审部门审定价的，乙方应立即将已收取的超出终审部门审定价的款项无条件退回。

10.3 乙方领取预付款（如有）、进度款、结算款等款项前均须按甲方的财务管理制度办理有关手续。符合付款条件的，乙方应向甲方提出书面付款申请。

☒本合同项目系甲方企业自筹资金项目或土地一级开发项目，乙方须开具符合国家有关法律规定要求的等额、有效期内、可抵扣的增值税专用发票.

☑本合同项目系政府投资项目，乙方应开具符合国家有关法律规定要求的等额增值税普通发票。

甲方在收到符合要求的付款申请及发票并审核无误后20个工作日内支付相应款项给乙方。乙方未提交书面付款申请及发票，或提交书面付款申请或发票不符合要求的，甲方有权暂缓支付价款，且不对延

期付款承担任何责任。

乙方应就本合同项下约定之业务向甲方开具真实、合法、有效票据（发票），若因乙方原因或所开票据（发票）存在问题造成甲方日后发生税收风险而产生的经济损失，全部由乙方承担。

本合同项下所指的合同价款及进度款等凡是涉及价格条款的内容均为含税款，税款均由乙方承担；如合同履行期间国家增值税税率发生调整，自税率发生调整之日起，支付款的含税金额按新税率进行调整，即调整后的支付款含税金额=支付款原含税金额÷（1+原税率）×（1+新税率）。

甲方有权直接从应付合同费用中扣除乙方应当承担的违约金、赔偿金等，不足抵扣的，乙方应对不足部分另行予以赔偿。

10.4 本合同项下所有款项通过银行转账方式支付至乙方指定账户，乙方的账户信息如下：

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（1）主办方：

开户名称：广州普邦园林股份有限公司

开户银行：招商银行广州分行五羊支行

账　　号：200382280310001

（2）成员方：

开户名称：华南农业大学

开户银行：中国工商银行广州市五山支行

账　　号：3602002609000310520

乙方变更以上账户的，需提前 7 日书面通知甲方，否则由此引发的一切损失将由咨询人承担。

10.5 在对已付款项进行汇总和复核中发现错误、遗漏或重复的，甲方和乙方均有权提出修正申请。经甲方和乙方同意的修正，应在下

期进度付款中支付或扣除。

☑10.6 鉴于本项目资金来源于财政资金，本合同中甲方付款指的是甲方向财政局转呈咨询人的付款申请，并由财政局完成最终付款；本合同中甲方付款时间（期间）指的是甲方向财政局转呈咨询人的付款的时间（期间），财政局完成付款审批流程并最终付款的时间不包含在甲方的付款时间之中，也不导致甲方延期付款或违约。此外若财政局需要其他付款申请材料，咨询人应当主动配合提交，否则由此导致咨询人无法如期获得款项的责任由咨询人自行承担，咨询人对此已充分了解并无任何异议。

第十一条　双方责任和义务

11.1 甲方责任和义务

11.1.1 甲方按本合同第七条约定向乙方提交基础资料及文件，并对其完整性、正确性及时限负责。甲方不得要求乙方违反国家有关标准进行可行性研究报告编制或工程设计。

11.1.2 甲方指定毛佳敏为甲方代表，甲方代表联系方式为0756-2991964，授权范围为本项目技术咨询及方案设计工作沟通事宜。甲方代表在甲方的授权范围内，负责处理合同履行过程中与甲方有关的具体事宜。甲方代表在授权范围内的行为由甲方承担法律责任。甲方更换甲方代表的，应提前书面通知乙方。

11.1.3 若甲方要求乙方比合同规定时间提前交付合同约定的成果文件的，应征得乙方同意，且不得严重背离合理的编制或技术咨询及方案设计周期。

11.1.4 甲方应按本合同约定按时足额支付合同约定的价款。

11.1.5 甲方在收到乙方有关可行性研究报告编制问题、设计问题及

确认问题的函件后，应在5个工作日内给予书面答复。

11.2 乙方责任和义务

11.2.1 乙方应按国家规定和合同约定的技术规范、标准完成合同约定范围内的技术咨询和方案设计工作，并对其所提交的成果质量负责。其中，技术咨询和方案设计文件编制深度必须达到相关规范所要求的深度，当前述规定存在不一致时，约定采用的规定应按严标准执行。

乙方发现甲方提供的工程设计资料有问题的，乙方应当及时通知甲方，否则因此造成设计返工而增加的设计费用和（或）工期延误的责任均由乙方自行承担。

11.2.2 乙方指定项目负责人为张文文，执业资格及等级为高级工程师，联系方式为13610115257，授权范围为本合同约定的相关工作，项目负责人代表乙方负责履行合同。

乙方需要更换项目负责人的，应当提前10日书面通知甲方，并征得甲方书面同意。通知中应当载明继任项目负责人的注册执业资格、管理经验等资料，继任项目负责人继续履行第11.2.2项约定的职责。继任项目负责人的执业资格和管理经验不得低于更换前的项目负责人。未经甲方书面同意，乙方不得擅自更换项目负责人。乙方擅自更换项目负责人的，应按照合同条款的约定承担违约责任。

甲方有权书面通知乙方更换其认为不称职的项目负责人，乙方应在收到书面更换通知后3天内进行更换，并将新任命的项目负责人的注册执业资格、管理经验等资料书面通知甲方，乙方新任命的项目负责人的执业资质和管理经验不得低于更换前的项目负责人，继任项目负责人继续履行第11.2.2项约定的职责，乙方无正当理由拒绝更换项目负责人的，应承担违约责任。

11.2.3 乙方委派的其他工作人员也应保持稳定。合同履行过程中如

有变动，乙方应及时向甲方提交工作人员变动情况报告并经甲方书面同意后方可变动（属于无法正常履职的情形除外），乙方须将更换后的工作人员的注册执业资格、执业经验等资料在报告中载明，更换后的工作人员执业资格和管理经验不得低于更换前的工作人员。

11.2.4 乙方不得将其承包的全部合同义务转包给第三人，或将其承包的全部合同义务肢解后以分包的名义转包给第三人。乙方如需进行分包，应取得甲方书面同意，并按甲方要求办理相应的分包手续。乙方不得违法进行分包。

11.2.5 乙方应按本合同第八条规定的内容、时间及份数向甲方交付合格的成果文件，并对提交的成果文件的质量负责。

11.2.6 乙方应根据法律、技术标准的要求，保证项目的合理使用寿命年限，并应在工程设计文件中注明相应的合理使用寿命年限（如需）。设计合理使用年限按国家有关规定执行。

11.2.7 负责本工程的技术咨询及方案设计联络工作。

11.2.8 乙方应对技术咨询成果及方案设计文件出现的遗漏或错误，负责在甲方指定的时间内无偿进行修改或补充，直至满足本合同要求的标准，由此增加的费用和（或）工期延误的责任由乙方承担。

11.2.9 乙方交付合同约定的成果文件或资料后，按规定参加有关部门的审批或审查，并根据审批或审查结论负责做必要调整补充，确保成果文件能通过审批部门的审查，取得审批部门通过的批文。

11.2.10 设计文件选用的国家标准图、部标准图及地方标准图由乙方负责解决。

11.2.11 乙方根据甲方需要负责完成技术咨询成果及方案设计成果文件报审报批及组织相关技术材料等工作。

11.2.12 在完成合同约定工作后，根据甲方需要提供其成果文件的

答疑、解释澄清和交底工作。

11.2.13 无论本合同因何原因被解除，乙方应当及时将从甲方处获得的全部技术资料全部返还给甲方，同时将乙方已经取得的新的技术成果（包括过程文件和半成品等）全部提交给甲方。甲方有权自由使用、处置所有编制成果文件（不限于本项目）。

11.2.14 乙方应负责协助甲方向有关部门办理合同约定工作需要报批成果或资料的审批手续，确保取得批复文件。

11.2.15 甲方因客观原因无法向乙方提供的基础资料及文件，由乙方负责自行收集。

11.2.16 依据法律规定和本合同约定应由乙方履行的其他义务。

第十二条　违约责任

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12.1 合同生效后，甲方因非乙方原因要求终止或解除合同，双方按乙方实际完成并经甲方认可的工作量核定乙方所完成的成果比例，且甲方按此比例支付相应的合同价款。除此之外，甲方无须向乙方支付任何补偿或赔偿。

12.2 合同生效后，乙方不得单方面终止或解除合同。否则，甲方有权不向乙方支付任何合同约定价款，并要求乙方支付本合同暂定总价的20%作为违约金。由此给甲方造成损失的，乙方还需对造成的损失承担赔偿责任。

12.3 因甲方的上级或相关审批部门对成果文件不进行审批或本合同工程停建、缓建的，甲方应在事件发生后及时通知乙方，并按第 12.1 款的约定向乙方结算和支付相应合同价款。

12.4 乙方对成果文件出现的遗漏或错误负责无偿修改或补充。由于设计缺陷、疏漏、错误等造成工程质量事故或损失，乙方除负责自

费采取补救措施并免收相应部分的费用外，还须向甲方承担赔偿责任并支付全额赔偿金。

12.5 乙方违反第 11.2.2 款、11.2.3 款的约定，擅自变更乙方派出的项目负责人及各专业负责人、专业技术人员，或者不按甲方要求更换不称职的项目负责人、各专业负责人、专业技术人员（含其他一般工作人员）的，应当按下列标准支付违约金：

项目负责人 5000 元/人次；专业负责人 3000 元/人次；专业技术人员（含其他一般工作人员）2000 元/人次。

12.6 非因甲方的原因，乙方延误成果文件交付时间或未按本合同第八条规定的时间完成成果文件及其修改工作的，每延误一天，应支付本合同暂定总价 1 %的违约金；延误超过 15 个日历天（含 15 天）的，甲方有权解除合同，乙方须承担本合同暂定总价 20%的违约金。如果因延误导致甲方遭受损失的，乙方还须赔偿甲方的全部经济损失。

12.7 乙方须独立完成本合同约定的全部工作内容，除经甲方事先书面同意外，不得进行任何形式的分包，不得转包。否则，甲方有权单方解除合同，乙方须承担本合同暂定总价 20%的违约金，由此给甲方造成损失的，乙方还须予以赔偿。

12.8 因乙方原因，相关成果文件未通过政府部门审查，政府部门要求修改、补充资料的，乙方修改、补充资料的时间计入工期时间，提交可相关成果文件的时间不顺延。若相关成果文件经修改后仍不能通过政府部门审查，无法取得批文的，甲方有权解除本合同，并有权要求乙方退还已收取的合同价款，未支付的合同价款不再支付。除此之外，乙方须向甲方支付本合同暂定总价 20%的违约金，给甲方造成损失的，乙方还须予以赔偿。

12.9 乙方根据本合同约定进行工作时，必须同时遵守甲方制定的

相关工程设计与工程管理方面的各项办法、规定和细则（详见附件5）。如乙方在履行合同期间违反甲方制定的各项管理办法、规定和细则的，甲方有权按相关管理办法和细则的规定对乙方处以违约金。若相关管理办法和细则对违约金没有规定的，则乙方每违反一次须向甲方支付本合同暂定总价0.5%的违约金。

第十三条　其他约定

13.1 乙方为本工程所采用的国家或地方标准图，由乙方自费向有关出版部门购买，甲方无需另行支付。

13.2 甲方委托乙方承担本合同内容之外的工作服务，由甲方与乙方协商并签订补充协议确认应承担的费用。

13.3 由于不可抗力因素致使合同无法履行时，双方应及时协商解决。

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第十四条 知识产权及保密

14.1 乙方保证其所提交的成果文件不得侵犯到任何第三人的合法权益（包括但不限于知识产权、或专有技术或商业秘密或其他合法权利）。因侵犯他人的著作权、专利权或其他知识产权所引起的一切法律责任均由乙方承担。若甲方因利用乙方所提交的成果而被指控侵犯他人权利，由此而产生的或与此有关的任何责任由乙方承担，甲方有权就由此发生的所有费用和损失（包括但不限于甲方因此而支付的赔偿金、仲裁费、律师费、调查费等）向乙方追偿。

14.2 乙方为履行本合同中所提交的全部成果文件的知识产权均为甲方所有。未经甲方书面许可，乙方不得将本合同的成果文件用做其他任何用途。否则，应赔偿因此给甲方造成的一切损失。

14.3 本合同无论什么原因解除或终止的，乙方均应当将甲方提供给乙方的全部资料及乙方已经完成的全部成果文件交给甲方。乙方利用甲方提交的技术资料和工作条件所完成的新的技术成果，其知识产权归甲方所有，涉及专利技术的，其专利申请权归甲方享有。

14.4 双方均应保护对方的知识产权，未经对方同意，任何一方均不得对他方的资料及文件擅自修改、复制使用或向第三人转让披露及用于本合同项目外的项目。如发生以上情况，泄密方承担一切由此引起的后果并承担赔偿责任。保密义务不因本合同的变更、解除、终止而受影响。

第十五条　争议解决

因履行本合同发生争议时，甲方与乙方应及时协商解决，也可由当地建设行政主管部门调解。协商或调解不成时，任何一方均有权提请珠海仲裁委员会仲裁。

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在双方解决争议的过程中，除甲方明示暂停的外，乙方均有义务继续进行本合同约定的工作,不得因争议而停工、怠工。

第十六条　合同文件的组成及优先次序

本合同由以下文件组成，文件之间互相解释、互为说明。如果合同文件存在歧义或不一致，则根据如下优先次序来判断：

16.1 经甲、乙双方确认的本合同的工程洽商、变更、会议纪要、补充协议、备忘录等相关文件；

16.2 本合同

16.3 中标通知书

16.4 本合同附件（附件中的中标通知书除外）

16.5 招标文件

16.6 投标文件（当投标文件中的技术标准和参数严于招标文件的，按投标文件中较严的技术标准和参数执行）。

上述所有内容都是构成合同文件不可分割的部分，当文件内容有矛盾或内容含糊不清时，按照上述顺序作出解释，即：如顺序在前的合同文件中没有规定，则双方按照顺序在后的相关文件约定或者规定执行；如前后文件约定或者规定内容互相矛盾时，按照顺序在前的文件约定或者规定执行。属于同一顺序的文件之间不一致时，以签署时间在后的文件为准。

☑第十七条　履约担保

乙方应当按照招标文件及合同的规定提交本合同暂定总价或包干价的10%的履约保函（保险）或履约保证金作为履约担保。

履约担保采取现金担保形式的，乙方应当于合同签订前，足额将担保金交于甲方指定的银行账户，若未在规定期限内交纳履约保证金的，经甲方同意保证金最迟必须于支付第一笔合同款项（含预付款）前交纳，否则不予支付合同款项。

履约担保采取履约保函担保形式的，若中标通知书中明确中标金额或中标金额可以明确估算的，履约保函原则上应当于合同签订前向甲方提交经甲方认可的国有商业银行和经国家相关部门批准成立的股份制商业银行、城市商业银行、农村商业银行的分行以上（含分行）机构或珠海市属全资国有企业、珠海市各区（功能区）区属全资国有企业所属全资及绝对控股的具有相应资质的担保公司开出的不可撤销、见索即付的《履约保函》原件。若中标通知书中未明确中标金额且中标金额无法明确估算的，或合同签订前未提交履约保函的，经发包人同意履约保函必须于支付第一笔合同款项（含预付款）前提交，否则不予支付合同款项。

招标文件如规定履约担保采取履约保险担保形式的，若中标通知书中明确中标金额或中标金额可以明确估算的，履约保险原则上应当于合同签订前向委托人提交经委托人认可的经委托人认可的由在中华人民共和国注册并经营的商业保险公司开出的《履约保险单》原件。若履约保险不能于合同签订前提交的，需经委托人同意并按照委托人财务管理制度的要求足额按时提交符合规定的保函。若中标通知书中未明确中标金额且中标金额无法明确估算的，或合同签订前未提交履约保险的，经发包人同意履约保险必须于支付第一笔合同款项（含预付款）前提交，否则不予支付合同款项。

本合同结算经终审部门审定且经乙方申请后30个日历天内甲方退还履约银行保函（保险）/担保金（无息）。

第十八条 乙方同意在履行本合同过程中接受珠海红宝石建设开发集团有限公司（以下简称“红宝石公司”）的管理，并将与建设管理相关的书面文件（包括但不限于通知、申请、报告、各阶段成果文件等）及非书面通知、报告等提交红宝石公司。

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第十九条 合同生效及其他

17.1 双方履行完本合同规定的义务后，本合同即行终止。但本合同内的知识产权及保密、违约责任及争议解决条款对双方仍具法律效力。

17.2 乙方承诺遵守甲方已制定及新制定或参照的各项建设工程管理制度（制度清单详见附件5），若有违反，乙方愿意承担全部法律责任。

17.3 本合同自双方法定代表人或授权代理人签字并加盖公章或合同专用章后生效，本合同一式捌份，其中甲方陆份，乙方贰份，具有同等法律效力。

17.4 未尽事宜，经双方另行协商一致，签订补充协议解决。

第二十条　补充条款

[无_____]

红宝石集团

（本页为合同签署页）

甲　方（盖章）：珠海红宝石建设开发集团有限公司

法定代表人：

或授权代理人：

邮政编码：

电　　话：

传　　真：

电子信箱：

开户银行：

账　　号：

乙　方（盖章）：广州普邦园林股份有限公司（主办方）

法定代表人：

或授权代理人：

邮政编码：510627

电　　话：020-87526029

传　　真：020-87526532

电子信箱：pb002663@163.com

开户银行：招商银行广州分行五羊支行

账　　号：308581002048

乙　方（盖章）：华南农业大学（成员方）

法定代表人：

或授权代理人：

邮政编码：510640

电　　话：13824432144

传　　真：020-85280256

电子信箱：tgd1101@126.com

开户银行：中国工商银行广州市五山支行

账　　号：3602002609000310520

签约日期：2023年 9月 14日

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附件 1：中标通知书

红宝石集团

附件 2：技术咨询及方案设计任务书（另册）

附件 3：主要乙方员配备表

序号	专业	姓名	职称	项目职务	联系电话	电子邮件	备注
技术咨询							
1		唐光大	副教授	植物技术咨询	13824432144	tgd1101@126.com	
2		冯娴慧	教授	方案技术咨询	13926497133	xhfeng@scut.edu.cn	
3		梁键明	研究生	乡土植物筛选	13232342015	2050203600@qq.com	
4		蒋庆莲	研究生	乡土植物筛选	18276817994	867399883@qq.com	
5		吴玉芬	研究生	植物文本编辑	19970040006	1712374820@qq.com	
6		邵彦清	研究生	植物文本编辑	15760156205	867399883@qq.com	
7		梁毓銮	研究生	规划策略研究	13132009737	ly160323@126.com	
8		汤凯婷	研究生	规划策略研究	17728102384	854212840@qq.com	
9		梁韵涵	研究生	规划策略研究	13377139261	yunhliang@163.com	
10		沈民秋	研究生	规划策略研究	18081646471	shenminqiu0117@163.com	
11		孙琬凝	研究生	规划策略研究	15896564515	2739683079@qq.com	
方案设计							
1	方案	叶劲枫	正高级工程师	项目总负责	13502419526		
2	方案	张文文	高级工程师	项目负责人	13610115257		
3	方案	程秋钿	高级工程师	项目负责人	18680589066		
4	方案	张志锴	中级工程师	主创设计师	15920402039		
5	方案	刘承枫	初级工程师	方案深化设计	13342891672		

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6	方案	舒福康	初级工程师	方案深化设计	15082340688		
7	方案	黄晓秋	初级工程师	方案深化设计	17868073158		
8	方案	梁家乐	初级工程师	方案深化设计	17329570141		
9	方案	莫嘉豪	初级工程师	方案深化设计	15627863229		
10	绿化	梁永平	高级工程师	绿化总设计师	13527823520		
11	绿化	陈静雯	中级工程师	绿化设计师	18814098794		

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附件 4：见索即付履约银行保函（格式）

见索即付履约银行保函

编号：******

珠海****公司：

鉴于******（下称“被保证人”）拟/已依法按照《******招标文件》和被保证人中标的投标文件与贵司签订《******合同》（合同编号：******，下称“合同”）。本行同意为被保证人出具本保函作为被保证人向贵司履约的担保，担保的范围为：合同项下被保证人应履行的全部义务以及因未能全面、及时履行义务而承担的债务，包括但不限于被保证人承诺投入的资金、人力资源、材料设备、成果文件编制/工程施工质量及工期、组织管理、专业协调及配合、违约金、损害赔偿等。

红宝石集团

本行及本行的继承人、受让人无条件且不可撤销地，同意并根据下列条款,保证支付贵司累计总额不超过人民币******元(小写:*****。下称“担保金额”）的款项：

1.本行承诺：在收到贵司法定代表人或委托代理人签字并加盖公章的索赔通知书（仅需声明被保证人违约及索赔金额）后 5 个工作日内，不挑剔、不争辩地按贵司所要求的方式支付给贵司累计总额不超过担保金额的款项，且不要求贵司出具任何其他证明文件或进行其他说明。

2.本行承诺支付的金额将是净数，不得扣除现在或将来应付的任何税费、手续费或任何性质、由任何人加予的保留款等。

3.合同或合同项下的项目发生任何补充、修改或其他变化，都不改变本行在本保函项下的义务。上述补充、修改和变化也无须通知本行。

4.本保函一经开立即生效，未经贵司同意不可撤销，有效期至******年****月****日。本保函项下的任何索赔通知必须在本保函有效期内本行营业时间结束前送达本行下述地址。

5.本保函为独立保函，本行的付款义务独立于基础交易关系及保函申请法律关系，见索即付。

6.本保函适用中华人民共和国法律。

银行（盖章）：******

银行负责人（或委授权理人）（签字或盖章）：

地址：

邮政编码：

联系电话：

日期：******年****月****日

矿宝石集团

附件 5：委托人的建设工程管理制度汇编（另册）

红宝石集团

珠海红宝石建设开发集团有限公司

中标通知书

红宝石集团

项目名称：人才公园-广东乡土树种博物馆项目技术咨询及方案设计

中标单位：广州普邦园林股份有限公司（主办方）、华南农业大学（成员方）

广州普邦园林股份有限公司（主办方）、华南农业大学（成员方）：

人才公园-广东乡土树种博物馆项目技术咨询及方案设计采用内部询价招标方式于2023年08月28日开标，确定贵公司为人才公园-广东乡土树种博物馆项目技术咨询及方案设计中标单位，中标价为：￥905,000.00（人民币玖拾万伍仟元整）；服务期限：按合同约定执行。

请贵单位在领取中标通知书后按规定与我司签订合同。如因贵司原因未按要求签订合同，视为放弃中标，我司将按照相关规定处理。

特此通知。

红宝石集团

招　标　人（公章）：

法定代表人或授权代表人（签名或签章）：

日　　期：2023年 8 月28日

HXNCJH/2023253

合同编号：

技术开发（委托）合同

项目名称：古树大树移植和智慧养护关键技术研究

委托方（甲方）：广州市华农大园林建设有限公司

受托方（乙方）：华南农业大学

签订时间：2023 年 10 月

签订地点：广东省广州市

有效期限：2023 年 11 月 1 日至 2028 年 12 月 31 日

中华人民共和国科学技术部印制

填 写 说 明

一、本合同为中华人民共和国科学技术部印制的技术开发（委托）合同示范文本，各技术合同认定登记机构可推介技术合同当事人参照使用。

二、本合同书适用于一方当事人委托另一方当事人进行新技术、新产品、新工艺或者新材料及其系统的研究开发所订立的技术开发合同。

三、签约一方为多个当事人的，可按各自在合同关系中的作用等，在“委托方”、“受托方”项下（增页）分别排列为共同委托人或共同受托人。

四、本合同书未尽事项，可由当事人附页另行约定，并可作为本合同的组成部分。

五、当事人使用本合同书时约定无需填写的条款，应在该条款处注明“无”等字样。

技术开发（委托）合同

委托方（甲方）：广州市华农大园林建设有限公司

住　所　地：广州市天河区五山华南农业大学农场五区

法定代表人：沈小芬

项目联系人：沈小芬

联系方式：13808891815

通讯地址：广州市天河区五山华南农业大学农场五区

电话：020-85283622　传真：020-85283622

电子信箱：scau_landscape@163.com

受托方（乙方）：华南农业大学

住　所　地：广州市天河区五山路 483 号

法定代表人：薛红卫

项目联系人：陈红跃

联系方式：13802446788

通讯地址：广州市天河区五山路 483 号

电话：020-85280256　传真：020-85280256

电子信箱：34752952@qq.com

本合同甲方委托乙方研究开发古树大树移植和智慧养护关键技术研究项目，并支付研究开发经费和报酬，乙方接受委托并进行此项研究开发工作。双方经过平等协商，在真实、充分地表达各自意愿的基础上，根据《中华人民共和国合同法》的规定，达成如下协议，并由双方共同恪守。

第一条　本合同研究开发项目的要求如下：

1．技术目标：在古树大树移植和智慧养护关键技术上进行合作研究，最终形成研究报告1份、申报或获批专利5个、行业标准草案申报立项5个。

2．技术内容：（1）古树、大树生长监测技术研究；（2）古树、大树健康评价技术研究；（3）古树、大树病虫害防治技术研究；（4）古树、大树专用肥料研发；（5）古树、大树移植和智慧养护技术及设备研发。

3．技术方法和路线：广泛收集全国古树大树移植和养护关键技术，找出关键的研究重点内容，根据技术开发内容，细化每项技术开发内容的实施方案，进行大量的调研和科学试验，整理资料和分析数据，申请专利，撰写行业标准草案，形成相关的技术报告，专家咨询和评审，完成项目全部内容。

第二条 乙方应在本合同生效后90日内向甲方提交研究开发计划。研究开发计划应包括以下主要内容：

1．古树、大树生长监测技术体系构建；

2．古树、大树健康评价内容和体系；

3．古树、大树主要病虫害资料收集和整理；

4．古树、大树专用肥料研发计划；

5．古树、大树移植和智慧养护计划实施方案。

第三条 乙方应按下列进度完成研究开发工作：

1.2024年12月底前，提交《古树、大树生长监测技术方法（初稿）》制定相关行业标准（草案）1项，申请专利1项，相应成果须得到甲方认可；

2.2024年12月底前，提交《古树、大树健康评价体系报告（初稿）》，制定相关行业标准（草案）1项，相应成果须得到甲方认可；

3.2025年12月底前，提交《古树、大树病虫害关键防治技术报告

（初稿）》，研发古树、大树专用肥料，申请相关专利 2 项，制定相关行业标准（草案）2 项，相应成果须得到甲方认可；

4. 2026 年 12 月底前，提交《古树、大树移植和智慧养护技术报告（初稿）》，研发技术及设备工具，申请相关专利 2 项，制定相关行业标准（草案）1 项，相应成果须得到甲方认可。

第四条 为保证项目有效进行，双方各负责提供下列工作条件和协作事项如下：

1．甲方提供项目：树木迁移养护项目及广东省广州市古树名木分布地点（具体待定）。

2．乙方提供的场地：华南农业大学农场五区（岑村桥头）农事训练中心林学与园林训练站。

3．技术资料清单：协调提供项目所需的相关资料。

4．提供时间和方式：项目执行期间，方式不限。

5．其他协作事项：（具体待定）。

第五条 甲方应按以下方式支付研究开发经费和报酬：

1．研究开发经费总额为 人民币壹佰万元（¥1,000,000.00）。

其中：（1） 学校管理费（6%）¥60,000.00 元；

（2） 税率（3.29%） ¥32,900.00 元；

（3） 课题绩效（30%） ¥300,000.00 元；

（4） 劳务费 ¥300,000.00 元；

（5） 材料费 ¥200,000.00 元；

（6） 知识产权、信息费 ¥107,100.00 元。

2．研究开发经费由甲方 分期 支付乙方。具体支付方式和时间如下：

（1）合同签订 7 个工作日内，甲方向乙方支付人民币壹拾万元整（¥100,000.00）。

（2）合同生效后 90 日内收到乙方提交研究开发计划，甲方向乙

方支付人民币贰拾万元整（¥200,000.00）。

（3）完成技术报告、技术标准草案、专利申报受理后，甲方向乙方支付总经费的 30%，甲方向乙方支付人民币叁拾万元整（¥300,000.00）。

（4）专利获批以及成果通过评审，甲方向乙方支付人民币肆拾万元整（¥400,000.00）。

乙方开户银行名称、地址和帐号为：

开户银行：华南农业大学

地址：广州工商银行五山支行

帐号：3602002609000310520

（5）根据合同约定开具发票，甲方收到乙方提供的发票后付款。

第六条 本合同的研究开发经费由乙方以横向课题项目经费的方式使用。

第七条 本合同的变更必须由双方协商一致，并以书面形式确定。

第八条 未经甲方同意，乙方不得将本合同项目部分或全部研究开发工作转让第三人承担。

第九条 在本合同履行中，因作为研究开发标的的技术已经由他人公开（包括以专利权方式公开），一方应在 30 日内通知另一方解除合同。逾期未通知并致使另一方产生损失的，另一方有权要求予以赔偿。

第十条 乙方应当按以下方式向甲方交付研究开发成果：

1．研究开发成果交付的形式及数量：纸质版和电子版的技术报告、草案和专利申请函等。

2．研究开发成果交付的时间及地点：按本合同约定的服务进度的时间节点交付，最迟不超过 2027 年 12 月 31 日。

第十一条 乙方应当保证其交付给甲方的研究开发成果不侵犯任何第三人的合法权益。

第十二条 双方确定，因履行本合同所产生的研究开发成果及其相关知识产权权利归属 甲 方享有申请专利的权利。

第十三条 乙方不得在向甲方交付研究开发成果之前，自行将研究开发成果转让给第三人。

第十四条 乙方完成本合同项目的研究开发人员享有在有关技术成果文件上写明技术成果完成者的权利和取得有关政府相关部门荣誉证书、奖励的权利，甲方优先享有参与权。

第十五条 乙方利用研究开发经费所购置与研究开发工作有关的设备、器材、资料等财产，归 乙 方所有。

第十六条 双方确定，乙方应在向甲方交付研究开发成果后，根据甲方的请求，为甲方指定的人员提供技术指导和培训，或提供与使用该研究开发成果相关的技术服务。

第十七条 双方确定，在本合同有效期内，甲方指定 沈小芬 为甲方项目联系人，乙方指定 陈红跃 为乙方项目联系人。项目联系人负责联系跟进本项目有关工作事宜。一方变更项目联系人的，应当及时以书面形式通知另一方。未及时通知并影响本合同履行或造成损失的，应承担相应的责任。如因不可抗拒的因素，影响项目的进度，双方协商项目延期或续签。

第十八条 双方确定，出现下列情形，致使本合同的履行成为不必要或不可能的，一方可以通知另一方解除本合同：

1．因发生不可抗力或技术风险；

2．工作内容、范围、时限发生较大变化。

第十九条： 双方因履行本合同而发生的争议，应协商、调解解决。协商、调解不成的，双方均同意向甲方所在地有管辖权的人民法院提起诉讼。

第二十条 本合同一式 陆 份，甲方执 叁 份，乙方执 叁 份具有同等法律效力。

第二十一条 本合同经双方签字盖章后生效。

甲方：_____（盖章）

法定代表人/委托代理人：_____（签名）

2023年 10月 30日

乙方：_____（盖章）

法定代表人/委托代理人：_____（签名）

2023年 10 月 30 日

印花税票粘贴处：

（以下由技术合同登记机构填写）

合同登记编号：

1．申请登记人：_____

2．登记材料：（1）_____

（2）_____

（3）_____

3．合同类型：_____

4．合同交易额：_____

5．技术交易额：_____

技术合同登记机构（印章）

经办人：

年　　月　　日

知情同意书

华南农业大学（科学研究院、财务处）：

2023 年我司与华南农业大学签订《古树大树移植和智慧养护关键技术研究》合同，华南农业大学方负责人为陈红跃老师。

2023 年 11 月因陈红跃老师退休，为确保该项目能够继续推进并确保顺利完成，经与相关方协商，同意华南农业大学方负责人更换为秦新生老师，后续项目相关事宜由其负责跟进。

广州市华农大园林建设有限公司（盖章）

法定代表人（签字）：

项目组成员（签字）：

2024 年 5 月 30 日

科研空间

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所有项目

职称评定
- 主持的项目
- 参与的项目

博硕导评定
- 主持的项目
- 参与的项目

项目性质
- 纵向(51项)
- 横向(34项)

项目分类
- 广东省林业科技创新专项资金项目(12项)
- 国家自然科学基金项目(5项)
- 省级生态公益林效益补偿资金(5项)
- 其他纵向(5项)
- 国家其它项目(4项)
- 广东省林业科技计划项目(4项)
- 2018年以前广东省自然科学基金(3项)
- 公益性行业(林业)科研专项经费项目(2项)
- 2014年以前项目(2项)
- 广东省林业行业标准项目(2项)
- 省级财政产业技术研究与开发资金(1项)
- 科技基础条件平台建设计划课题(1项)
- 广东省动植物防疫检疫科研专项经费(1项)
- 广东省中医药强省课题(1项)
- 广州市科技计划项目(1项)
- 广州市科普项目(1项)
- 厅级其它项目(1项)
- 技术服务(31项)
- 技术咨询(2项)
- 技术开发(1项)

参与形式
- 主持(27项)
- 参与(58项)

总数:50项 (表中经费单位：万元) 项目名称 查询 新增 删除 导出

全选	项目名称	项目分类	项目成员	起止日期	合同金额	项目状态	审核状态	操作
	村庄绿化技术服务	技术服务	何茜,阙青敏,阙青敏,苏艳,单体江,陈晓胜,秦新生,邱权,高伟,胡盛劼,余美萱	2025-01-22—2025-04-30	82	进行	学校通过	
	珍稀濒危树种花榈木和广东紫薇种质资源保护与扩繁	省级生态公益林效益补偿资金	邓小梅,奚如春,秦新生	2025-01-01—2025-12-31	50	进行	学校通过	
	.珍稀濒危树种花榈木和广东紫薇种质资源保护与扩繁	省级生态公益林效益补偿资金	邓小梅,奚如春,秦新生	2025-01-01—2025-12-31	50	进行	学校不通过	
	全省林草种质资源调查收集	省级生态公益林效益补偿资金	刘天颐,周峰,李玉玲,施诗,郑明轩,吴奉奇,黄久香,秦新生,吴永彬,李镇魁	2025-01-01—2025-12-31	100	进行	暂存	
	古树大树移植和智慧养护关键技术研究	技术服务	秦新生,陈红跃,翁殊斐,彭昌操,冼丽铧,刘天颐,单体江,潘澜,吴奉奇,帅晓迈（学）,李程（学）,杨佳曼（学）	2023-10-30—2028-12-31	100	进行	学校通过	编辑 项目结项
	人才公园-广东乡土树种博物馆项目技术咨询及方案设计	技术服务	秦新生,梁键明（学）,蒋庆莲（学）,梁毓銮（外）	2023-09-14—2025-09-15	57.5	完成	学校通过	编辑 项目结项 结题表
	紫薇属树种种质创新与产业化利用研究	广东省林业科技创新专项资金项目	邓小梅,奚如春,孙晔,秦新生,骈瑞琪	2023-01-01—2027-12-31	150	进行	学校通过	
	林木种质资源调查（2022-2024）	广东省林业科技计划项目	黄少伟,刘天颐,崔大方,吴永彬,秦新生,黄久香,李镇魁,冯志坚,李玉玲,吴奉奇,羊海军,施诗,刘纯鑫,郑明轩,周峰	2022-01-01—2024-12-01	750	进行	学校通过	
	碳中和背景下广东省典型优势树种大径材培育关键技术体系构建与示范	广东省林业科技创新专项资金项目	曾曙才,何茜,莫其锋,周庆,吴道铭,秦新生,贾小容,刘效东,张俊杰,林蔚,孙思,邱权,张璐,马玲,赵倩,苏艳,龙凤玲	2021-11-29—2024-12-31	300	进行	学校通过	
	东莞市大岭山森林公园生态公益林道路植物科普展示服务	技术服务	秦新生,何科稣（外）,阳君（学）,梁妙婷（学）,左子旋（学）	2021-07-08—2021-12-31	28.8	完成	学校通过	编辑 项目结项 结题表
	东莞市自然保护区植物多样性固定样地监测	技术服务	秦新生,阳君（学）,陈美思（学）,何科稣（外）	2021-05-06—2022-12-20	106.3	完成	学校通过	编辑 项目结项 结题表
	植物标本翻新制作	技术咨询	秦新生	2020-12-11—2021-09-01	3.5	完成	学校通过	编辑 项目结项 结题表
	广东乳源大峡谷省级自然保护区植物调查监测项目	技术咨询	秦新生	2020-06-01—2020-11-30	32	完成	学校通过	编辑 项目结项 结题表
	第四次全国中药资源普查-广东省汕尾市城区、陆丰市中药资源普查	国家其它项目	秦新生,洪家乐（学）,陈美思（学）,张冉（学）,方惠婷（学）	2019-09-01—2020-10-01	55	完成	学校通过	编辑
	深圳市宝安区石岩街道主要道路和公园绿化问题调研与应对策略分析	其他纵向	秦新生,张冉（学）,陈美思（学）,洪家乐（学）	2019-07-20—2019-11-20	9	完成	学校通过	编辑
	广东省南澳县中药资源普查	广东省中医药强省课题	施诗,丁明艳（外）,李玉玲,秦新生,郑明轩,黄锐洲（学）	2019-06-28—2019-12-31	0	进行	机构通过	
	广东石灰岩山区生态公益林植物资源及生态效益研究	省级生态公益林效益补偿资金	唐光大,姜春宁,张卓欣,秦新生,郑明轩,施诗,姚纲,李玉玲,黄锐洲（学）,廖苗（学）,李佳雨（学）	2019-03-18—2021-12-31	50	完成	学校通过	
	特大台风"山竹"对宝安区城市道路行道树树							

木破坏情况的调查及基于抗风性的宝安区行道树树种安全评价、筛选与管护标准体系研究	其他纵向	秦新生,施诗,李玉玲,张冉（学）,叶圣林（学）	2018-09-17--2019-02-28	42	完成	学校通过	编辑
深圳市宝安区绿化管养监管评价及绿化管养精细化指引编制	其他纵向	秦新生,郑明轩,张冉（学）,何科稣（外）	2018-09-14--2018-12-30	48	完成	学校通过	编辑
基于古树资源综合评价的高密度城市行道树树种选择指引研究——以澳门为例	国家自然科学基金项目	秦新生,佘美萱,易绮斐（外）,刘东明（外）,冯志坚,许冲勇,李玉玲,李剑,杨舒（学）,张冉（学）	2018-08-16--2022-12-31	70.8	完成	学校通过	编辑
第四次全国中药资源普查—广东省汕头市濠江区、金平区等中药资源普查	国家其它项目	李镇魁,秦新生,冯志坚,黄久香,姜春宁,郑明轩,谢家敏（学）	2018-08-01--2019-12-31	50	完成	学校通过	
第四次全国中药资源普查-广东省汕头南澳县中药资源普查	国家其它项目	施诗,秦新生,丁明艳（外）,李玉玲,郑明轩,张锐洲（学）	2018-08-01--2019-11-30	25	完成	学校通过	
狗牙花属药赏两用树种种质资源评价与繁育技术研究	广东省林业科技创新专项资金项目	秦新生,李少勤（外）,邓小梅,李秉滔,何科稣（外）,姜春宁,施诗,李玉玲,郑明轩,张波,张冉（学）	2018-06-01--2021-12-31	30	进行	学校通过	编辑
广东省东部地区野生兰科植物资源调查	省级生态公益林效益补偿资金	张荣京,张永夏（外）,秦新生,李玉玲,王美娜（外）,李富强（外）,陆炜斌,石燕珍（外）,张斌（外）,杜家贤（学）,殷崇敏（学）,张冉（学）,陈美思（学）,洪家乐（学）	2018-05-20--2020-05-31	30	进行	学校通过	
梅州市五华县红色文旅项目概念策划技术服务	技术服务	古德泉,黄家平,秦新生,林云	2018-05-01--2019-12-31	12	完成	学校通过	
广东省兰科植物资源调查和监测	技术服务	李玉玲,秦新生,黄久香,姜春宁,施诗	2018-03-26--2018-12-31	19	完成	学校通过	
深圳宝安区城市道路园林植物及其景观提升导则 编研	其他纵向	秦新生,杨舒（学）,张冉（学）	2018-01-01--2018-04-15	7.8	完成	学校通过	编辑
苦楮和钩锥的基因组异质性分化和渗透研究	国家自然科学基金项目	孙晔,秦新生,张卓欣,刘潼俭（学）,袁勋（学）,殷琪（学）	2017-08-18--2021-12-31	69.6	完成	学校通过	
林业规划设计合作协议	技术服务	冯志坚,李镇魁,翁殊斐,秦新生,袁森（学）	2017-07-11--2020-06-30	10	进行	学校通过	
台湾-西南-喜马拉雅间断分布物种银叶委陵菜的谱系地理学研究	2018年以前广东省自然科学基金	施诗,秦新生,张卓欣,羊海军,曾思金（学）,王洁雨（学）,申长青（学）	2017-06-27--2020-04-30	5	完成	学校通过	
深圳宝安区城市道路园林植物资源及其景观调研	其他纵向	秦新生,杨舒（学）,张冉（学）	2017-06-25--2017-11-30	20	完成	学校通过	编辑
220千伏纵江至长安线路等工程输电线路经过森林公园环境影响报告编制技术服务合同	技术服务	奚如春,陈世清,邓小梅,秦新生,张鹏（学）	2017-05-15--2018-12-31	83.95	完成	学校通过	
适宜珠三角地区湿生木本植物筛选及评价研究	厅级其它项目	冯志坚,李镇魁,秦新生,徐茵（学）,卢艺菲（学）,袁森（学）	2017-05-04--2017-12-30	19.7	完成	学校通过	
适宜珠三角地区湿生木本植物筛选及评价研究	技术服务	冯志坚,李镇魁,秦新生,徐茵（学）,卢艺菲（学）,袁森（学）	2017-05-04--2017-12-15	19.7	进行	机构通过	
广东从化陈禾洞省级自然保护区生物多样性监测（技术服务部分）	技术服务	黄久香,郑明轩,王本洋,羊海军,秦新生,周玉洁（学）,陈晓熹（学）,李群（学）,韦雪芬（学）	2017-04-12--2019-07-15	30	完成	学校通过	
润楠属景观树种筛选与示范栽培（2017年）	广东省林业科技创新专项资金项目	冯志坚,张波,翁殊斐,李镇魁,唐光大,秦新生,郑明轩,卢艺菲（学）,徐茵（学）,袁森	2017-04-01--2018-12-31	25	完成	学校通过	

			（学）				
	大果木莲等珍贵木兰科树种种质资源与繁育技术研究（2017年）	广东省林业科技创新专项资金项目	邓小梅,奚如春,吴谦民,虞依娜,秦新生,骈瑞琪,倪慧群,张波	2017-04-01--2018-12-31	25	完成	学校通过	
	广东省翁源青云山省级自然保护区科研监测体系建设	技术服务	黄久香,秦新生,郑明轩,姜春宁,施诗,陈晓熹（学）,要群（学）	2016-11-16--2017-06-16	15	完成	学校通过	
	翁源青云山自然保护区植物综合调查研究项目	技术服务	秦新生,杨舒（学）	2016-11-15--2019-09-01	10	完成	学校通过	编辑 项目结项 结题表
	坪山新区古树资源普查（古树志编辑）服务项目	技术服务	秦新生,冯志坚,王茫（学）,杨舒（学）	2016-11-04--2016-12-31	11	完成	学校通过	编辑 项目结项 结题表
	广东翁源青云山省级自然保护区科研监测体系建设项目——植物标本制作	技术服务	黄久香,施诗,姜春宁,郑明轩,秦新生,陈晓熹（学）,李群（学）	2016-10-13--2017-05-05	5	完成	学校通过	
	云浮市植物园总体规划采购项目	技术服务	冯志坚,李剑,李镇魁,翁殊斐,秦新生	2016-09-05--2016-10-05	17.8	完成	学校通过	
	黄花风铃木苗木栽培技术规程	广东省林业行业标准项目	冯志坚,张波,翁殊斐,李镇魁,秦新生,丁雨霜（学）,张育恺（学）,卢艺菲（学）,徐茵（学）	2016-07-01--2018-12-28	9	完成	学校通过	
	华南地区植物物种多样性信息收集	技术服务	冯志坚,翁殊斐,李镇魁,秦新生,卢艺菲（学）,徐茵（学）	2016-05-18--2017-11-30	16	完成	学校通过	
	黄粱木基因组测序及重要功能基因的挖掘	广州市科技计划项目	彭昌操,陈晓阳,吴谦民,欧阳昆唏,胡新生,刘振兰,秦新生,骈瑞琪,林元震,李培,李俊成（学）,赵先海（学）,阙青敏（学）,白雪（学）,任陈希（学）,卢好君（学）,江左杰（学）,贺俊波（学）	2016-04-01--2019-03-31	170	完成	学校通过	
	广东罗坑鳄蜥国家级自然保护区古茶树资源普查	技术服务	秦新生,唐光大,吴永彬,黄久香,姜春宁,郑明轩,施诗	2016-03-17--2016-12-30	19.5	完成	学校通过	编辑 项目结项 结题表
	500千伏纵江变电站配套500千伏线路二期工程林业调查报告编制项目技术服务合同	技术服务	奚如春,李吉跃,陈世清,邓小梅,秦新生	2016-02-26--2017-06-30	39.5	完成	学校通过	
	广东省河源市第二次全国重点保护野生植物资源调查（河源市重点保护野生植物资源调查）	广东省林业科技计划项目	秦新生,王茫（学）,赵可欣（学）	2016-01-01--2017-12-30	12	完成	学校通过	编辑
	惠州、中山两市国家重点保护野生植物调查	技术服务	冯志坚,庄雪影,李镇魁,吴永彬,黄久香,秦新生,唐光大,姜春宁,郑明轩	2015-11-30--2016-06-30	15	完成	学校通过	
	广东南山森林公园植物资源调查	技术服务	冯志坚,李镇魁,秦新生,姜春宁,张育恺（学）,丁雨霜（学）	2015-11-27--2016-09-30	3.5	完成	学校通过	

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检索证明

根据委托人提供的论文材料，委托人**华南农业大学林学与风景园林学院 秦新生** 10 篇论文收录情况如下表。

序号	论文名称	发表刊物及发表的年月卷期/页码等	作者排名	论文等级	作者文中单位	收录情况	影响因子	中科院大类分区
1	Predicting the Potential Distribution of Oxalis debilis Kunth, an Invasive Species in China with a Maximum Entropy Model	PLANTS-BASEL 出版年：2023 出版日期：DEC 卷期：12 23 页码：- 文献号：3999 文献类型：Article	第一作者	A 类	华南农业大学林学与风景园林学院	SCI	IF2-year=4.0 IF5-year=4.4 （2023）	生物学 2 区 Top 期刊：否 （2023）
2	3 种乌桕属植物根化学成分的 GC-MS 分析	福建农林大学学报（自然科学版） 出版年：2014 卷期： 页码：- 文献号： 文献类型：	第一作者	B 类	华南农业大学林学与风景园林学院	北大核心	无	无
3	海南石灰岩地区的种子植物区系	华南农业大学学报（自然科学版） 出版年：2014 卷期： 页码：- 文献号： 文献类型：	第一作者	B 类	华南农业大学林学与风景园林学院	北大核心	无	无

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4	A STUDY ON THE FLORA AND VEGETATION OF CAT DUA ISLAND, NORTHEASTERN VIETNAM	PAKISTAN JOURNAL OF BOTANY 出版年：2012 出版日期：AUG 卷期：44 4 页码：1229-1232 文献类型：Article	第一作者	B 类	华南农业大学林学院	SCI	IF2-year=0.872 IF5-year=0.913 （2012）	生物 4 区 Top 期刊：否 （2012）
5	海南俄贤岭石灰岩山地海南凤仙花所在群落植物区系及生态特征	华南农业大学学报（自然科学版） 出版年：2012 卷期： 页码：- 文献号： 文献类型：	第一作者	B 类	华南农业大学林学与风景园林学院	北大核心	无	无
6	东莞园林植物及其应用现状研究	广东园林 出版年：2011 卷期： 页码：- 文献号： 文献类型：	第一作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
7	中国鹅绒藤属（萝藦科）植物研究进展	中国野生植物资源 出版年：2011 卷期： 页码：- 文献号： 文献类型：	第一作者		华南农业大学林学院	CNKI	无	无

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8	海南特有野生花卉资源及其利用	中国园林 出版年：2011 卷期： 页码：- 文献号： 文献类型：	第一作者	B 类	华南农业大学林学院	CNKI	无	无
9	适合园林应用的三种乌桕属乡土观赏植物	广东园林 出版年：2011 卷期： 页码：- 文献号： 文献类型：	第一作者	普刊类	华南农业大学林学院	CNKI	无	无
10	2 种石灰岩特有植物的特性及园林应用价值	广东园林 出版年：2011 卷期： 页码：- 文献号： 文献类型：	第一作者	普刊类	华南农业大学林学院	CNKI	无	无

说明：论文等级和中科院大类分区按《华南农业大学学术论文评价方案（试行）》划分。

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检索证明

根据委托人提供的论文材料，委托人**华南农业大学林学与风景园林学院 秦新生** 27 篇论文收录情况如下表。

序号	论文名称	发表刊物及发表的年月卷期/页码等	作者排名	论文等级	作者文中单位	收录情况	影响因子	中科院大类分区
1	Delineating the Area for Sustainable Cultivation of Morinda officinalis Based on the MaxEnt Model	AGRONOMY-BASEL 出版年：2024 出版日期：JUN 卷期：14 6 页码：- 文献号：1134 文献类型：Article	通讯作者	A 类	华南农业大学林学与风景园林学院	SCI	IF2-year=3.4 IF5-year=3.8 （2024）	农林科学 2 区 Top 期刊：否 （2025）
2	Research progress on Brassicaceae plants: a bibliometrics analysis	FRONTIERS IN PLANT SCIENCE 出版年：2024 出版日期：JAN 31 卷期：15 页码：- 文献号：1285050 文献类型：Review	通讯作者	A 类	华南农业大学林学与风景园林学院	SCI	IF2-year=4.8 IF5-year=5.7 （2024）	生物学 2 区 Top 期刊：否 （2025）
3	Ophioglossum hongii (Ophioglossaceae), a new species from Xizang, China	PHYTOTAXA 出版年：2024 出版日期：DEC 10 卷期：676 2 页码：169-180	共同通讯作者(倒数第一)	B 类	华南农业大学林学与风景园林学院	SCI	IF2-year=1.0 IF5-year=1.0 （2024）	生物学 4 区 Top 期刊：否 （2025）

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		文献类型：Article						
4	基于 CiteSpace 文献计量分析的红豆属植物研究进展	安徽农学通报 出版年：2024 卷期：30　15 页码：- 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
5	广东省封开县野生林木种质资源调查研究	中国野生植物资源 出版年：2024 卷期：43 8 页码：- 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
6	Vein hierarchy mediates the 2D relationship between leaf size and drought tolerance across subtropical forest tree species	TREE PHYSIOLOGY 出版年：2024 出版日期：FEB 6 卷期：44 1 页码：- 文献类型：Article	共同通讯作者（倒数第一）	A 类	华南农业大学林学与风景园林学院	SCI	IF2-year=3.7 IF5-year=4.1 （2024）	农林科学　2 区 Top 期刊：是 （2025）
7	Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in Phyllostachys propinqua McClure across Northern China	FORESTS 出版年：2023 出版日期：NOV 卷期：14 11 页码：- 文献号：2243	共同通讯作者（倒数第一）	A 类	华南农业大学林学与风景园林学院	SCI	IF2-year=2.4 IF5-year=2.7 （2023）	农林科学　2 区 Top 期刊：否 （2023）

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		文献类型：Article						
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9	基于 CiteSpace 的萝芙木属植物研究知识图谱可视化分析	北京大学学报（自然科学版） 出版年：2023 卷期：59 6 页码：1011-1024- 文献号： 文献类型：	通讯作者	A 类	华南农业大学林学与风景园林学院	北大核心	无	无
10	海丰县野生林木种质资源研究	中国野生植物资源 出版年：2023 卷期：42 3 页码：9-14 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无

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11	Species characteristics and cultural value of stone wall trees in the urban area of Macao	SCIENTIFIC REPORTS 出版年：2022 出版日期：JAN 28 卷期：12 1 页码：- 文献号：1562 文献类型：Article	共同通讯作者（倒数第一）	B 类	华南农业大学林学与风景园林学院	SCI	IF2-year=4.6 IF5-year=4.9 （2022）	综合性期刊 3区 Top 期刊：否 （2022）
12	广东陆丰市豆科野生药用植物资源调查分析	福建林业科技 出版年：2022 卷期：49 2 页码：116-121 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
13	Purification Efficiency of Three Combinations of Native Aquatic Macrophytes in Artificial Wastewater in Autumn	INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH 出版年：2021 出版日期：JUN 卷期：18 11 页码：- 文献号：6162 文献类型：Article	共同通讯作者（倒数第二）	B 类	华南农业大学林学与风景园林学院	SCI	IF2-year=4.614 IF5-year=4.799 （2021）	医学 3区 Top 期刊：否 （2021）
14	澳门地被植物资源	广东园林 出版年：2021 卷期：43 4 页码：79-84 文献号：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无

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15	澳门药用植物资源	广东园林 出版年：2021 卷期：43 1 页码：60-63 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
16	海南夹竹桃科植物园林应用分析与评价	环境生态学 出版年：2019 卷期：1 5 页码：47-56 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
17	Gomphogyne hainanensis (Cucurbitaceae), a new species from Hainan Island, China	ANNALES BOTANICI FENNICI 出版年：2017 出版日期：MAY 卷期：54 1-3 页码：7-11 文献类型：Article	通讯作者	B 类	华南农业大学林学与风景园林学院	SCI	IF2-year=0.872 IF5-year=0.788 （2017）	生物 4 区 Top 期刊：否 （2017）
18	海南尖峰岭热带山地雨林 2 种夹竹桃科植物的空间分布格局与关联性	生物多样性 出版年：2017 卷期：25 10 页码：1065-1074 文献号：	通讯作者	B 类	华南农业大学林学与风景园林学院	北大核心	无	无

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19	广州市广雅中学植物造景特点浅析	广东园林 出版年：2015 卷期：37 6 页码：66-69 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学与风景园林学院	CNKI	无	无
20	广州市培正中学园林植物及其应用现状研究	广东园林 出版年：2015 卷期：37 5 页码：56-58 文献号： 文献类型：	通讯作者	普刊类	华南农业大学林学院	CNKI	无	无
21	9 种鹅绒藤属(萝藦科)植物种子微形态特征研究	西南农业学报 出版年：2014 卷期：27 2 页码：797-800 文献号： 文献类型：	通讯作者	B 类	华南农业大学林学院	北大核心	无	无
22	石灰岩特有植物圆叶乌桕土壤与叶片化学元素含量特征	西南农业学报 出版年：2013 卷期：26 3 页码：1195-1200 文献号：	通讯作者	B 类	华南农业大学林学院	北大核心	无	无

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23	中国鹅绒藤属（萝藦科）植物叶表皮微形态扫描电镜研究	西南农业学报 出版年：2013 卷期：26 2 页码：742-749 文献号： 文献类型：	通讯作者	B 类	华南农业大学林学院	北大核心	无	无
24	17 种 1 亚种鹅绒藤属植物花粉器形态学研究	西北植物学报 出版年：2012 卷期：32 9 页码：1758-1762 文献号： 文献类型：	通讯作者	B 类	华南农业大学林学院	北大核心	无	无
25	石灰岩特有植物圆叶乌桕叶表皮形态特征及其生态适应性研究	西北植物学报 出版年：2012 卷期：32 4 页码：0709-0715 文献号： 文献类型：	通讯作者	B 类	华南农业大学林学院	北大核心	无	无
26	12 种鹅绒藤属（萝藦科）植物花粉器形态学研究	植物研究 出版年：2012 卷期：32 2 页码：137-142	通讯作者	C 类	华南农业大学林学院	北大核心	无	无

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27	海南浆纸林林下维管植物区系研究.	中南林业科技大学学报 出版年：2011 卷期：31　9 页码：91-96 文献号： 文献类型：	通讯作者	C 类	华南农业大学林学院	北大核心	无	无

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Article

Predicting the Potential Distribution of *Oxalis debilis* Kunth, an Invasive Species in China with a Maximum Entropy Model

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Abstract: *Oxalis debilis* Kunth, an invasive plant native to South America, has already spread extensively throughout various regions in China including West China, East China, Central China, and South China. It poses a certain degree of damage to the local ecosystem and demonstrates significant invasive potential. Utilizing distribution information along with environmental variables such as bioclimate, soil factors, elevation, and UV-B radiation, the MaxEnt model combined with ArcGIS was employed to forecast the potential distribution of *O. debilis* in China. The ROC curve was employed to assess the accuracy of the model, while the jackknife test was utilized to identify dominant environmental variables and determine their optimal values. The simulated AUC value was 0.946 ± 0.004, and the predicted results exhibited a remarkable concordance with the actual outcomes, thereby indicating that the Maxent model demonstrated a high level of confidence in its predictive capabilities. The potential distribution of *O. debilis* in China spanned 18,914,237 km^2, accounting for 19.70% of the total land area. This distribution was primarily observed in East, Central, and South China, with Guangdong, Guangxi, and Guizhou being identified as highly suitable habitats for *O. debilis*. Furthermore, it was observed that the distribution of *O. debilis* is primarily influenced by environmental variables such as the precipitation of the driest month, the monthly diurnal range, the mean temperature of the wettest quarter, and the isothermality. The findings can serve as a valuable point of reference for the prevention and monitoring of *O. debilis* spread, thereby contributing to the protection of China's agricultural, forestry, and ecological environments. It is imperative to acknowledge the hazards associated with *O. debilis*, closely monitor its invasion, and prevent uncontrolled dissemination.

Keywords: potential geographic area; MaxEnt model; environmental variable; *Oxalis debilis*; invasive plant

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Citation: Qin, X.; Li, M. Predicting the Potential Distribution of *Oxalis debilis* Kunth, an Invasive Species in China with a Maximum Entropy Model. *Plants* **2023**, *12*, 3999. https://doi.org/10.3390/plants12233999

Academic Editor: Alex Troitsky

Received: 22 September 2023
Revised: 23 November 2023
Accepted: 26 November 2023
Published: 28 November 2023

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1. Introduction

Oxalis debilis Kunth is a significant perennial herb with medicinal and edible properties as well as environmental uses, commonly referred to as pink wood sorrel, which belongs to the family Oxalidaceae [1]. The plant species is indigenous to Central and South America and has a global distribution, including India, particularly in the north-eastern states [2]. It is a tuberous geophyte and primarily thrives in the subtropical biome. *O. debilis* was introduced to China as an ornamental plant in the 19th century [3]. The species is currently widely distributed throughout East, Central, and South China, with notable populations in Guangxi, Hebei, Fujian, Shaanxi, Sichuan, and Yunnan [4]. The species can be readily observed in low mountain ranges, rice fields, agricultural lands, horticultural areas, road verges, residential compounds, public parks, and lawns [5]. Due to its high ornamental value in terms of color and leaf shape, it is extensively utilized for landscaping purposes [6] (Figure 1).



Figure 1. Photograph of *Oxalis debilis* Kunth. (**a**) A whole plant with a shoot and root system; (**b**) growing in the lawn; (**c**) leaves; (**d**) flowers; (**e**) plant in a flower bed.

O. debilis thrives in a sunny, warm, and humid environment. It is tolerant to barren conditions, acid–alkaline soil, and a drought climate. The plant possesses a wide range of adaptability, strong vitality, and cold resistance [7], enabling rapid growth even during the monsoon season [8]. In recent years, the population of *O. debilis* has undergone rapid growth, leading to an expanded distribution range. Consequently, the ecological impact of *O. debilis* on local environments and surrounding fauna has become increasingly evident, necessitating heightened attention and vigilance from individuals. First, as an alien species, it has the potential to cause ecological disasters. This plant primarily propagates through subterranean bulbs, rendering them highly invasive [9]. Additionally, it exhibits strong allelopathic effects that can impede the growth of other crops and weeds, thereby exerting a significant impact on the ecosystem structure and even posing a threat [10]. Second, it will engender substantial economic ramifications. As an outbreak weed, it has a serious impact on the growth of farmland crops and garden greening plants; for example, the yield of potatoes, peppers, and watermelons grown near *O. debilis* have all experienced various degrees of reduction of up to a 100% reduction [11], which will lead to serious economic losses. According to the risk analysis methods of pests at home and abroad, it was found that the risk value of *O. debilis* was 1.94, indicating that it is a medium or even high-risk plant [12,13].

In recent years, numerous methods have been proposed to predict the species potential distribution using niche models, including BIOCLIM, GARP, CLIMEX, Domain, MaxEnt [14,15]. These models share a similar underlying principle and are all based on known geographic distribution data of a species along with corresponding environmental variables. Specific algorithms are used to calculate the ecological requirements of the species [16], and then project the operation results into a different space and time to predict the potential distribution of the species [17,18]. As a result, these models are extensively employed for the assessment of invasion risks posed by foreign pests, conservation of endangered flora and fauna, as well as analysis of deforestation processes and ecological degradation [19]. The maximum entropy method primarily aims to determine the maximum entropy of known distribution points for species and environmental variables, enabling the prediction and evaluation of species distribution [20]. This approach is characterized by its requirement for a small sample size and minimal sample bias [21]. The economic, social, ecological, and other impacts of *O. debilis* as an invasive plant are evident. This research used MaxEnt to predict the potential distribution of *O. debilis* in China based on the occurrence records of *O. debilis* in China and comprehensively analyzed the key environmental variables affecting its distribution. The objective of this research was to provide an important reference and a theoretical foundation for monitoring, prevention, control, and resource utilization of *O. debilis.*

2. Results

2.1. Verification of Model Accuracy

The simulation results of this study demonstrated that the MaxEnt model achieves an average AUC value of 0.946 (standard deviation ± 0.004) on the training data after 10 repeated runs, indicating its strong predictive performance (Figure 2).

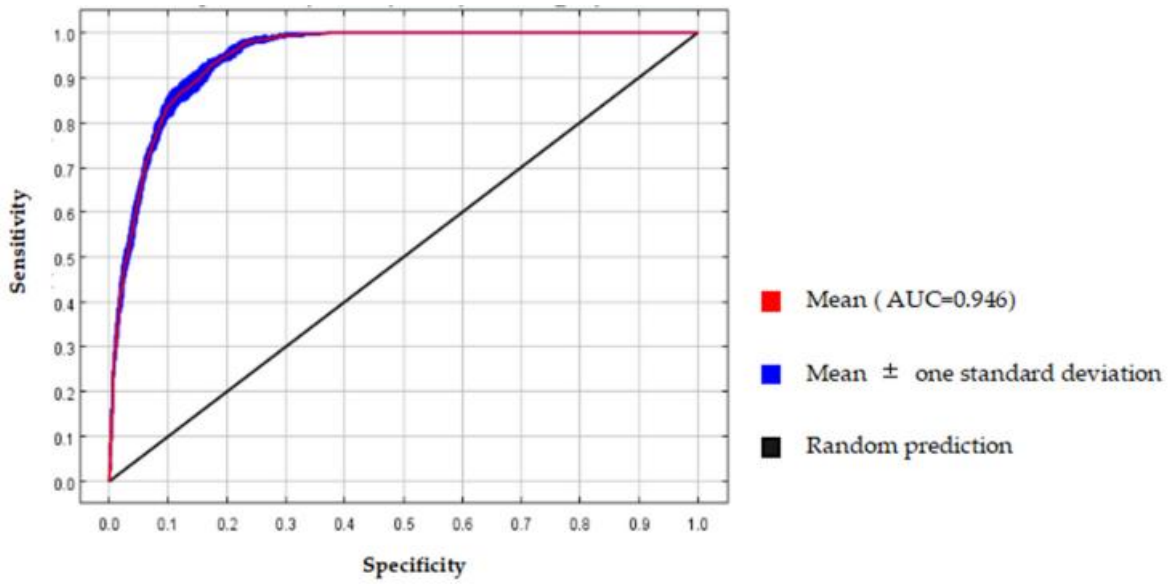


Figure 2. Operating characteristic curve of *Oxalis debilis* Kunth predicted by MaxEnt model.

2.2. Predicting Habitat Suitability of O. debilis in China with MaxEnt

The prediction results indicated that the suitable areas of *O. debilis* in China were widespread, mainly centered in the east and south while a few areas in the western and northeastern regions were poorly suited for it (Figure 3).

The potential suitable area of *O. debilis* in China was approximately 1,891,4237 km^2, representing 19.70% of the country's total land area. Within the area, highly suitable habitat encompassed 563,700 km^2, accounting for roughly 5.87% of the land area and mainly concentrated in the southern region and coastal area. The first part comprised Eastern

China which exhibited a wide distribution but was particularly concentrated in Jiangsu, Shanghai, Zhejiang, Central Jiangxi, as well as Taiwan and Fujian coastal regions. The second part was located in Central China, primarily concentrated in Hunan. The third part covered the eastern portion of the southwest regions, mainly distributed in the junction of Sichuan, Chongqing, and the east of Guizhou. Most of South China, particularly Guangxi and Guangdong, was covered by the fourth part. These findings suggested a higher likelihood of reproductive success for *O. debilis* in these areas, indicating an elevated risk of invasion.

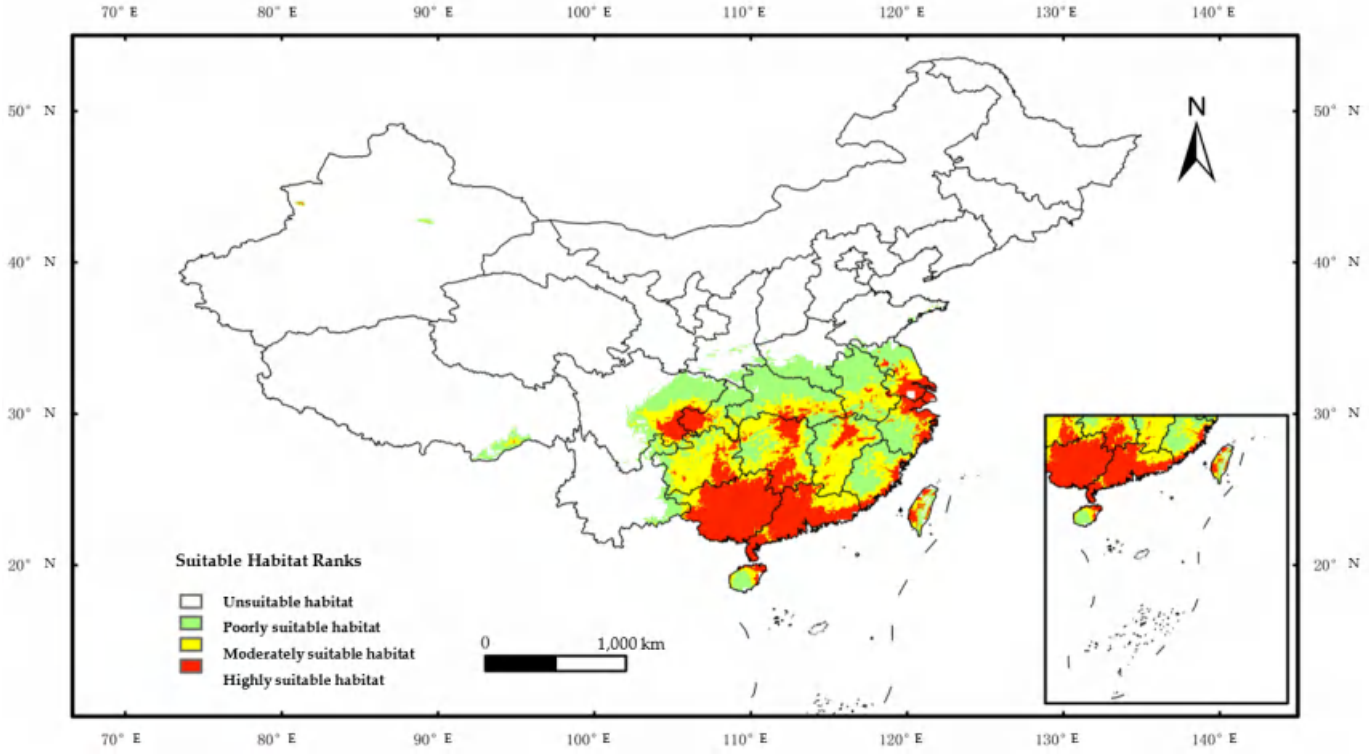


Figure 3. The potential current habitat suitability of *Oxalis debilis* Kunth according to occurrence records in China.

The moderately suitable habitat covered 600.75 million km^2, or 6.33% of the total area, and was mainly in Anhui, Jiangxi, Hubei, Hunan, Sichuan, Chongqing, and Guizhou, with scattered occurrences in the south-eastern coastal areas, South China, Yunnan, and Tibet, suggesting that the introduction and invasion of *O. debilis* in these areas poses a moderate risk.

The poorly suitable habitat covered an area of 720,200 km^2, which represents 7.50% of the total land area. The plant had a wide distribution range, mainly in Southeast China, with limited distribution in central Henan and Shaanxi, as well as Western Yunnan, Tibet, and Xinjiang. These findings suggested that *O. debilis* had a low potential to colonize these areas.

2.3. Environmental Variables That Affect the Prediction of Suitability

SpH (Soil pH), UV-B (Annual Mean UV-B), Bio2 (Monthly diurnal range), Bio3 (Isothermality), Bio8 (Mean Temperature of wettest quarter), Bio10 (Mean temperature of the warmest quarter), Bio14 (Precipitation of the driest month), Bio15 (Precipitation seasonality), Bio17 (Precipitation of the driest quarter), and Elve (Elevation) were obtained after checking for collinearity. The MaxEnt model was applied to assess the relative importance of each environmental variable by analyzing their contribution rates to the potential distribution area of *O. debilis*. The correlation coefficients between environmental variables are presented in Table 1.

Table 1. Pearson correlation coefficients among the important environmental variables.

Variables	SpH	UV-B	Bio2	Bio3	Bio8	Bio10	Bio14	Bio15	Bio17
UV-B	−0.431								
Bio2	0.211	−0.256							
Bio3	−0.344	0.758	0.275						
Bio8	0.128	0.334	−0.329	0.165					
Bio10	−0.095	0.314	−0.294	0.006	0.705				
Bio14	−0.153	0.075	−0.446	−0.405	0.043	0.437			
Bio15	−0.173	0.329	0.244	−0.630	0.150	−0.126	−0.635		
Bio17	−0.247	0.096	−0.397	−0.353	−0.054	0.427	0.966	−0.585	
Elve	−0.170	−0.054	0.269	0.253	−0.682	−0.919	0.468	0.302	−0.422

The results showed that Bio14 was the most important environmental variable affecting the distribution of *O. debilis* (Table 2), with a contribution rate of up to 72.1%. It was followed by Bio2, Bio8, Bio3, and UV-B, which contributed 5.9%, 5.0%, 3.8%, and 3.5%, respectively. The environmental variables with little influence were Elev, Bio10, Bio15, SpH, and Bio17, with a total contribution rate of 9.8%. Briefly, the main environmental variables influencing the potential distribution of *O. debilis* were Bio14, Bio2, Bio8, and Bio3. It is noteworthy that Bio14 exhibits the highest contribution rate, reaching an impressive 72.1%.

Table 2. Percentage contribution and permutation importance of the environmental variables that contribute more than 1%.

Variable	Description (Unit)	Percent Contribution (%)	Permutation Importance (%)
Bio14	Precipitation of the driest month (mm)	72.1	26.3
Bio2	Monthly diurnal range (mean of monthly (max temp − min temp)) (°C)	5.9	7.4
Bio8	Mean temperature of wettest quarter (°C)	5	12.5
Bio3	Isothermality (bio02/bio07) (×100) (°C)	3.8	3.5
UV-B	Annual mean UV-B (kJ/m^2)	3.5	32.6
Elev	Elevation (m)	2.9	2.6
Bio10	Mean temperature of the warmest quarter (°C)	2.2	4.6
Bio15	Precipitation seasonality (coefficient of variation)	2.1	2.9
SpH	soil pH	1.3	1.1
Bio17	Precipitation of the driest quarter (mm)	1.3	6.5

The jackknife test was used to determine the importance of the environmental variables for *O. debilis*. The jackknife test results (Figure 4) suggested that the environmental variable had the greatest influence on the prediction gain of the model training when a single environmental variable acts. The gain values of Bio14, Bio2, and Bio17 were all greater than 1.3 when acting alone, showing that water and temperature were the main factors affecting the prediction results of suitability of *O. debilis*. Meanwhile, Bio10 and Bio15 also had a large influence on the gain of model training and prediction, as their mean values fluctuated around 1.0. Bio3 had minor impact on the gaining of prediction results when it acted alone.

2.4. Effects of Environmental Variables on the Habitat Adaptability of O. debilis

By analyzing the response curves of four major environmental variables affecting the potential distribution of *O. debilis* (Figure 5), we can determine the specific temperature and precipitation ranges that affect the growth of *O. debilis*. When the precipitation of the driest month (Bio14) dropped below 20 mm, the habitat adaptability of *O. debilis* decreased to less than 0.3, whereas an increase in precipitation significantly enhanced its habitat adaptability. Conversely, when the precipitation in the driest month exceeded 60 mm, there was a consistent habitat adaptability for *O. debilis* at approximately 1.0 (Figure 5a). The habitat adaptability of *O. debilis* was deemed unsuitable when the monthly diurnal range (Bio2) fell

below 5 °C or exceeded 14 °C, exhibiting an adaptability lower than 0.2. As the monthly diurnal range increased, the habitat adaptability demonstrated a sharp rise and reached its peak at approximately 6 °C, reaching nearly 0.84; however, beyond this threshold, the adaptability gradually declined and dropped below 0.5 when the temperature difference surpassed 9 °C (Figure 5b). The habitat adaptability of *O. debilis* initially increased with the rise in mean temperature during the wettest quarter (Bio8). When the mean temperature during the wettest quarter was below 15 °C, the habitat adaptability of *O. debilis* remained below 0.2, reaching a peak value of 0.75 at 26 °C. Subsequently, there was a decline in habitat adaptability. Once the mean temperature during the wettest quarter exceeded 32 °C, the habitat adaptability stabilized at 0.35. This indicates that *O. debilis* exhibits a preference for warm and humid environments (Figure 5c). When the isothermality (Bio3) ranged from 15 to 20, it stabilized at 0.8 and increased with an elevated ratio of diurnal temperature difference to annual temperature difference, reaching a peak of 0.9 at 23. Subsequently, the habitat adaptability gradually declined and dropped below 0.2 when the isothermality exceeded 45. However, as long as the isothermality was maintained within the range of 15–38, the adaptability consistently remained above 0.5 (Figure 5d). The factors influencing the diurnal and annual temperature ranges included latitude, terrain characteristics, topography, underlying surface properties, land-sea distribution, and vegetation status. Diurnal temperature difference can be increased by low latitudes, valleys with lower elevation, and land areas with higher terrain features, while annual temperature difference can be increased by higher latitudes, low-lying lands, and areas with less vegetation cover. Therefore, it can be concluded that environments characterized by medium to low latitudes, coastal regions with flat terrains and certain levels of vegetation cover are more favorable for the growth of *O. debilis*.

In conclusion, *O. debilis* is more likely to be found in a warm and humid environment characterized by minimal temperature fluctuations between day and night as well as throughout the year. The precipitation during the driest month exceeded 40 mm, while the monthly diurnal range ranged from 6 °C to 8 °C. Moreover, the mean temperature of the wettest quarter fell within the range of 22 °C to 30 °C, and isothermality values varied between 15 and 24, making it an optimal habitat for survival.

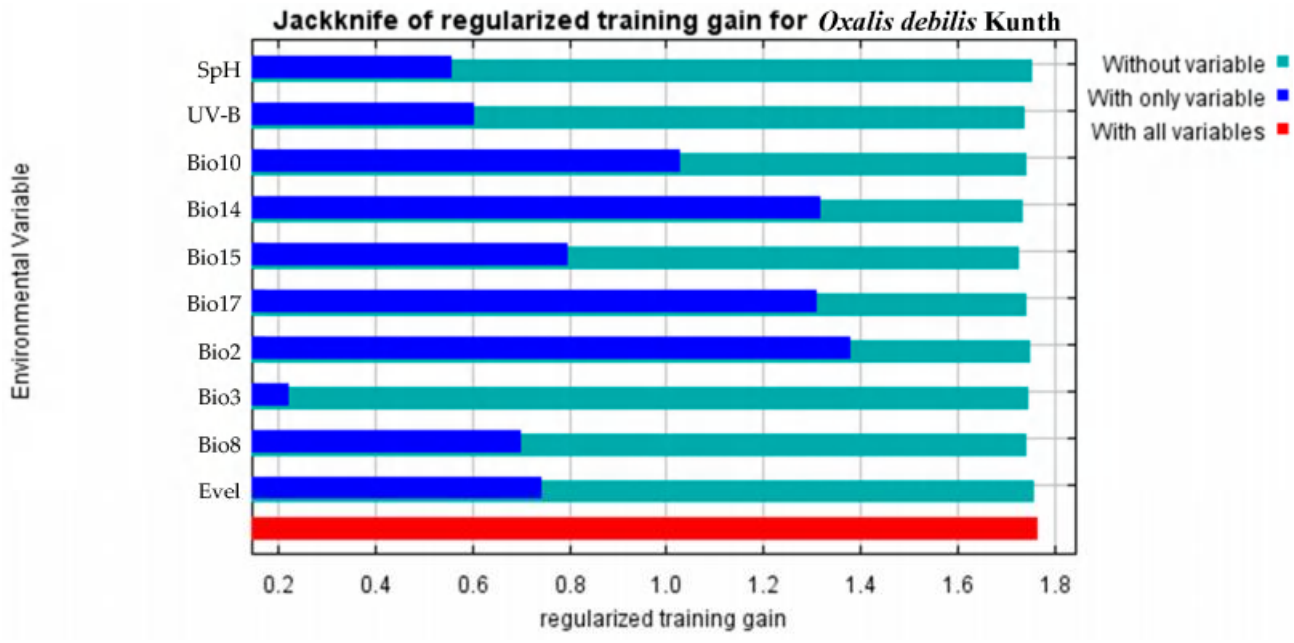


Figure 4. The jackknife of the regularized training gain for environmental variables.

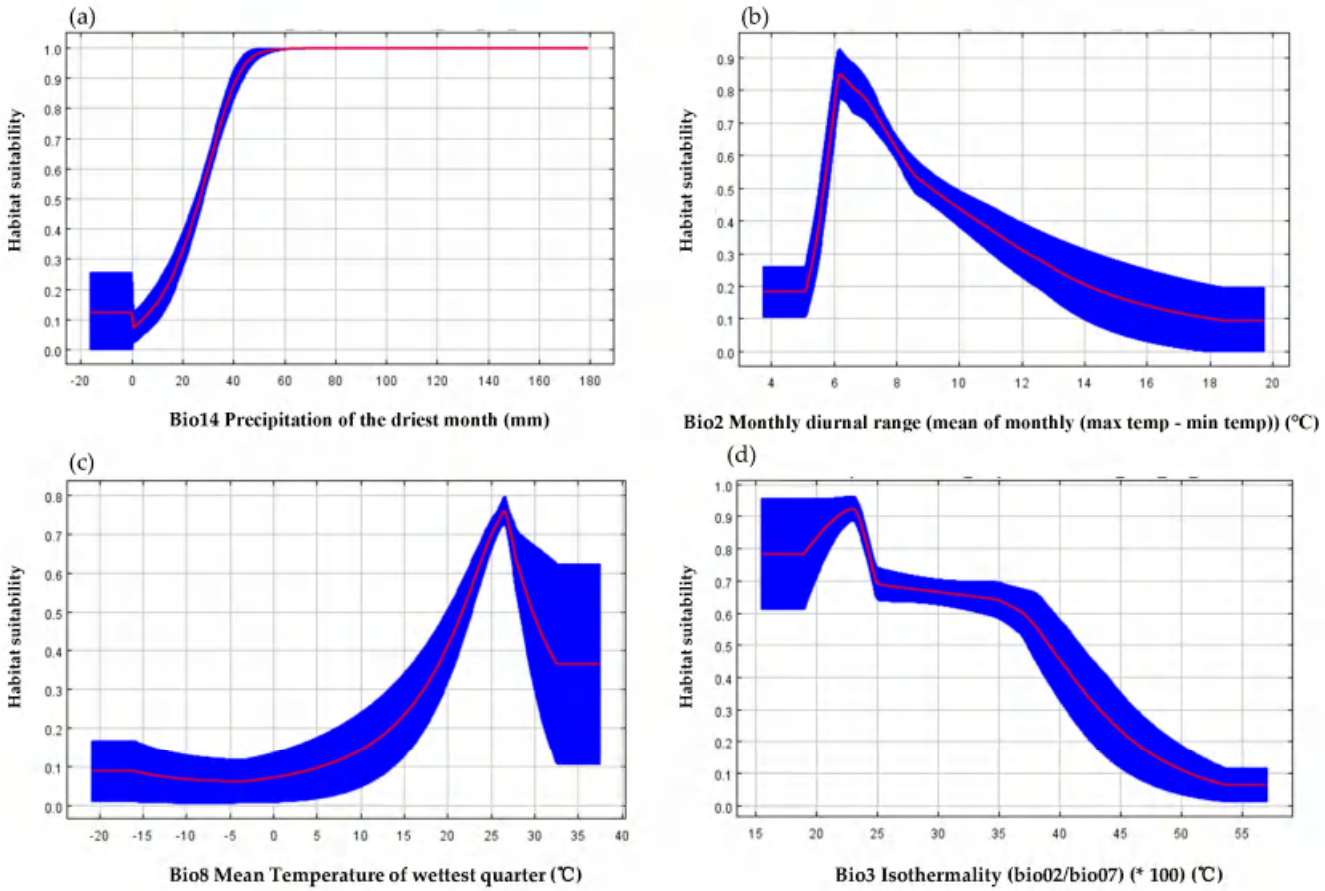


Figure 5. Response curve using only the corresponding variable. (**a**) Bio14 Precipitation of the driest month; (**b**) Bio2 Monthly diurnal range (mean of monthly (max temp − min temp)); (**c**) Bio8 Mean Temperature of wettest quarter; (**d**) Bio3 Isothermality (bio02/bio07) (×100).

3. Discussion

3.1. The Predictive Accuracy and Contemporary Issues of the MaxEnt Model

The MaxEnt model integrates species distribution data with corresponding environmental variables to find the maximum entropy of species distribution patterns, enabling the accurate prediction of potential species distributions. This method offers high precision and significant practical implications [22,23]. Additionally, the MaxEnt model exhibits a strong reliance on the species distribution data. In general, a larger dataset of distribution points improves the accuracy and reliability of prediction results [24]. In this research, a substantial number of distribution points were selected, and the prediction results were evaluated by accuracy using ROC curves. The results demonstrate that this model exhibits excellent predictive performance and high reliability for predicting the distribution area of *O. debilis*. However, the MaxEnt model run in this research is based on the assumption of ideal ecological conditions and does not consider the influence of other factors like soil type, interspecific relationships, species adaptations, geology, topography, etc., which are all factors that need to be taken into account [25]. Consequently, there could be a potential discrepancy between the predicted outcomes and the actual distribution range of *O. debilis*. Moreover, it is imperative to incorporate additional variables beyond environmental factors in order to augment the predictive accuracy of the model, thus necessitating further investigation.

3.2. The Distribution Characteristics of O. debilis and Its Response to Environmental Factors in the Current Period

Among the biological environmental factors, climatic variables (temperature and precipitation) play a pivotal role in determining the potential geographic distribution of species [26]. This research revealed that within the contemporary climatic context, the suitable habitats of *O. debilis* were predominantly distributed across central, eastern, and southern regions of China, with a concentration of medium to high suitability observed in Guangxi, Guangdong, Guizhou, and Yunnan. The model demonstrated that *O. debilis* exhibited the highest sensitivity to precipitation of the driest month, and its fitness level increased significantly with precipitation, reaching its peak when precipitation of the driest month exceeded 60 mm. The results of the model simulation are consistent with the main distribution areas of *O. debilis*, which are characterized by being relatively humid in the dry season [27]. It demonstrates that *O. debilis* exhibits a high degree of sensitivity to variations in precipitation. The maximum habitat adaptability value of 0.75 was observed at a mean temperature of 26 °C during the wettest quarter, indicating a preference for warm and humid climatic conditions of this species. The leaves will be scorched by excessively high temperatures, while insufficiently low temperatures will hinder blooming. This aligns closely with the habitat description of *O. debilis* community in Zhou et al. [28].

3.3. Comprehensive Treatment of O. debilis

O. debilis has a large seed quantity, easy separation of bulbs, easy propagation of stems along with soil seedlings, rapid asexual reproduction, strong adaptability [29], fast growth rate, strong regeneration performance, high reproduction rate, strong encroachment, and extremely strong stress resistance. It inflicts significant harm to the low-growing herbs in its vicinity [30] and is exceptionally challenging to eradicate. Meanwhile, the shade-tolerant evergreen ground cover, *O. debilis*, exhibits a well-organized growth pattern with densely packed leaves, vibrant flowers, and an extended period of blooming [31]. Due to its high aesthetic value, many individuals perceive it as an ornamental plant suitable for cultivation or unrestricted harvesting, thereby facilitating its potential spread and consequently elevating the associated risks. Therefore, enhanced publicity and education should be conducted to increase public awareness of prevention measures. This involves establishing and enhancing the database for invasive alien organisms and plant pests, improving the data quality and functionality of existing domestic databases, and optimizing their practicality and user-friendliness, thereby creating favorable conditions for promoting scientific knowledge dissemination, engaging public participation, and fostering the advancement of citizen science [32]. Relevant quarantine agencies need to be established while strictly implementing quarantine protocols to effectively control species introductions. The concerned regulatory bodies should strengthen monitoring efforts for early detection and prevention purposes. Rational control measures must be implemented to impede the further spread of *O. debilis*. The integration of remote sensing technology and mathematical models through comprehensive research will enable a more precise understanding of the ecological risks faced by species, facilitating the identification of effective solutions.

4. Materials and Methods

The research methodology is illustrated in Figure 6. First, data collection and preprocessing were conducted. Second, the MaxEnt model was executed to predict potential distribution. Third, a comprehensive analysis and evaluation of the obtained data were performed.

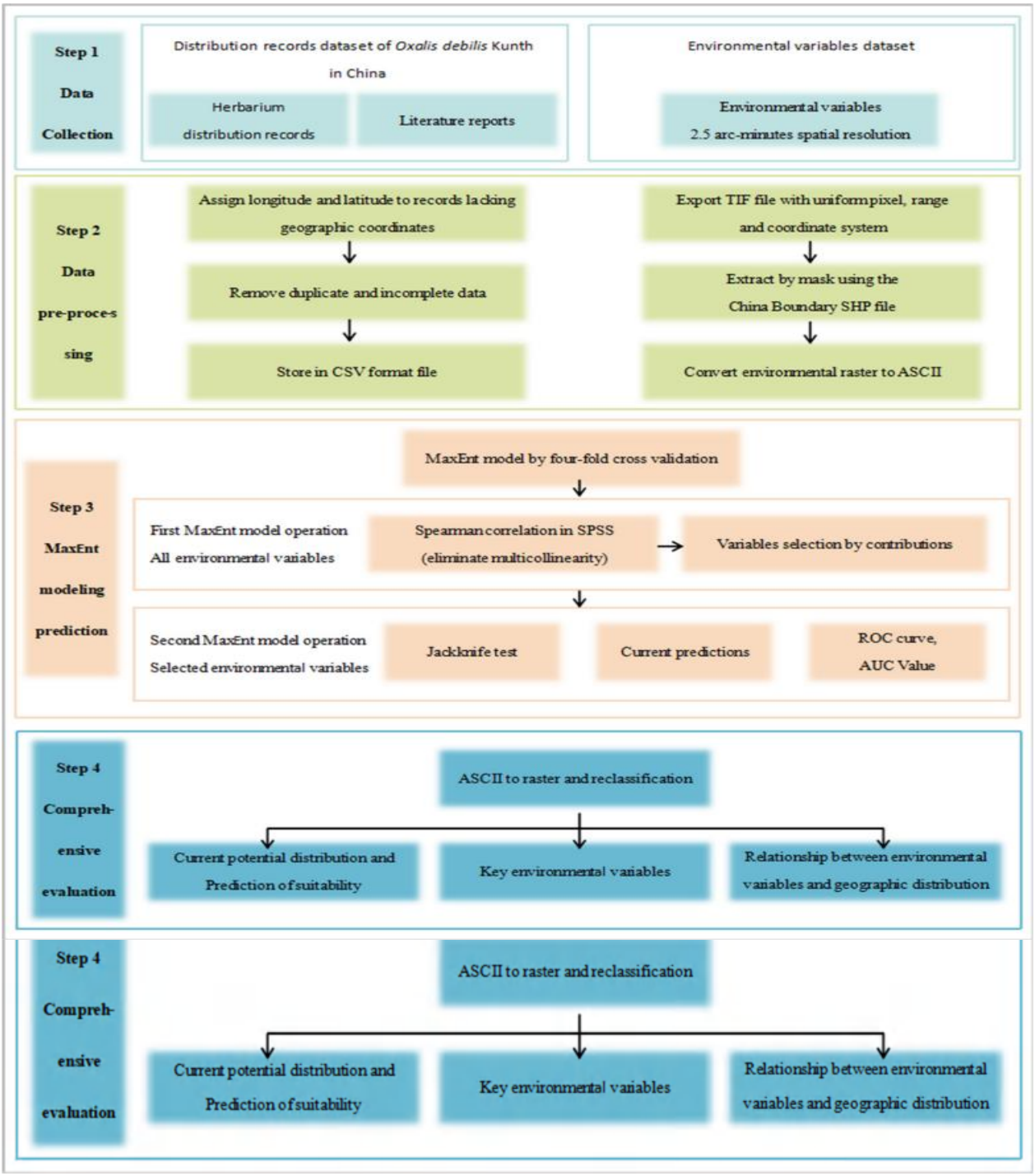


Figure 6. The framework of the operation process.

4.1. Data Sources

4.1.1. Software Sources

The ArcGIS software (Version 10.7; http://www.arcgis.com/features/index.html (accessed on 20 May 2020)) was used for data pre-processing for MaxEnt and image rendering. The MaxEnt software (Version 3.4.3; https://biodiversityinformatics.amnh.org/open_source/maxent/ (accessed on 7 July 2023)) was used to predict the potential distribution range of this species, and to obtain the ROC curve, percentage contributions of environmental variables, jackknife test, and response curves. The SPSS (http://www.spss.

com.cn (accessed on 14 July 2023)) was used to examine the correlation, while the highly correlated environmental variables were removed.

4.1.2. Occurrence Records of *O. debilis* in China

The data sources for *O. debilis* distribution points were: 1. Specimen records: the Chinese Virtual Herbarium (CVH, http://www.cvh.ac.cn/ (accessed on 26 June 2023)), the National Specimen Information Infrastructure (NSII, http://www.nsii.org.cn/ (accessed on 28 June 2023)), the Plant Photo Bank of China (PPBC, http://ppbc.iplant.cn/ (accessed on 29 June 2023)), and the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/ (accessed on 29 June 2023)). Record the address indicated in the image based on the query results. 2. Literature reports: Search the published journals and academic papers on *O. debilis* in China to obtain its geographic distribution information [33–36]. In cases where records lacked precise geographic coordinates, Amap maps (https://ditu.amap.com/ (accessed on 30 June 2023)) were employed to ascertain latitude and longitude values accurately, as well as to eliminate any duplicate distribution points. Among them, due to the absence of precise geographical coordinates, certain data are assigned to the administrative unit center at the most granular level of specimen markers. To comply with the MaxEnt software requirements, the distribution points of *O. debilis* were arranged in the order of species name, longitude, and latitude to generate CSV format files. All obtained distribution point data underwent a process to remove duplicate items and redundant points. This process retained one distribution point every 2.5 arc-minutes, resulting in a total of 299 valid data points. These data points were saved in CSV format for ArcGIS to perform the subsequent analysis [37] (Figure 7).

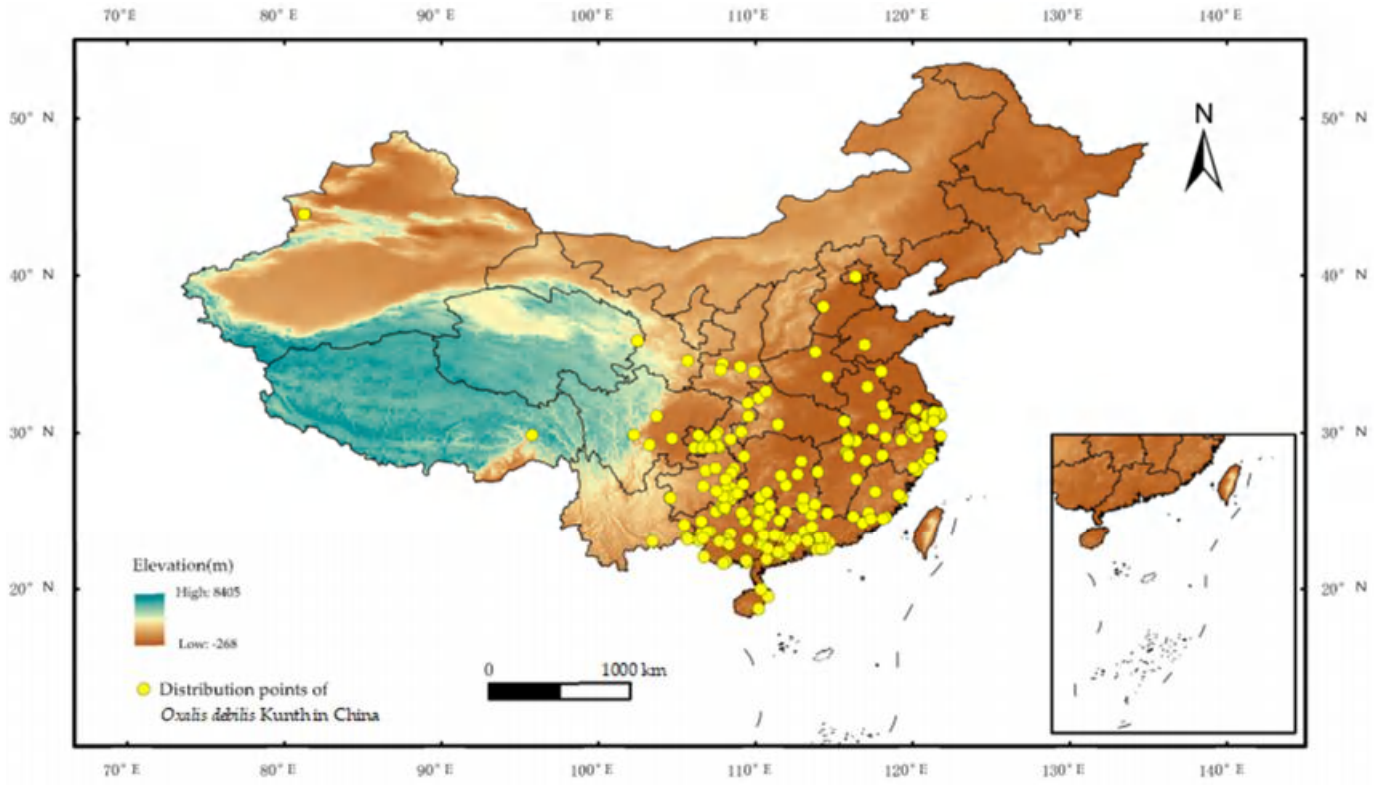


Figure 7. Distribution points of *Oxalis debilis* Kunth in China.

4.1.3. Selection of Environmental Variables

Climate, landform, and soil are crucial environmental factors that affect plant growth and distribution [38]. In this research, 19 bioclimatic factors, 1 altitude factor, 2 soil factors, and the UV-B4 radiation factor were selected as initial environmental variables. These included temperature related (Bio01–Bio11) and precipitation related (Bio12–Bio19), 19 biolog-

ical climate factors, and one global altitude factor (Elev) with 2.5 min spatial resolution obtained from the World Climate Database (http://www.worldclim.org/ (accessed on 14 July 2023)) [39]; soil pH (SpH) and soil organic carbon (SC) from the Center for Sustainability and the Global Environment (http://www.sage.wisc.edu/atlas/index.php (accessed on 14 July 2023)) [40]; and global UV-B radiation from the gIUV database (http://www.ufz.de/gluv/ (accessed on 14 July 2023)) [41] (Table 3).

Table 3. List of environmental variables used in this research.

Type	Variable	Description (Unit)
Bioclimatic variable	Bio1	Annual mean temperature (°C)
	Bio2	Monthly diurnal range (mean of monthly (max temp − min temp)) (°C)
	Bio3	Isothermality (bio02/bio07) (×100) (°C)
	Bio4	Temperature seasonality (standard deviation × 100) (°C)
	Bio5	Max temperature of the warmest month (°C)
	Bio6	Min temperature of the coldest month (°C)
	Bio7	Temperature annual range (Bio5–Bio6) (°C)
	Bio8	Mean temperature of wettest quarter (°C)
	Bio9	Mean temperature of the driest quarter (°C)
	Bio10	Mean temperature of the warmest quarter (°C)
	Bio11	Mean temperature of the coldest quarter (°C)
	Bio12	Annual precipitation (mm)
	Bio13	Precipitation of the wettest month (mm)
	Bio14	Precipitation of the driest month (mm)
	Bio15	Precipitation seasonality (coefficient of variation)
	Bio16	Precipitation of the wettest quarter (mm)
	Bio17	Precipitation of the driest quarter (mm)
	Bio18	Precipitation of the warmest quarter (mm)
	Bio19	Precipitation of the coldest quarter (mm)
	Elev	Elevation (m)
Landform variable	SpH	soil pH
	SC	soil organic carbon (%)
Radiation variable	UV-B	Annual mean UV-B (kJ/m^2)

First, ArcGIS was used to unify the spatial reference of these 23 variables into the geographic coordinate system GCS_WGS_1984. The tool also converted all layers into ASCII format and unified the pixel and range of each layer before converting them all into TIF format. Second, these were overlaid onto a 1:4,000,000 scale base map and an administrative division map of China, obtained from the National Geomatics Center of China (http://nfgis.nsdi.gov.cn/ (accessed on 14 July 2023)), to extract the environmental data [41].

4.2. Methods

4.2.1. Testing and Screening for Correlation of Environmental Variables

Not all environmental variables were found to impact the prediction of *O. debilis* distribution when using the MaxEnt model. As a result, it was necessary to exclude the environmental variables with a low contribution rate and retain variables with a contribution rate greater than 1.0% for model fitting to make accurate predictions [42,43]. The Extract Multi Value to Points function of the Spatial Analyst Tool of ArcGIS was used to extract the environmental variable values corresponding to 299 distribution points. The Pearson correlation coefficient method was then employed in SPSS to calculate the correlation between the remaining environmental variables. If the absolute value of the correlation coefficient exceeded 0.8, it indicated collinearity between the variables, and only one environmental factor needed to be retained [44,45].

4.2.2. MaxEnt Modeling Process

The latitude and longitude data of *O. debilis* in China and screened environmental variables were imported into MaxEnt software to predict the potential geographical distribution of *O. debilis* in China in the context of modern climate change. The specific parameters of the model were set as follows: the random test percentage was set to 25%, 25% of the samples were used as the test set, and the remaining 75% as the training set. The replicated run type was chosen as bootstrap, with the number of replicates set to ten times. The prediction result was computed as the average value of the results obtained from the ten operations. The options 'Create response curves', 'Make pictures of predictions', and 'Do jackknife to measure variable importance' were selected. The output format was set to 'Cloglog' and the output type was set to 'ASC'. Other basic settings were set to their default values.

4.2.3. Maxent Model Accuracy Checking

The ROC curve is widely used in the evaluation of the species potential distribution prediction model which is a highly recognized diagnostic test evaluation index. The area under the ROC curve (AUC value), ranging from 0 to 1, represents the model's performance, with values closer to 1 indicating superior performance [46,47].

4.2.4. Categorization of the Suitable Habitat Ranks

The MaxEnt output was imported into ArcGIS, converted to raster data by Conversion tools in the toolbar, and then the Reclassify program was used in Spatial analyst tools, and Natural breaks (Jenks) selected to divide the four classes of existence probability (P) of *O. debilis*, 'unsuitable habitat' ($0 < P \leq 0.1$), 'poorly suitable habitat' ($0.1 < P \leq 0.3$), 'moderately suitable habitat' ($0.3 < P \leq 0.5$), and 'highly suitable habitat' ($0.5 < P \leq 1$) [12].

5. Conclusions

The management of invasive alien species and their influence is a vital ecological protection challenge in China. Using ArcGIS techniques and the MaxEnt model, we accurately predicted areas conducive to the growth of *O. debilis*. The research revealed that the ideal environment for *O. debilis* growth was found mainly in East China and Central China, covering an estimated 563,700 km^2. These habitats offer a consistent, balmy, and humid climate. The crucial environmental variables impacting the distribution of this species are the precipitation of the driest month, the monthly diurnal range, the mean temperature of the wettest quarter, and the isothermality. The findings of this research could enable environmental managers to promptly implement measures to prevent further spread of this species in mainland China.

Author Contributions: Conceptualization, X.Q.; methodology, X.Q.; software, M.L.; data collection, M.L.; writing—original draft, M.L.; writing—review and editing, X.Q.; supervision, X.Q.; funding acquisition, X.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Forestry Science and Technology Innovation Project of Guangdong Forestry Bureau (Grant No. GDZZDC20228703), and thanks to the support of SCAU Wushan Campus Teaching & Research Base.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: Thanks to the anonymous reviewers for their constructive and valuable comments, and to the editors for their help in refining this article.

Conflicts of Interest: The authors declared that they have no conflict of interest to this work. We declare that we do not have any commercial or associative interest that represents a conflict of interest related to the work submitted.

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中文核心期刊

ISSN 1671-5470
CN 35-1255/S

福建农林大学学报

JOURNAL OF FUJIAN AGRICULTURE AND FORESTRY UNIVERSITY

自然科学版
NATURAL SCIENCE EDITION



ISSN 1671-5470
9 771671 547149 05>

第43卷 第3期 Vol.43 No.3
中国·福州 Fuzhou,China
2014年5月 May, 2014

福建农林大学学报(自然科学版)

Fujian Nonglin Daxue Xuebao (Ziran Kexue Ban)　　2014年5月18日　第43卷第3期

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期刊基本参数：CN 35－1255/S＊1953＊b＊A4＊112＊zh＊P＊￥8.00＊1200＊21＊2014-03

DOI:10.13323/j.cnki.j.fafu(nat.sci.).2014.03.017

3种乌桕属植物根化学成分的GC-MS分析

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摘要: 采用气相色谱-质谱联法(GC-MS)分析圆叶乌桕、乌桕和山乌桕根的化学成分,结果表明:三者根的化学成分差异较大,圆叶乌桕中化学成分多样性相对较高,富含萜烯类化合物;乌桕以吡喃环类化合物为主;而山乌桕中β-谷甾醇的含量较高.三者根的化学成分差异与其生长基质和环境适应性密切相关.

关键词: 圆叶乌桕;乌桕;山乌桕;化学成分;气相色谱-质谱
中图分类号: Q946 **文献标识码:** A **文章编号:** 1671-5470(2014)03-0273-04

Chemical constituents in the roots of three species of *Triadica* by GC-MS

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Abstract: The chemical constituents in the roots from three species of *Triadica* were analyzed by capillary gas chromatography-mass spectrometry (GC-MS). The results showed that chemical constituents were obviously different among *T. rotundifolia*, *T. sebifera*, and *T. cochinchinensis*. The terpenoids, pyran ring and beta sitosterol compounds were main constituents of *T. rotundifolia*, *T. sebifera* and *T. cochinchinensis*, respectively. The kinds of chemical compositions in *T. rotundifolia* were more abundant than those of the other two species. The differences of chemical constituents of three species were closely related with their growing environment and adaptation.

Key words: *Triadica rotundifolia*; *Triadica sebifera*; *Triadica cochinchinensis*; chemical constituent; gas chromatography-mass spectrometry (GC-MS)

乌桕属(*Triadica*)隶属大戟科(Euphorbiaceae),包含圆叶乌桕(*T. rotundifolia*)、乌桕(*T. sebifera*)和山乌桕(*T. cochinchinensis*),分布于亚洲东部和南部[1-2],其中圆叶乌桕为石灰岩地区特有植物.乌桕属植物具有较高的经济价值,种子外被蜡质假种皮可用于制造蜡烛、肥皂等;种子富含油脂,可经榨油制作油漆.乌桕属植物性凉、味苦、具小毒,其叶、根、皮入药能清热解毒、消肿、杀虫等,主治头痛、水肿和肝硬化等病症[3].此外,乌桕属植物具有株形美观、叶形秀丽、叶色富于变化、适应性强、分布范围广、繁殖容易、生长速度快等特点,是我国具有较高开发利用前景的优良乡土植物[4-5].目前乌桕属植物化学成分及其活性的研究主要集中在乌桕和山乌桕的叶、茎枝、树皮等部位[6-8],圆叶乌桕相关研究尚未见报道.

笔者以上述3种乌桕属植物为研究对象,通过气相色谱-质谱联法(GC-MS)对其根的化学成分进行分析研究,比较其不同生境之间适应性的差异,以期为该属植物的环境适应机制、植物化学分类及其栽培引种等研究提供依据.

1 材料与方法

1.1 材料

所有材料均取自野外生长植株,同时采集根际土壤.材料来源见表1.

GC-MS联用仪型号为Agilent 6890 GC-7890A MS;石油醚(60-90 ℃)、丙酮均为分析纯.

1.2 方法

将圆叶乌桕、乌桕和山乌桕的根各100 g粉碎,然后用石油醚回流提取6 h,过滤后减压浓缩,以丙酮

收稿日期:2013-07-03 修回日期:2013-10-12
基金项目:广东省自然科学基金资助项目(8451064201001149);国家科技基础性工作重点专项资助项目(2008FY110400).
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作为溶剂,配成浓度为 50 μg · mL^{-1}的样品,用 0.45 μm 滤膜过滤,待测.

表 1 材料来源

Table 1 Source of materials

种名	样品采集地点	根际土壤 pH 值
圆叶乌桕(*T. rotundifolia*)	广东省广州市从化吕田镇石灰岩山	7.17
乌桕(*T. sebifera*)	广东省广州市天河区华南农业大学树木园	6.17
山乌桕(*T. cochinchinensis*)	广东省广州市天河区火炉山森林公园	–

1.3 气相色谱和质谱条件

(1) 色谱条件: HP-5 MS 毛细管色谱柱(30 m × 0.32 mm,0.5 μm),载气为氦气,流速 1.0 mL · min^{-1};进样口温度 250 ℃;起始柱温 80 ℃,不保留;先从 5 ℃升至 180 ℃,再从 6 ℃升至 260 ℃,保持 5 min;不分流进样. (2) 质谱条件: 离子源温度 230 ℃;电离方式 EI,电子能量 70 eV;质量扫描 *m/z* 为 35 – 400. 用玻璃电极法测定根际土壤的 pH 值.

2 结果与分析

2.1 圆叶乌桕根化学成分的 GC-MS 分析

圆叶乌桕根石油醚提取液经 GC-MS 分析的总离子流图见图 1,分离出 53 个色谱峰.

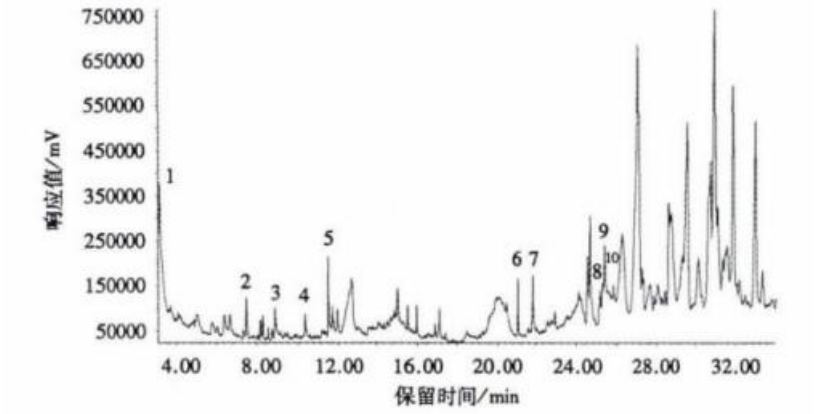


图 1 圆叶乌桕根的总离子流图

Fig. 1 Total ion chromatograms of the root of *T. rotundifolia*

经 GC-MS 联用仪标准质谱数据库检索,鉴定出 10 个相似度为 90% 以上的化合物,采用 GC 峰面积归一法计算各组分的含量,结果见表 2.

表 2 圆叶乌桕根化学成分 GC-MS 分析结果

Table 2 Chemical constituents in the root of *T. rotundifolia* by GC-MS

序号	保留时间/min	化合物	分子式	相对质量分数/%	相似度/%
1	3.12	γ-松油烯	$C_{10}H_{16}$	5.20	93
2	7.50	吡喃酮	$C_7H_8O_3$	0.49	91
3	8.88	5-羟甲基-2-呋喃醛	$C_6H_6O_3$	0.48	90
4	10.36	4-乙烯基-愈创木酚	$C_9H_{10}O_2$	0.38	93
5	11.51	肉桂酸	$C_9H_8O_2$	0.71	97
6	21.10	棕榈酸甲酯	$C_{17}H_{34}O_2$	0.54	97
7	21.84	棕榈酸	$C_{16}H_{32}O_2$	0.69	97
8	25.31	α-亚麻酸	$C_{18}H_{30}O_2$	0.60	93
9	25.43	α-亚麻醇	$C_{18}H_{32}O$	1.78	99
10	25.85	硬脂酸	$C_{18}H_{36}O_2$	1.12	97

2.2 乌桕根化学成分的 GC-MS 分析

对乌桕根石油醚提取液进行分析后得到相应的总离子流色谱图(图 2),分离出 13 个色谱峰.

利用 GC-MS 联用仪标准质谱数据库检索出相似度为 90% 以上的化合物,鉴定出 3 个化合物,采用 GC

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峰面积归一法计算各组分的含量,结果见表 3.

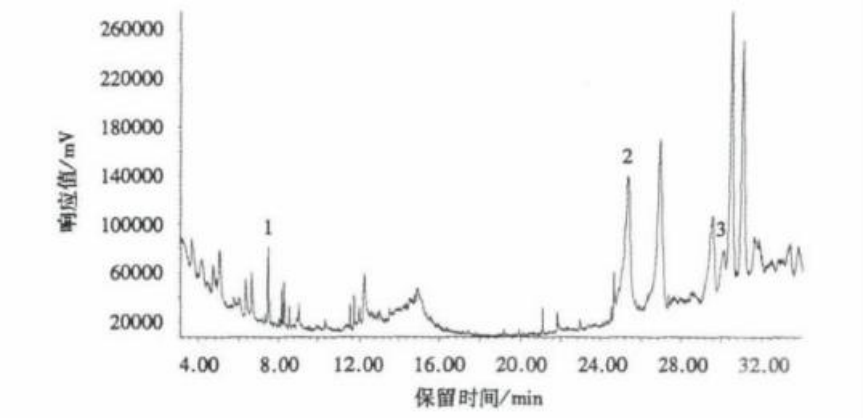


图 2　乌桕根的总离子流图

Fig. 2　Total ion chromatograms of the root of *T. sebifera*

表 3　乌桕根化学成分 GC-MS 分析结果

Table 3　Chemical constituents in the root of *T. sebifera* by GC-MS

序号	保留时间/min	化合物	分子式	相对质量分数/%	相似度/%
1	7.48	吡喃酮	$C_7H_8O_3$	2.00	90
2	25.30	3-β-氯苯基-6-氯-2-氢喹啉酮	$C_{15}H_{13}ClNO$	18.54	92
3	30.07	十八烯	$C_{18}H_{36}$	3.42	91

2.3　山乌桕根化学成分的 GC-MS 分析

山乌桕根石油醚提取液经 GC-MS 分析的总离子流图见图 3,分离出 16 个色谱峰.

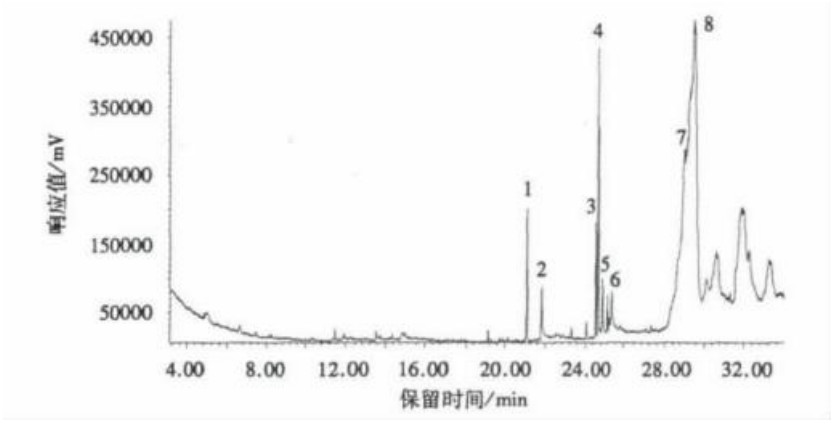


图 3　山乌桕根的总离子流图

Fig. 3　Total ion chromatograms of the root of *T. cochinchinensis*

利用 GC-MS 联用仪标准质谱数据库检索出相似度为 90% 以上的化合物,鉴定出 8 个化合物,用 GC 峰面积归一法计算各组分的含量,结果见表 4.

表 4　山乌桕根化学成分 GC-MS 分析结果

Table 4　Chemical constituents in the root of *T. cochinchinensis* by GC-MS

序号	保留时间/min	化合物	分子式	相对质量分数/%	相似度/%
1	21.09	棕榈酸甲酯	$C_{17}H_{34}O_2$	1.89	97
2	21.83	棕榈酸	$C_{16}H_{32}O$	0.89	98
3	24.57	8,11-十八碳二烯酸甲酯	$C_{10}H_{34}O_2$	1.66	99
4	24.70	α-亚麻酸甲酯	$C_{19}H_{32}O_2$	4.02	99
5	25.19	硬脂酸甲酯	$C_{19}H_{38}O_2$	0.50	99
6	25.42	11,14,17-二十碳三烯酸甲酯	$C_{21}H_{36}O_2$	1.19	83
7	29.03	γ-谷甾醇	$C_{29}H_{50}O$	18.05	99
8	29.48	β-谷甾醇	$C_{29}H_{50}O$	41.40	98

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3 讨论

3.1 乌桕和山乌桕化学成分分析

乌桕叶和茎皮中主要成分为黄酮类、香豆素类、三萜类、二萜类及其他酚酸类成分等化合物[9]. 山乌桕茎枝中主要有甾醇类及酚性化合物[7-8],其中甾醇类为其与根共有成分. 本研究得到的化学成分与前人研究结果相差较大,共有成分少,可能与植物不同部位成分的差异性以及取样时间、地点、植株个体、提取与检测方法等因素有关.

3.2 3 种乌桕属植物根化学成分 GC-MS 对比分析

3 种乌桕属植物根化学成分 GC-MS 分析结果差异较大. 圆叶乌桕根中化合物种类较乌桕和山乌桕丰富,富含萜烯类化合物; 脂肪酸类化合物也较多,包含 γ-松油烯(含量最高,达 5.2%)、α-亚麻醇和硬脂酸. 乌桕以吡喃环类化合物为主,3-[β-氯苯基]-6-氯-2-氢喹啉酮相对含量最高,达 18.54%. 山乌桕中 β-谷甾醇的相对含量最高,达 41.4%; 脂肪酸类含量次之; γ-谷甾醇的相对含量达 18.05%. 圆叶乌桕和乌桕共有成分仅包括吡喃酮,圆叶乌桕和山乌桕共有成分则包括棕榈酸甲酯和棕榈酸.

3.3 GC-MS 分析方法在乌桕属植物环境适应性及其分类研究中的应用

植物化学成分与其生长环境关系密切. 圆叶乌桕是石灰岩基质的专性特有植物,石灰岩基质通常具有地表水少、土层稀薄且偏碱性等特点. 本研究中圆叶乌桕根际土壤 pH 值为 7.17,其叶片革质、表面蜡质明显,是适应干旱环境的表征之一; 根中含有 γ-松油烯等萜烯类化合物. 研究[10-12]表明萜烯类化合物是大部分植物精油的主要组成成分,具抑菌抗菌作用. 其根含硬脂酸、肉桂酸和棕榈酸等有机酸类成分,适应碱性基质,与辛宁等[13]研究结果基本一致. 乌桕和山乌桕主要分布于酸性土壤,在石灰岩基质也能生长. 本研究中乌桕根际土壤 pH 值为 6.17,根中甾醇类、三萜类等含量相对较高,与辛宁等[13]研究结果一致,但有关黄酮类、挥发油类的研究结果与其不一致.

植物次生代谢产物虽然对生长环境的依赖性较强,但也具有遗传性,可以作为植物化学分类参考的依据[14]. GC-MS 作为一种有效的现代检测手段,在植物化学成分的检测及鉴定中发挥着重要作用[15]. 本研究中 3 种乌桕属植物化学成分提取过程中总离子流图差异明显,圆叶乌桕与乌桕和山乌桕因生长基质不同,主要化学成分间差异也较大,表明 GC-MS 分析方法在乌桕属植物分类中具有一定参考价值.

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(责任编辑: 叶济蓉)

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本刊为中文核心期刊、中国期刊方阵“双效”期刊、中国高校精品科技期刊

- 1999年获全国高校自然科学学报及教育部优秀科技期刊二等奖、福建省高校优秀自然科学学报一等奖
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本刊被下列数据库和检索刊物固定收录:

- 中国科学引文数据库
- 中国学术期刊综合评价数据库
- 国际农业与生物科学中心数据库（CAB）
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福建农林大学学报（自然科学版）
Fujian Nonglin Daxue Xuebao(Ziran Kexue Ban)
（双月刊 1953年创刊）
第43卷 第3期 2014年5月18日

Journal of Fujian Agriculture and Forestry University
(Natural Science Edition)
(Bimonthly, Started in 1953)
Vol. 43 No. 3 May 18, 2014

主办单位 福建农林大学
主管单位 福建农林大学
编辑出版 福建农林大学学报编辑部
（福州金山，邮政编码 350002）
Email: jfau@fafu.edu.cn
主　　编 兰思仁
副 主 编 尤民生 何海斌 林国栋(常务)
印　　刷 福建农林大学印刷厂
（福州金山，邮政编码 350002）
发行范围 公开发行
国内发行 福州市邮政局
订　　阅 全国各地邮局（所）
国外发行 中国国际图书贸易总公司
（北京399信箱，邮政编码100044）

Sponsored by Fujian Agriculture and Forestry University
Edited and Published by Editorial Department of Journal of Fujian Agriculture and Forestry University
(Jinshan, Fuzhou, Fujian 350002, China)
Email: jfau@fafu.edu.cn
Chief Editor: Lan Siren
Deputy Chief Editors: You Minsheng, He Haibin, Lin Guodong
Issued in Public
Distributed by China International Book Trading Corporation (P.O.Box 399, Beijing 100044, China)

ISSN 1671-5470
CN 35-1255/S
国外代号: **BM 675**　　报刊代号: **34-16**　　国内定价: **8.00元**

華南農業大學学报

JOURNAL OF SOUTH CHINA AGRICULTURAL UNIVERSITY

ISSN 1001-411X
CODEN HNDXBH

全国中文核心期刊

中国·广州
GUANGZHOU CHINA

2014

5月 第35卷 第3期
May. Vol.35 No.3

《华南农业大学学报》自2004年以来获得的荣誉

国家期刊奖百种重点期刊(2004年)
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《华南农业大学学报》被国内外数据库收录情况

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華南農業大學学报

JOURNAL OF SOUTH CHINA AGRICULTURAL UNIVERSITY

· 双月刊 ·

2014 年第 3 期

（第 35 卷）

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第35卷 第3期 2014年5月

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期刊基本参数：CN44-1110/S＊1959＊b＊A4＊116＊zh＋en＊P＊￥15.00＊1600＊21＊2014-05 封面设计：林 敏

JOURNAL OF SOUTH CHINA AGRICULTURAL UNIVERSITY

Vol. 35 No. 3 May 2014

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华南农业大学学报 2014,35(3):90-99
Journal of South China Agricultural University
http://xuebao.scau.edu.cn
doi:10.7671/j.issn.1001-411X.2014.03.017

秦新生,张荣京,邢福武.海南石灰岩地区的种子植物区系[J].华南农业大学学报,2014,35(3):90-99.

海南石灰岩地区的种子植物区系

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摘要:【目的】了解海南石灰岩地区种子植物区系组成、性质等基本特征.【方法】野外实地调查、标本采集与鉴定,数据统计分析.【结果和结论】海南石灰岩地区现共记录种子植物1 176种58变种1变型,隶属于142科645属,其中裸子植物5科5属7种,被子植物137科640属1 169种58变种1变型.具有明显的热带性质,以热带、亚热带成分尤其是热带亚洲成分为主,热带、亚热带成分分别占总科数和总属数的73.24%和87.75%;温带成分在海南石灰岩地区得到一定的发展,温带性质科占总科数的11.97%,属占总属数的7.29%.该地区物种丰富,以占不到全岛2%的面积,分布高达27.26%的种类,但属内种类较为贫乏,以单种科和寡种科为主,共计113科,占总科数的79.58%;中国特有属有2属.

关键词:海南;种子植物;区系;石灰岩
中图分类号:Q948 **文献标志码:**A **文章编号:**1001-411X(2014)03-0090-10

Flora of seed plants in the limestone areas of Hainan

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3 College of Life Science, South China Agricultural University, Guangzhou 510642, China)

Abstract 【Objective】The purpose of this study was to reveal the floristic composition and characteristics of seed plants in limestone areas in Hainan. 【Method】Extensive field work, specimens collection and identification were conducted to collect data for the analysis. 【Result and conclusion】A total of 1 176 species, 58 varieties and 1 forma belonging to 645 genera and 142 families were recorded. The tropical and subtropical distribution elements, especially tropical Asia ones, were dominant in the limestone flora in Hainan. The tropical and subtropical distribution families accounted for 73.24% of the total and the genera accounted for 87.75%. The proportions of temperate distribution families and genera accounted for 11.97% and 7.29%, respectively. The limestone areas contributed about 27.26% to the total number of species with less than 2% land area of the whole island. However, many genera include only one or very few species. There are 113 single and few species families, accounting for 79.58% of the total families. There are 2 genera endemic to China.

Key words: Hainan; seed plants; flora; limestone

收稿日期:2013-07-26 **优先出版时间:**2014-03-31
优先出版网址:http://www.cnki.net/kcms/doi/10.7671/j.issn.1001-411X.2014.03.017.html
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基金项目:国家自然科学基金(30270122);国家科技基础性工作专项(2008FY110400)

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全球岩溶地貌分布广泛，主要集中分布在欧洲地中海沿岸、美国东部和中国西南部，总面积达 2.2×10^7 km^2，占陆地面积的 15%；中国岩溶地貌面积达 3.34×10^6 km^2，约占国土面积的 30%，主要分布在贵州、广西、云南、四川、湖南、湖北等省份[1-3]. 中国石灰岩植物研究起步较晚，直到 20 世纪 50 年代初期才有侯学煜[4]开始研究中国境内钙质土的指示植物及钙质土上的植物群落. 梁畴芬等[5]是国内进行石灰岩植物区系研究的开创者，20 世纪 70 年代他们对广西弄岗石灰岩地区进行了较为详尽的植物区系和植被研究工作.

海南植物种类丰富，植物采集、研究的历史悠久，但海南石灰岩地区由于大部分地处偏远山区，交通、食宿不便，在 20 世纪 80 年代以前仍鲜为人知，植物标本采集也少人涉猎. 作者自 2002—2006 年在海南石灰岩地区进行植物区系和植被调查，2007—2012 年陆续有补充调查，采集植物标本累计 3 000 余份，全部存放于中国科学院华南植物园标本馆(IBSC)，在此基础上对海南石灰岩地区植物区系组成、性质进行统计分析，以期为海南植物区系及中国石灰岩植物区系的起源、形成和演化等研究提供基础依据.

1　自然概况

海南岛位于中国南端，面积约 3.4 万 km^2，是中国仅次于台湾的第二大岛. 全岛气候温和，年平均气温 22～26 ℃，终年无霜雪，雨量充沛，年平均降雨量为 1 500～2 000 mm，具有我国最为典型的热带季风气候[6]. 根据笔者近年来实地考察，现已发现海南 6 个县(市)有石灰岩分布，总面积约达 400 km^2(图 1).

2　研究方法

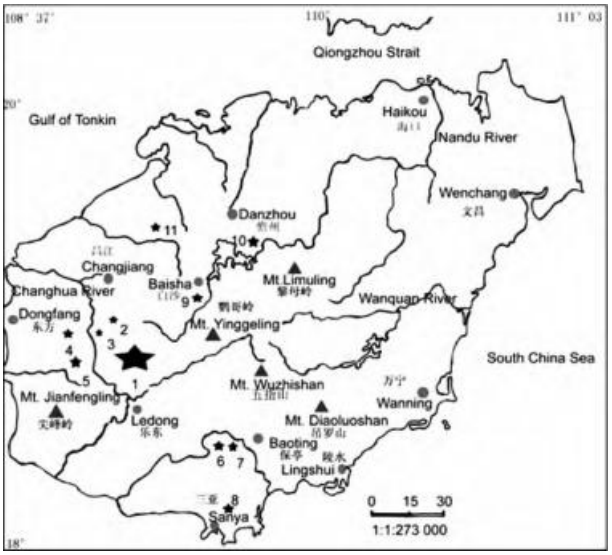
在资料收集的基础上，分不同的季节进行植物标本采集，从不同的海拔高度、坡向、生境等选取不同的采集路线，做到所列名录均有凭证标本. 裸子植物和被子植物分类分别采用郑万钧系统[7]和 Hutchinson J[8]系统. 科、属的分布区类型参考吴征镒等[9-11]的划分方法.

科、属的相似性系数[12] (S) = [共有的科数(属数)/甲乙两地总科数(属数)] ×100.

3　结果与分析

3.1　种子植物区系组成

3.1.1　*数量特征*　根据实地调查，并参考现有的研究资料[13-16]，海南石灰岩地区共统计有野生种子植物 1 176 种 58 变种 1 变型，隶属于 142 科 645 属，其中裸子植物 5 科 5 属 7 种，被子植物 137 科 640 属 1 169 种 58 变种 1 变型(表 1).



“●”表示县(市)；“▲”表示山岭　“★”表示石灰岩地区，其中，1 为昌江县王下乡与东方市东河镇南浪村交界处(俄贤岭)，2 为昌江县霸王岭泥下村机报山(燕窝岭)，3 为东方市东河镇红村，4 为东方市天安乡雅隆村小桂林，5 为东方市江边乡白查村和东河镇报白苗村猕猴洞，6、7 为保亭县毛感乡仙安石林和千龙洞，8 为三亚市荔枝沟镇落笔洞，9 为白沙县白沙镇向民蝙蝠洞，10 为儋州市南洋镇观音洞，11 为儋州市雅星镇英岛山溶洞.

图 1　海南石灰岩地区分布图

Fig. 1　The distribution map of the limestone areas in Hainan

表 1　海南石灰岩地区种子植物数量组成统计

Tab. 1　The number of seed plants in the limestone areas in Hainan

分类单位	种子植物数量			占海南比例/%	占中国比例/%
	海南石灰岩	海南[17-18]	中国[19-21]		
裸子植物					
科	5	6	10	83.33	50.00
属	5	10	34	50.00	14.71
种	7	28	250	25.00	2.80
被子植物					
科	137	220	327	62.27	41.90
属	640	1 320	3 246	48.48	19.72
种及种下单位	1 228	4 502	约 2.6 万	27.28	4.72

海南石灰岩地区裸子植物种类较为贫乏，仅占该地区种子植物总数的 0.57%，以热带、亚热带成分为主. 被子植物约占种子植物总数的 99.43%，是该地区植物区系的主要组成部分. 种子植物以单种科和寡种科(2～10 种)为主，单种科和寡种科共计 113 科，占总科数的 79.58%.

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3.1.2 优势科和表征科 在植被或植物群落中占优势或所含种类相对较多的科，常被称为某一地区植物区系的优势科[22-23]. 该地区所含种类10种以上的科有40科(表2)，单属单种科有32科. 兰科、大戟科、茜草科、蝶形花科、桑科等所含种类均在10种以上，且在群落中占优势. 而禾本科、莎草科、菊科、旋

表2 海南石灰岩地区种子植物的科(10种以上)大小排列

Tab. 2 The families(≥10 species) of seed plants in the limestone areas in Hainan

科名	海南石灰岩地区		世界区系[24-25]		海南石灰岩占世界比例/%	
	属数	种数	属数	种数	属数	种数
兰科 Orchidaceae	36	92	869	18 500	4.14	0.50
大戟科 Euphorbiaceae	39	88	320	8 000	12.19	1.10
茜草科 Rubiaceae	38	81	606	10 200	5.52	0.79
禾本科 Poaceae	39	55	688	9 500	5.67	0.58
蝶形花科 Papilionaceae	26	51	634	17 275	4.10	0.30
莎草科 Cyperaceae	9	39	80	4 300	11.25	0.91
桑科 Moraceae	8	36	37	1 100	21.62	3.27
樟科 Lauraceae	12	31	45	2 500	21.67	1.24
菊科 Compositae	18	28	1 509	22 750	1.19	0.12
番荔枝科 Annonaceae	12	28	120	2 150	10.00	1.30
紫金牛科 Myrsinaceae	4	24	42	1 600	9.52	1.50
芸香科 Rutaceae	10	23	156	1 650	6.41	1.39
爵床科 Acanthaceae	17	19	228	3 925	7.46	0.48
荨麻科 Urticaceae	9	19	45	1 000	20.00	1.90
楝科 Meliaceae	9	18	50	600	18.00	3.00
梧桐科 Sterculiaceae	9	17	67	1 500	13.43	1.13
旋花科 Convolvulaceae	10	16	56	1 600	17.86	1.00
苦苣苔科 Gesneriaceae	10	16	133	2 600	7.52	0.62
马鞭草科 Verbenaceae	7	15	31	1 070	22.58	1.40
无患子科 Sapindaceae	12	14	131	1 350	9.16	1.04
天南星科 Araceae	11	14	105	2 550	10.48	0.55
葫芦科 Cucurbitaceae	11	14	110	868	10.00	1.61
唇形科 Labiatae	9	14	294	5 600	3.06	0.25
防己科 Menispermaceae	9	14	72	450	12.50	3.11
夹竹桃科 Apocynaceae	11	13	165	1 900	6.67	0.68
野牡丹科 Melastomataceae	4	13	182	4 200	2.20	0.31
葡萄科 Vitaceae	5	13	74	800	6.76	1.63
萝藦科 Asclepiadaceae	8	12	260	3 000	3.08	0.40
锦葵科 Malvaceae	6	12	116	1 600	5.17	0.75
桃金娘科 Myrtaceae	5	12	130	4 200	3.85	0.29
榆科 Ulmaceae	4	12	15	180	26.67	6.67
姜科 Zingiberaceae	4	12	50	1 300	8.00	0.92
鸭跖草科 Commelinaceae	6	11	40	640	15.00	1.72
五加科 Araliaceae	6	10	50	1 200	12.00	0.83
百合科 Liliaceae	6	10	11	560	54.55	1.79
棕榈科 Palmaceae	6	10	190	2 325	3.16	0.43
苏木科 Caesalpiniaceae	5	10	153	2 175	3.27	0.46
椴树科 Tiliaceae	5	10	46	450	10.87	2.22
白花菜科 Capparidaceae	4	10	35	540	11.43	1.85
壳斗科 Fagaceae	4	10	7	790	57.14	1.27

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花科、唇形科、锦葵科等所含种类虽也在 10 种以上，但其多为世界广布种，且多分布在石灰岩山区农田、坡耕地和植被被破坏后的灌丛、林缘空旷处，在植被保存较好的林内并不多见. 使君子科 Combretaceae、千屈菜科 Lythraceae、紫葳科 Bignoniaceae、天料木科 Samydaceae、大风子科 Flacourtiaceae 和清风藤科 Sabiaceae 等科所含种类虽然在 10 种以下，但这些种类在群落中出现的频率相对较高. 按各科所含属数占世界属数的百分比排序，排在前面的科在一定程度上能反映该地区植物区系的发生特征，可视为该植物区系起源意义上的代表科[22-23]. 该地区被子植物优势科中，按其所含属数占世界属数的比例从大到小排序依次为壳斗科、百合科、榆科、马鞭草科、樟科、桑科、荨麻科、楝科、旋花科、梧桐科、防己科、大戟科、五加科、白花菜科、莎草科、椴树科、番荔枝科、紫金牛科、天南星科等. 而按所含种占世界种数的比例排序，排在前面的为榆科、桑科、防己科、楝科、椴树科、荨麻科、白花菜科、百合科、葡萄科和紫金牛科等.

3.1.3　属的大小统计　种子植物含 5 种以上的属有 48 属(表 3)，占种子植物总属数的 7.44%；该地区主要由单种属组成，有 387 属，占总属数的 60%.

被子植物中以榕属(24 种)所含种类最多，从海拔 100 m 以下的山脚、密林一直到海拔 1 000 ~ 1 200 m 的裸露山顶均有分布；其次是紫金牛属(14 种)，多分布在密林中，仅肉根紫金牛 *Ardisia crassinervosa* 分布在近裸露山顶灌丛；莎草属 *Cyperus*(13 种)虽然所含种类较多，但多生长在石灰岩山脚荒地、田野等潮湿生境，且多为广布种；石斛属(11 种)从密林到裸露山顶石上、树上均有分布，且数量较多；野桐属(9 种)为季雨林中常见的灌木至小乔木，林缘、密林和山顶均有分布；耳草属(9 种)植物多分布在林缘、荒坡；木姜子属(8 种)多分布在中海拔密林中，且少数种类数量较多；蒲桃属(8 种)从低海拔到高海拔均有，其中海南蒲桃 *Syzygium hainanense*、红鳞蒲桃 *S. hancei* 和短药蒲桃 *S. brachyantherum* 等数量较多；兰科植物在该地区分布较为广泛，其中很多分布于干燥的石灰岩山顶，如毛兰属(8 种)和羊耳蒜属(8 种)等.

除了以上属含种数量较多外，紫薇属 *Lagerstroemia*、青梅属 *Vatica*、榄仁属 *Terminalia*、翅子树属 *Pterospermum*、轮叶戟属 *Lasiococca*、厚皮树属 *Lannea*、猫尾木属 *Dolichandrone*、菜豆树属 *Radermachera* 以及桄榔属 *Arenga* 等虽然所含种类不多，但多为乔木层优势树种. 扁担杆属 *Grewia*、破布叶属 *Microcos*、喜光花属 *Actephila*、留萼木属 *Blachia* 及仔榄树属 *Hunteria*

表 3　海南石灰岩地区种子植物含 5 种以上的属

Tab. 3　The genera (≥5 species) of seed plants in the limestone areas in Hainan

属名	种数	占总种数的比例/%
榕属 *Ficus*	24	1.94
紫金牛属 *Ardisia*	14	1.13
莎草属 *Cyperus*	13	1.05
石斛属 *Dendrobium*	11	0.89
野桐属 *Mallotus*	9	0.73
耳草属 *Hedyotis*	9	0.73
木姜子属 *Litsea*	8	0.65
蒲桃属 *Syzygium*	8	0.65
毛兰属 *Eria*	8	0.65
羊耳蒜属 *Liparis*	8	0.65
暗罗属 *Polyalthia*	7	0.57
叶下珠属 *Phyllanthus*	7	0.57
柿树属 *Diospyros*	7	0.57
茄属 *Solanum*	7	0.57
石豆兰属 *Bulbophyllum*	7	0.57
隔距兰属 *Cleisostoma*	7	0.57
兰属 *Cymbidium*	7	0.57
飘拂草属 *Fimbristylis*	7	0.57
樟属 *Cinnamomum*	6	0.49
槌果藤属 *Capparis*	6	0.49
五月茶属 *Antidesma*	6	0.49
粗叶木属 *Lasianthus*	6	0.49
山姜属 *Alpinia*	6	0.49
薯蓣属 *Dioscorea*	6	0.49
苔草属 *Carex*	6	0.49
丁香蓼属 *Ludwigia*	5	0.40
山龙眼属 *Helicia*	5	0.40
野牡丹属 *Melastoma*	5	0.40
谷木属 *Memecylon*	5	0.40
黄花稔属 *Sida*	5	0.40
土蜜树属 *Bridelia*	5	0.40
巴豆属 *Croton*	5	0.40
核果木属 *Drypetes*	5	0.40
羊蹄甲属 *Bauhinia*	5	0.40
黄檀属 *Dalbergia*	5	0.40
鱼藤属 *Derris*	5	0.40
崖豆藤属 *Millettia*	5	0.40
朴属 *Celtis*	5	0.40
杜茎山属 *Maesa*	5	0.40
球兰属 *Hoya*	5	0.40
龙船花属 *Ixora*	5	0.40
斑鸠菊属 *Vernonia*	5	0.40
厚壳树属 *Ehretia*	5	0.40
母草属 *Lindernia*	5	0.40
菝葜属 *Smilax*	5	0.40
扁莎属 *Pycreus*	5	0.40
黍属 *Panicum*	5	0.40
狗尾草属 *Setaria*	5	0.40
合计	325	26.32

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等属所含种类也不多，但其种类多为灌木至小乔木层主要成分. 草胡椒属 *Peperomia*、感应草属 *Biophytum*、唇柱苣苔属 *Chirita*、杜若属 *Pollia*、山麦冬属 *Liriope* 及球子草属 *Peliosanthes* 所含种类在草本层中较为常见. 瓜馥木属 *Fissistigma*、钩枝藤属 *Ancistroladus*、翼核果属 *Ventilago*、崖爬藤属 *Tetrastigma* 及崖角藤属 *Rhaphidophora* 则是构成藤本层的重要成分.

3.2 海南石灰岩地区种子植物区系性质分析

3.2.1 *科的分布区类型* 根据科的地理分布特征，并参照前人的观点[9-11]，对海南石灰岩地区种子植物进行科的分布区类型划分(表4).

表4 海南石灰岩地区种子植物科的分布区类型

Tab. 4 The distribution types of families of seed plants in the limestone areas in Hainan

分布区类型	科数	占除世界分布外总科数的比例/%
世界分布	21	
泛热带分布	83	68.60
热带亚洲至热带美洲间断分布	4	3.31
旧世界热带分布	6	4.96
热带亚洲至热带大洋州分布	1	0.83
热带亚洲至热带非洲分布	5	4.13
热带亚洲分布	5	4.13
温带分布	15	12.40
东亚和北美间断分布	2	1.65
合计	142	100

海南石灰岩地区以热带、亚热带分布科为主，占除世界分布外总科数的85.95%，其中泛热带分布占68.60%. 该地区中包括典型的热带科，如龙脑香科 Dipterocarpaceae、毒鼠子科 Dichapetalaceae、五桠果科 Dilleniaceae 及金虎尾科 Malpighiaceae 等. 种类较多的兰科、大戟科、茜草科、蝶形花科、桑科、番荔枝科等所含的属种均以热带、亚热带分布为主.

世界分布科有21科，除了马齿苋科 Portulacaceae、苋科 Amaranthaceae、菊科、车前草科 Plantaginaceae、旋花科、玄参科 Scrophulariaceae、唇形科、禾本科、莎草科等的多数种类常见于山间林缘、荒坡、田野外，其余世界分布科多见于林内. 海南石灰岩地区的世界分布科多数虽然可以延伸分布到温带地区，但仍以热带、亚热带分布为主，并且较多属种是我国华南特别是海南和中南半岛、马来群岛甚至热带澳大利亚共有，如酢浆草科 Oxalidaceae 主产南美，其所含的分枝感应草 *Biophytum fruticosum* 分布于我国南部至中南半岛、马来西亚，感应草 *B. sensitivum* 则热带亚洲广布，这2种在海南石灰岩地区均较为常见.

温带分布科有17科，占除世界分布外总科数的14.05%，但温带性科在该地区分布的各科所含属种数较少，如榛科 Corylaceae、胡颓子科 Elaeagnaceae、山茱萸科 Cornaceae、桔梗科 Campanulaceae、绣球花科 Hydrangeaceae 都仅含1属1种，毛茛科 Ranunculaceae、槭树科 Aceraceae 含1属2种，忍冬科 Caprifoliaceae 含2属3种，金缕梅科 Hamamelidaceae 含3属4种，这些成分在森林群落中出现的几率也较小.

3.2.2 *属的分布区类型* 根据吴征镒等[9-11]对中国种子植物属的分布区类型划分，该地区种子植物所含的645属可划分为14个分布区类型和9个变型(表5).

表5 海南石灰岩地区种子植物属的分布区类型

Tab. 5 The distribution types of genera of seed plants in the limestone areas in Hainan

分布区类型	属数	占除世界分布外总属数的比例/%
世界分布	25	
泛热带分布	171	27.58
热带亚洲、大洋洲和南美洲(或墨西哥)间断	2	0.32
热带亚洲、非洲和南美洲间断	6	0.97
热带亚洲和热带美洲间断	14	2.26
旧世界热带分布	76	12.26
热带亚洲、非洲和大洋洲间断分布	8	1.29
热带亚洲至热带大洋洲	66	10.65
热带亚洲至热带非洲	56	9.03
热带亚洲和东非间断	2	0.32
热带亚洲(印度-马来西亚)分布	151	24.35
瓜哇、喜马拉雅和华南、西南星散	8	1.29
热带印度至华南	3	0.48
缅甸、泰国至华西南	2	0.32
越南(或东南半岛)至华南(或西南)	6	0.97
北温带分布	13	2.10
北温带和南温带间断分布	3	0.48
东亚和北美洲间断分布	13	2.10
旧世界温带分布	1	0.16
温带亚洲分布	1	0.16
地中海区、西亚至中亚分布	2	0.32
东亚(东喜马拉雅—日本)分布	14	2.26
中国特有分布	2	0.32
合计	645	100

世界分布的属有25属，如铁线莲属 *Clematis*、远志属 *Polygala*、蓼属 *Polygonum*、酢浆草属 *Oxalis*、悬钩子属 *Rubus*、白花丹属 *Plumbago* 等，其中木本属仅3属，即悬钩子属 *Rubus*、鼠李属 *Rhamnus* 和茄属 *Solanum* 部分种类；草本共有22属，占世界分布属的88%，多分布在荒坡、水边、田野或山顶裸露处.

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泛热带及其亚型分布的属共有 179 属，占非世界分布属数的 28.87%，所占比例最大，这些属所含的种类在植物群落中起着重要的作用，有的是群落中的优势类群. 如榕属、厚壳桂属 *Cryptocarya*、核果木属 *Drypetes*、黄檀属 *Dalbergia*、榄仁属 *Terminalia* 等在乔木层起重要作用. 灌木层常见的有巴豆属 *Croton*、风车子属 *Combretum*、铁苋菜属 *Acalypha*、山麻杆属 *Alchornea*、粗叶木属 *Lasianthus* 及棒柄花属 *Cleidion* 等. 而牛膝属 *Achyranthes*、感应草属、凤仙花属 *Impatiens*、黄花稔属 *Sida*、草胡椒属 *Peperomia* 等则在林下或山顶草本层中占重要地位. 藤本植物中常见的有锡叶藤属 *Tetracera*、羊蹄甲属 *Bauhinia*、鱼藤属 *Derris* 及崖豆藤属等.

热带亚洲和热带美洲间断分布的属有 14 属，占非世界分布属数的 2.26%. 除了木姜子属在森林群落中占据重要地位，种类较多外，其余如雀梅藤属 *Sageretia*、水东哥属 *Saurauia*、山香圆属 *Turpinia*、槟榔青属 *Spondias* 以及竹茎兰属 *Tropidia* 等多为单种属或寡种属，它们在群落中不起主要作用，多分布在山脚、裸露石灰岩山顶、水边或海拔 200 m 以上的密林.

旧世界热带及其亚型分布的属有 84 属，占非世界分布属数的 13.55%. 属于旧世界热带分布在乔木层占优势的有蒲桃属、暗罗属及猫尾木属等. 灌木至小乔木层种类较多、分布较广的有野桐属、五月茶属及杜茎山属等. 草本层主要有山姜属和杜若属.

热带亚洲至热带大洋洲分布的属有 66 属，占非世界分布属数的 10.65%. 乔木层起重要作用的有樟属、山龙眼属、紫薇属、五桠果属 *Dillenia* 及桄榔属等. 喜光花属以及赤才属 *Erioglossum* 等在灌木层中较常见. 而毛兰属、隔距兰属等多分布在山顶裸露石灰岩岩石和树干上. 藤本植物中以崖爬藤属、眼树莲属 *Dischidia* 及球兰属等常见.

热带亚洲至热带非洲分布的属有 56 属，占非世界分布属数的 9.03%. 厚皮树属和仔榄树属虽然在海南石灰岩地区均仅 1 种，即厚皮树 *Lannea coromandelica* 和仔榄树 *Hunteria zeylanica*，但这 2 种在乔木层常见，是群落中的优势种，厚皮树也是该地区季雨林中的主要落叶树种之一. 灌木至小乔木层以海漆属 *Excoecaria*、土蜜树属及龙船花属多见. 藤本植物则以钩枝藤属、微花藤属 *Iodes* 居多，其中钩枝藤 *Ancistroladus tectorius* 是我国海南季雨林与东南亚、马来共有的热带植物种类.

热带亚洲及其变型分布共有 170 属，占非世界分布属数的 27.42%，是该地区除泛热带分布外的第 2 大分布类型. 藤春属 *Alphonsea*、莲桂属 *Dehaasia*、轮叶戟属、割舌树属 *Walsura* 及菜豆树属等在乔木层占据重要地位，东南亚热带雨林优势科龙脑香科也有分布. 灌木至小乔木层中常见的有染木树属 *Saprosma*、草珊瑚属 *Sarcandra* 及破布叶属. 壳斗科在热带亚洲分布广泛，该地区仅青冈属 *Cyclobalanopsis* 3 种，其中 1 种仅见于海拔 1 000 m 以上的裸露山顶，另外 2 种则分布于石灰岩与非石灰岩交界处，并非典型的石灰岩植物. 鸡仔木属 *Sinoadina* 在我国南方、日本、泰国和缅甸均有分布，但在海南现仅发现在昌江王下石灰岩 900 m 以上山顶有少量分布. 草本层中石斛属、贝母兰属 *Coelogyne*、野扇花属 *Sarcococca* 及唇柱苣苔属较为常见.

北温带及其亚型分布的属有 16 属，占非世界分布属数的 2.58%. 该地区植物区系以热带、亚热带为主，但仍有一定比例的温带分布属，如鹅耳枥属 *Carpinus*、榆属 *Ulmus*、胡颓子属 *Elaeagnus*、槭树属 *Acer*、梣属 *Fraxinus*、忍冬属 *Lonicera* 及接骨木属 *Sambucus* 等，这些属多为单种属或寡种属，且多分布在生境较为特殊的地方，如鹅耳枥属、槭树属、梣属等均在山顶或近山顶干燥处才有分布. 北美、中美和中南半岛均有分布的栎属 *Quercus* 在该地区海拔 1 200 m 以上山顶有一特有种，即坝王栎 *Q. bawanglingensis*.

东亚和北美洲间断分布有 13 属，占非世界分布属数的 2.10%. 属于这一分布类型的属所含种类较少，多为单种属，在群落中也不起重要作用，如十大功劳属 *Mahonia*、皂荚属 *Gleditsia*、山蚂蝗属 *Desmodium*、锥属 *Castanopsis*、柯属 *Lithocarpus*、勾儿茶属 *Berchemia* 及木犀属 *Osmanthus* 等，其中壳斗科的锥属和柯属分布于石灰岩与非石灰岩交界处. 木兰科 Magnoliaceae 植物被公认为是最原始的被子植物，在该地区分布非常少，仅有长叶木兰 *Magnolia paenetalauma* 1 种.

旧世界温带分布的属仅有水芹属 *Oenanthe* 1 属，仅见于石灰岩山脚水边，不是典型的石灰岩植物.

温带亚洲分布的属仅有杭子梢属 *Campylotropis* 1 属，该属从印尼、中南半岛热带地区直到我国华南北部均有.

地中海区、西亚至中亚分布的属有 2 属，即黄连木属 *Pistacia* 和木犀榄属 *Olea*. 黄连木属我国有 3 种，除东北和内蒙古外广布，其中黄连木 *Pistacia chinensis* 广布于我国长江以南、华北、西北及菲律宾，多生长在石灰岩地区，在海南石灰岩也有分布. 印度－马来至东亚被认为是木犀榄属的分化中心，在海南石灰岩地区分布有该属 2 种.

东亚(东喜马拉雅—日本)分布的属有 14 属，占非世界分布属数的 2.26%. 属于这一类型的除了梧

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桐属 *Firmiana*、南酸枣属 *Choerospondias* 在乔木层分布较为广泛外，其余的如野鸦椿属 *Euscaphis*、石斑木属 *Raphiolepis* 和桃叶珊瑚属 *Aucuba* 等分布范围较小，其中石斑木属仅分布在山顶裸露处. 吊石苣苔属 *Lysionotus*、黄猄草属 *Championella*、蜘蛛抱蛋属 *Aspidistra*、沿阶草属 *Ophiopogon* 及金发草属 *Pogonatherum* 等在密林、裸露石上、路旁较为常见.

中国特有属仅有2属，即海南椴属 *Diplodiscus* 和盾叶苣苔属 *Metapetrocosmea*. 其中盾叶苣苔属也是海南特有属，生长环境较为特殊；海南椴 *Diplodiscus trichospermus* 是我国海南和广西共同特有的属，在海南昌江、东方石灰岩地区有少量分布.

3.3 与邻近地区植物区系的比较

海南石灰岩地区植物区系与周围邻近地区有着紧密的联系，为了进一步探讨分析该地区区系性质及其起源等，选取邻近石灰岩地区与非石灰岩地区从各自植物区系组成特点以及科、属的相似性系数等方面进行比较.

3.3.1 与海南邻近非石灰岩地区植物区系的比较

1) 与海南霸王岭植物区系的比较. 霸王岭林区位于海南西部(19°02′～19°10′ N，109°02′～109°14′ E)，该林区与海南石灰岩集中分布的俄贤岭相距约20 km，自然地理条件相似. 霸王岭林区现记录野生种子植物110科368属572种[26-29]，这一数据将随着调查的深入而增加. 两地种子植物共同的科有101科，科的相似性系数为40.08%. 两地都包括一些世界分布科，如远志科 Polygalaceae、苋科、千屈菜科、瑞香科 Thymelaeaceae、金丝桃科 Hypericaceae 等；一些热带、亚热带分布为主的科，如番荔枝科、樟科、白花菜科、使君子科、山龙眼科 Proteaceae、五桠果科、大风子科、天料木科、金莲木科 Ochnaceae、钩枝藤科 Ancistrocladaceae、藤黄科 Clusiaceae、杜英科 Elaeocarpaceae、梧桐科、蝶形花科、黄杨科 Buxaceae、芸香科等，以及典型的热带科如龙脑香科、毒鼠子科等两地都有分布. 一些温带科如金缕梅科、胡颓子科、胡桃科 Juglandaceae 等也两地共有. 不同的是霸王岭林区中山茶科 Theaceae 植物明显增多，这可能与两地的土壤基质有关；霸王岭地区种子植物分布种类数量较多的山矾科 Symplocaceae、冬青科 Aquifoliaceae、木兰科在石灰岩地区分布种类较少；壳斗科、蔷薇科 Rosaceae 等在霸王岭分布较多，但在石灰岩地区则数量较少. 石灰岩地区分布较多的苦苣苔科、楝科等在霸王岭分布较少. 泛热带性科粘木科 Ixonanthaceae 和杨梅科 Myricaceae、热带亚洲性科五列木科 Pentaphylacaceae 以及温带性科杜鹃花科 Ericaceae 和世界性科越橘科 Vacciniaceae 在霸王岭有分布，但在邻近的石灰岩地区不见有分布. 同样，石灰岩有分布的泛热带性科肉豆蔻科 Myristicaceae、蒟蒻薯科 Taccaceae，温带性科山茱萸科、列当科 Orobanchaceae，以及东亚和北美间断分布性科小檗科 Berberidaceae 在霸王岭也未见有记录.

两地共有的属有325属，属的相似性系数为32.08%，一些在石灰岩地区广泛分布的热带属如五月茶属、土蜜树属、巴豆属、核果木属、野桐属、羊蹄甲属、鱼藤属等在霸王岭种类数量不多. 霸王岭分布的拟单性木兰属 *Parakmeria*、含笑属 *Michelia*、木莲属 *Manglietia*、八角属 *Illicium* 等原始类群在石灰岩地区没有分布. 在种级水平上，在霸王岭分布广泛的陆均松 *Dacrydium pierrei*、鸡毛松 *Podocarpus imbricatus*、五列木 *Pentaphylax euryoides*、臀形果 *Pygeum topengii*、榕叶冬青 *Ilex ficoidea* 等在海南石灰岩地区未见分布. 海南石灰岩地区同样分布有很多不见于霸王岭的特有种，如霸王远志 *Polygala bawanglingensis*、海南凤仙花 *Impatiens hainanensis*、盾叶秋海棠 *Begonia peltatifolia*、海南大戟 *Euphorbia hainanensis*、霸王栎 *Quercus bawanglingensis* 及昌江厚壳树 *Ehretia changjiangensis* 等.

2) 与海南尖峰岭植物区系的比较. 尖峰岭位于海南西南部(18°23′～18°50′ N，108°36′～109°05′ E)，总面积约470 km^2，现记录有野生种子植物202科1 139属2 684种[30-31]，以樟科、壳斗科、桃金娘科、山茶科、大戟科、金缕梅科、榆科、山矾科、木犀科 Oleaceae、无患子科、蝶形花科等热带性科为主，这和海南石灰岩地区的植物区系性质是一致的. 两地种子植物共有科为141个，科的相似性系数为40.99%，共有属为512属，属的相似性系数为28.70%.

两地共有的科包括一些世界性科，如远志科、景天科 Crassulaceae、酢浆草科、千屈菜科、瑞香科及金丝桃科等；一些热带性科如番荔枝科、樟科、钩枝藤科、龙脑香科、桑科、紫金牛科、茜草科在两地群落中均占优势；少数温带性科如蓼科 Polygonaceae、胡颓子科和列当科也两地共有. 但尖峰岭有分布的鸡毛松、陆均松、竹柏 *Nageia nagi*、长叶竹柏 *N. fleuryi* 等在石灰岩地区未见有分布. 茅膏菜科 Droseraceae、五列木科、猕猴桃科 Actinidiaceae、粘木科、古柯科 Erythroxylaceae、鼠刺科 Iteaceae、杠柳科 Periplocaceae、龙胆科 Gentianaceae、狸藻科 Lentibulariaceae、假兰科 Apostrasiaceae、水玉簪科 Burmanniaceae、越橘科等，以及一些温带科如报春花科 Primulaceae、桦木科 Betulaceae 和杜鹃花科在尖峰岭有分布，但在石灰岩地区没有. 木兰科、山茶科、蔷薇科、壳斗科和冬青科等在尖峰岭发现有较多的属种，石灰岩地区仅有少

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数属种分布. 尖峰岭占优势的蒲桃属、榕属、琼楠属 *Beilschmiedia*、木姜子属、润楠属 *Machilus*、紫金牛属、粗叶木属、韶子属 *Nephelium* 等在石灰岩地区分布也较广泛. 而山矾属 *Symplocos*、冬青属 *Ilex*、柯属、锥属、青冈属等仅在尖峰岭占优势，在石灰岩地区种类较少. 尖峰岭的优势种海南蕈树 *Altingia chinensis* 在石灰岩未见分布，而海南韶子 *Nephelium topengii*、白颜树 *Gironniera subaequalis* 在尖峰岭和石灰岩都较常见.

以上海南石灰岩地区与非石灰岩地区植物区系比较可以看出，海南石灰岩地区与非石灰岩地区的植物区系性质相似，具有很强的热带性质，很多科属相互共有. 然而，一些嫌钙性的种类和亚热带、温带分布为主的科属在石灰岩地区分布较少. 海南石灰岩地区植物区系相对非石灰岩地区而言具有较强的岩溶性质，分布有一些石灰岩地区的特有种.

3.3.2　*与邻近石灰岩地区植物区系比较*　为了解海南石灰岩地区植物区系与邻近石灰岩地区植物区系的关系，选取与海南邻近的广西弄岗[5]、云南西双版纳[23]、越南 Cuc Phong[32]、马来半岛等[33]石灰岩地区进行植物区系组成的比较(表 6).

表 6　海南石灰岩地区与被比较地区种子植物区系比较[1)]

Tab. 6　Comparison of floristic similarities between Hainan and the neighbouring limestone areas

地点	面积/	各级分类单位数量			与海南石灰岩共有科属数及各自占比[1)] /%						相似性系数	
	km^2	科	属	种	科	A	B	属	C	D	科	属
海南石灰岩	400	142	645	1 235								
广西弄岗[5]	101	146	656	1 340	124	84.93	87.32	319	48.63	49.46	43.06	24.52
云南西双版纳[23]	3 600	129	558	1 269	112	86.82	78.87	348	62.37	53.95	41.33	28.93
越南 Cuc Phuong[32]	250	160	778	1 679	120	75.00	84.51	393	50.51	60.93	41.38	27.62
马来半岛[33]	260	117	539	1 119	69	87.34	48.59	177	61.67	27.44	44.44	14.95

1)　表中 A、C 分别表示共有科、属数占被比较地科、属数比例，B、D 分别表示共有科、属数占海南石灰岩地区科、属数比例.

1) 与广西弄岗石灰岩地区植物区系的比较. 弄岗自然保护区位于广西西南部(22°13′～22°33′ N，106°42′～107°04′ E)，面积约 101 km^2[34]，现记录有种子植物 146 科 656 属 1 340 种[5]. 通过比较可看出海南石灰岩地区和弄岗植物区系具有较强的相似性. 两地种子植物共有的科有 124 科，科的相似性系数为 43.06%，共有的属有 319 属，属的相似性系数为 24.52%. 弄岗植物区系也具有明显的热带性，如防己科、葡萄科、梧桐科、姜科、番荔枝科等占优势；其优势科大戟科、蝶形花科、茜草科、桑科、紫金牛科、菊科、芸香科、樟科、兰科、萝摩科、番荔枝科、楝科、苦苣苔科等在海南石灰岩地区也占优势.

一些亚热带分布为主的科在广西弄岗也有较多分布，如金缕梅科、茶科、冬青科、木兰科、壳斗科、山矾科、杜英科、樟科等. 两地科的属种组成也有不同，如弄岗石灰岩龙脑香科植物擎天树 *Parashorea chinensis* 在海南石灰岩不见分布，而海南石灰岩分布的青梅 *Vatica mangachapoi* 同样也不见于广西弄岗. 大戟科的肥牛树 *Cephalomappa sinensis*、桂林乌桕 *Triadica chihsinianum*、广西马兜铃 *Aristolochia kwangsiensis* 等广西特有植物均不见于海南石灰岩. 广西弄岗分布的大血藤科 Sargentodoxaceae、亚麻科 Linaceae、猕猴桃科、红树科 Rhizophoraceae、报春花科等在海南石灰岩没有分布，而海南石灰岩分布的金莲木科、钩枝藤科、肉实树科 Sarcospermataceae、列当科在广西弄岗未见有分布.

2) 与云南西双版纳石灰岩地区植物区系的比较. 西双版纳石灰岩地区(99°58′～101°50′ E，21°09′～22°36′ N)位于云南南部，与老挝和缅甸交界，面积约 3 600 km^2，现记录有维管植物 1 394 种(包括变种)，隶属于 153 科 640 属，其中蕨类 24 科 82 属 125 种，种子植物 129 科 558 属 1 269 种[23]. 两地种子植物共有的科有 112 科，占西双版纳石灰岩地区种子植物总科数的 86.82%，占海南石灰岩地区种子植物总科数的 78.87%，科的相似性系数为 41.33%，共有的属有 348 属，属的相似性系数为 28.93%. 可见两地植物区系具有较高的相似性. 西双版纳石灰岩地区的优势科如兰科、茜草科、大戟科、蝶形花科、桑科、番荔枝科、爵床科、芸香科、楝科、荨麻科等在海南石灰岩地区也占优势，而鼠李科 Rhamnaceae、胡椒科 Piperaceae、薯蓣科 Dioscoreaceae、防己科、百合科、含羞草科 Mimosaceae 等在西双版纳石灰岩占优势，但在海南石灰岩地区并不占优势. 两地共有东南亚热带成分较多，如番荔枝科、大戟科、龙舌兰科 Agavaceae 的一些属种. 而典型热带性科金莲木科、钩枝藤科、龙脑香科、毒鼠子科等在西双版纳石灰岩地区不见有分布，可见海南石灰岩地区具有更强的热带性. 印度至西、中马来特有的隐翼科 Crypteroniaceae 植物在西双版纳石灰岩上层乔木占优势，但在海南石灰岩地区没有分布，这可能与西双版纳与中南半岛陆地连接，植物区系更易相互渗透有关.

3) 与越南 Cuc Phuong 石灰岩地区植物区系的比

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较. Cuc Phuong 国家公园位于越南北部河内西南约 120 km(20°14′~20°24′ N,105°29′~105°44′ E),面积约250 km²,现记录有种子植物160科778属1 679种,其中裸子植物3科3属3种[32],主要以印度至中国起源成分为主,楝科、樟科、兰科植物较多. 两地种子植物共有的科有120科,占Cuc Phuong种子植物总科数的75%,占海南石灰岩地区种子植物总科数的84.51%,科的相似性系数为41.38%,共有的属有393属,属的相似性系数为27.62%.

由于与海南地理位置相近,仅隔着北部湾,气候条件也相似,两地石灰岩地区植物种类共有很多热带成分,如热带雨林的特征成分龙脑香科植物,以及牛栓藤科 Connaraceae、茜草科. 八角枫科 Alangiaceae、苋科、蛇菰科 Balanophoraceae、秋海棠科 Begoniaceae、紫葳科、木棉科 Bombacaceae 在 Cuc Phuong 和海南石灰岩地区分布的种类数量差异不大,但爵床科、番荔枝科、夹竹桃科、萝藦科、菊科等在 Cuc Phuong 分布的种类明显比海南石灰岩地区丰富,槭树科、漆树科 Anacardiaceae、冬青科、五加科在 Cuc Phuong 的种类也多于海南石灰岩地区.

4) 与马来半岛石灰岩地区植物区系的比较. 马来半岛石灰岩分布广泛,据 Chin[33] 记载,马来半岛石灰岩地区有维管植物1 216种,隶属于582属124科,其中蕨类植物7科43属97种,种子植物117科539属1 119种. 两地共有种子植物116科,占马来半岛石灰岩地区种子植物总科数的97.48%,占海南石灰岩地区总科数的81.69%,科的相似性系数为44.44%,共有的属有177属,属的相似性系数为14.95%. 马来半岛石灰岩地区的绝大部分科均见于海南石灰岩地区,仅杜鹃花科、报春花科、狸藻科、八角科 Illiciaceae、心翼果科 Cardiopteridaceae 等不见于海南石灰岩地区.

由上可见,海南石灰岩地区具有较强的热带石灰岩植物区系特点,但也受地带性植物区系影响. 海南石灰岩地区与邻近石灰岩地区在科级和属级水平上的相似性有所不同,在科级水平上与马来半岛、越南和我国广西、云南等有较大的相似性,而在属级水平上,则与越南、我国云南具有较大的相似性,其中与云南西双版纳石灰岩关系最近(两地科的相似性系数达41.33%,属的相似性系数为28.93%),其次是越南、我国广西和马来半岛.

4 讨论

植物区系是自然形成物,植物区系的深入研究,必然要涉及到植物区系的起源以及种群的演化与发展问题,只有在现代植物分布的基础上充分结合被研究地区的古植物、孢粉、古地理和古气候等资料,才能很好地研究并解决这一难题. 海南石灰岩地区种子植物区系具有种类丰富、物种密度高、热带性质明显、特有属贫乏等特点. 相对其他石灰岩地区在特有化水平上不是很明显,如广西10个特有属中,就有8个苦苣苔科的属是石灰岩山地的特有属[35],而在海南石灰岩地区仅2种为中国特有. 另外,一些在中国南部石灰岩地区广泛分布的种如圆叶乌桕 *Triadica rotundifolia*、化香树 *Platycarya strobilaceas* 等在海南石灰岩地区尚未发现. 海南石灰岩特有种的比例比马来半岛和我国广西均低,特有属的缺乏也反映了该地区植物区系分化历史相对较短,属内种系的缺少是岛屿植物区系的重要特点,这和海南植物区系的大环境有关,但也可能和石灰岩与非石灰岩地区由于生境隔离形成的小环境有关,地质历史的相对年轻性可能是造成其特有植物不甚丰富的主要因素[36].

从海南石灰岩地区的地质历史可以看出,该地区最初为中寒武世末到晚寒武世由于海退而沉积下来的石灰岩,当时是藻类繁盛时期,而后经历奥陶纪、晚古生代至中生代多次沉积和地壳运动,现在海南石灰岩地区发现最老的地层为上古生界岩石. 裸子植物在海南石灰岩地区现代植物区系中种类较少,最早的化石见于东方江边和南龙晚二迭纪的苏铁纲类植物,苏铁类植物被认为是种子植物中最原始和古老的类群,该科在海南石灰岩地区现仅存1种,且数量较少,海南石灰岩地区裸子植物的起源时间至少应在晚二迭纪. 被子植物中原始的木兰科植物在海南石灰岩地区分布有木兰属 *Magnolia* 1种,木兰科孢粉化石在海南见于第三纪始新世至早渐新世[37].

海南石灰岩地区与邻近非石灰岩地区共有科的相似性系数均在40%以上,可见海南石灰岩地区植物区系受地带性气候影响较大,一些科属与非石灰岩地区具有起源或来源上的同一性,只是由于石灰岩地区生境隔离作用,在裸露石灰岩地区,如山顶、洞口、石壁等形成与其他地区相差甚大的小生境,在这些地区往往种系分化较为厉害,形成一些石灰岩地区的特有种. 石灰岩山地由于特殊的生境条件,如地表水缺乏、土层浅薄、岩层淋溶、山体陡峭等,起了一种"隔离"作用,促进了石灰岩山地植物区系的特有化发展. 海南石灰岩地区的专性种和适宜种与岩溶地貌、土壤因子以及岛屿效应密切相关. 对于石灰岩地区一些温带成分的分布,这些成分的分布中心仍在温带,这可能是由于第三纪末期到第四纪随着冰期的出现,全球气候变冷,许多温带成分往南迁移到华南地区,而后在第四纪冰期和间冰期交替出现,植物迁移也交替进行,冰后期气候变暖,迁移到华南

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地区的温带成分也开始回迁,但仍有一些种类遗留下来,这些种类为了适应干旱、炎热环境与温带地区的种类在外部形态、生理上有些变异,如杭子梢属主要分布在亚洲温带地区,在海南石灰岩地区山顶分布有杭子梢 *Campylotropis macrocarpa* 1 种,数量较少,但明显矮化,植株被毛多且密.

致谢: 在野外工作中得到海南省林业厅野生动植物保护管理局、霸王岭国家级自然保护区管理局、昌江县王下乡政府、东方市东河镇南浪村村委和江边乡政府、保亭县毛感乡林业站及香港嘉道理农场暨植物园吴世捷博士等单位和个人的热情帮助,中国科学院华南植物园李泽贤、张桂才高级工程师和胡启明、叶华谷研究员等在标本鉴定中给予了大力支持,在此一并致谢!

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【责任编辑　李晓卉】

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華南農業大學学报

JOURNAL OF SOUTH CHINA AGRICULTURAL UNIVERSITY

华南农业大学学报

Huanan Nongye Daxue Xuebao

（双月刊，1959 年创刊，1980 年复刊）

第 35 卷　第 3 期　2014 年 5 月

Journal of South China Agricultural University

(Bimonthly, Started 1959, Resumed 1980)

Vol.35 No.3 May. 2014

主管单位：华南农业大学

主办单位：华南农业大学

主　　编：陈晓阳

编辑出版：华南农业大学学报编辑部

（广州五山，邮政编码: 510642）

网　　址：http://xuebao.scau.edu.cn

电子邮箱：journal@scau.edu.cn

电　　话：(020)85280069/38746672

印刷单位：暨南大学印刷厂

发行订购：华南农业大学学报编辑部

国外发行：中国国际图书贸易总公司

（中国国际书店）北京399信箱

Responsible Institution: South China Agricultural University

Sponsor: South China Agricultural University

Chief Editor: CHEN Xiaoyang

Edited and Published by Editorial Department, Journal of South China Agricultural University

Address: Wushan, Guangzhou, 510642, China

Website: http://xuebao.scau.edu.cn

E-mail: journal@scau.edu.cn

Tel: (86-20)85280069/38746672

Distributed by China International Book Trading Corporation(P.O.Box 399 Beijing, China)

国内外公开发行

国内定价：15.00 元/册

刊号：ISSN 1001-411X / CN 44-1110/S

ISSN 1001-411X

05>

9 771001 411140

Pak. J. Bot., 44(4): 1229-1232, 2012.

A STUDY ON THE FLORA AND VEGETATION OF CAT DUA ISLAND, NORTHEASTERN VIETNAM

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Abstract

Cat Dua Island (namely Monkey Island) is situated in the Gulf of Tonkin, belonging to the Quang Ninh Province in Vietnam. A total vascular flora of 88 species belonging to 44 families and 76 genera was recorded from the island. The dominant families of the flora are Euphorbiaceae, Papilionaceae, Moraceae, Rutaceae and Rubiaceae etc. Most of the genera in the flora are tropical characteristic. In the island, there are few endemic species, which may be due to its young flora in geological respect. The vegetation are mainly classified as the evergreen broad-leaved forests, scrub forests and beach vegetation. It is urgent to protect biodiversity in limestone regions and how to deal with the relationship between development and protection is still a difficult task.

Introduction

Karst landscape is one kind of specific habitat distributed widely in the world. Because of the great diversity of edaphic conditions and topography, vegetation types on karst are extremely diverse and rich in endemic taxa. However, limestone area is a very fragile habitat and is being threatened by human activities, therefore plants those are endemic to this kind of habitat are at a high risk of extinction. Due to inconsiderate pursuit for development, ex-situ conservation is a next best alternative for species survival. There are large limestone areas in Southeast Asia, including China, Vietnam, Thailand, and Philippine etc. Furthermore, in some Asian countries such as Vietnam and China, limestone vegetation is poorly studied and collections of herbarium specimens are few, therefore there is a possibility of disappearance of unnamed species (Clements *et al*., 2006). Vietnam is the country in Asia which has about 18% area of limestone mountains (Furey & Infield, 2007), mainly occurring in the north, including Long Son, Hoa Binh, Quang Ninh and Ninh Binh provinces etc.. Ha Long Bay, a World Heritage Site, is a famous karst landscape in Vietnam. It has an area of 1,553 sq. km with thousands of eccentric isles emerging above the sea surface (Anon., 2003). The biodiversity are very rich there. However, there is no adequate inventory of plants so far in Ha Long Bay area, so the rich and fascinating flora remains unknown to most people. Cat Dua Island is one island nearby Ha Long Bay. We investigated the flora and vegetation of Cat Dua Island in September 2004 when we attended the International Transdisciplinary Conference on Development and Conservation of Karst Regions in Vietnam. A primary analysis of the flora and vegetation of Cat Dua Island is given by us in this paper.

Materials and Methods

Cat Dua Island lies in the Northeast of Vietnam and belongs to the Quang Ninh province. It is located about 150km to the Southeast of Hanoi, on the west side of the Gulf of Tonkin. Geologically it is closely attached to the Hainan Island in South China. It can be accessed very conveniently by boat or canoe from Hai Phong or Quang Ninh. The Island is composed of limestone, it has an area of about 12 sq. km, in which the elevation of the highest peaks is about 100 m. It is a part of the 'Quang Ninh anticlinorium' (Tri, 2003). This structure occoupies most of Quang Ninh province and the southern margin of Hai Phong city. The climate of Cat Dua Island is monsoon tropical, being hot and wet from May to October with temperatures averaging between 27-29°C but cool and dry in the winter (Hiep & Kiew, 2000).

The information including number, height and habitat of each species were recorded in the field. Plants were identified with the help of some botany monographs of Vietnam (Lecomte, 1907-1951; Aubrevile *et al*., 1960-1994; Pham, 1991-1993).

Results

Flora: There were 88 vascular plants belonging to 44 families and 76 genera in the island according to the authors' investigation. The largest families more than 4 species were Euphorbiaceae, Papilionaceae, Moraceae, Rutaceae and Rubiaceae. The most common genera were *Capparis*, *Croton*, *Dunbaria*, and *Ficus*. Within these families, about 81.8% of the total families are tropical (Annonaceae, Moraceae, Euphorbiaceae and Rubiaceae), 11.4% are cosmopolitan (Hypericaceae, Rhamnaceae and Compositae), and the rest are temperate (Ranunculaceae and Boraginaceae). In terms of genera, about 93.3% of the total genera are tropical elements (*Ficus*, *Scaevola*, and *Rinorea*), 4% are cosmopolitan (*Clematis*, *Bidens*, and *Sophora*), and the rest being temperate (*Vitis* and *Rhus*). About 43.2% species belong to Pantropic, and 22.7% belong to Old World Tropics. It is obvious that the flora character of Cat Dua Island are tropical. Many species have adapted to the xerothermic and rainy climate. Endemic species are few in the island. All the plants come from the near mainlands or islands. Some plants are transmitted by human or animals such as *Bidens alba* and *Cassytha filiformis*. Some are transmitted by sea water

such as *Cocos nucifera* and *Pandanus tectorius*. Some are transmitted by wind such as *Chromolaena odoratum* and *Clematis uncinata*.

According to phytogeographical distribution and their habit, these plants can be divided into four types, *viz*. eurytopic plants, accidental plants, preferential plants and endemic plants.

Eurytopic plants: They distribute widely, not only in limestone regions, but also in other bedrock regions such as granite regions. They need no special soil during their growth, so they have no special association with limestone. They are mainly some species of Lauraceae, Euphorbiaceae, Moraceae, Compositae, and Rutaceae, including *Bridelia tomentosa, Ficus virens* var. *sublanceolata,* and *Murraya alata*.

Accidental plants: These plants are found only occasionally on limestone or strangers to limestone such as *Murraya microphylla* and *Clerodendrum inerme*.

Preferential plants: They are dominant on limestone. Although these plants distribute both in limestone regions and in granite regions, they prefer to grow in the former. Many species of them are dominant species in the limestone communities. They are mainly some species of Euphorbiaceae, Papilionaceae and Sterculiaceae, including *Pterospermum heterophyllum, Mallotus repandus, Croton cascarilloides, Sarcostemma brevistigma,* and *Dracaena cambodiana*.

Endemic plants: They grow only in the limestone regions or they are only found in limestone regions so far. The characters of these plants are calciphilous, and drought-tolerant. They are always thorny and pileous on their stems and leaves. They are mainly some species of Euphorbiaceae, Gesneriaceae, Balsaminaceae, and Urticaceae, such as *Triadica rotundifolium* and *Impatiens verrucifer*.

Vegetation: The vegetation of the region as a whole is dominated by low shrubs. According to the distributional elevation and habitat of these plants, they can be divided into several types.

Seashore plant community: There are some kinds of grasses and trees on sandy shores. Nearby the sea, most plants are creeping and rooting. The dominant species are *Canavalia maritima , Vitex trifolia* var. *simplicifolia, Sophora tomentosa,* and *Cajanus scarabaeoides.* There are some typical seashore plants such as *Pandanus tectorius, Scaevola sericea,* and *Cerbera manghas*. Just like other islands, some alien species which come from tropical American invaded the seashore first, such as *Bidens alba* and *Chromolaena odoratum*. In some regions the alien plants spread widely. It seems that sparse forests are easier to be invaded by alien plants than dense forests. Some plants were planted by fishers or villagers for food or resisting the wind, such as *Casuarina equisetifolia, Annona squamosa,* and *Cocos nucifera*.

Slope plant community: On the slope of the rocky island there are usually some shrubs and liane including the evergreen trees with a height of 2-4 m such as *Hibiscus tiliaceus, Triadica rotundifolium,* and *Arytera littoralis*. Beside the wooden trees the climbers can be found here such as *Cassytha filiformis, Tetrastigma tonkinense,* and *Vitis balanseana*.

Cliff plant community: The habitat of these plants is very dicky. Their roots penetrate in the cracks firmly to prevent the trees from falling down and to take nutrition. Only some species can survive on such severe conditions. Typical species include *Sarcostemma brevistigma* and *Dracaena cambodiana.*

Hill top flora community: Some summits (hill tops) are covered by a thin layer of soil or uncovered entirely. The small, bushy, thorny and climbing species grow there. Some typical species include *Clematis uncinata, Pilea peltata, Impatiens verrucifer, Mallotus repandus* and *Celtis philippensis*.

Discussion

The richness of the flora, both in the variety of different communities and the number of species, contribute to the area's biodiversity, and some problems on utilization and conservation are urgent to be studied and resolved (Chaghtai & Yusaf, 1976; Khan *et al*., 2011). Most species of Cat Dua Island are similar to those of the neighbouring regions and countries such as the Ha Long Bay, Cat Ba Island in Vietnam, and Hainan Island in South China. Cat Ba Island, Ha Long Bay and Cat Dua Island are parts of Quangninh anticlinorium. Tri (2003) considered they are parts of the Vietnam-China composite territory that has experienced a common evolution of rifting, drifting, collision and subsequent modification since the Late Pre-Cambrian throughout the whole Phanerozoic era. So almost all the species in Cat Dua Island can be found in Ha Long Bay or Cat Ba Island. Although Cat Dua Island and Hainan Island are separated by the Gulf of Tonkin, their flora are very similar. The limestone regions of Hainan Island is mainly distributed in Changjiang County and Baoting County, which lie on the east side of the Gulf of Tonkin. The authors had studied the flora of limestone in Hainan Island for several years. According to the present investigation, most species of Cat Dua Island are the same as those of Hainan Island, such as *Pterospermum heterophyllum, Mallotus repandus, Croton cascarilloides, Atalantia sessiliflora,* and *Murraya alata*. However, there are still some species of Cat Dua Island which can not be found in limestone areas in Hainan Island, such as *Triadica rotundifolium, Sarcostemma brevistigma, Chirita hamosa,* and the other seashore plants. It is interesting that the similar species in Cat Dua Island and in Hainan Island are used different scientific names, such as the *Impatiens verrucifer* in Vietnam is very similar to *I. hainanensis* in China in the wild. It is possible that they are the same species, and they should be studied carefully in the future. Maybe there are still some taxonomic problems in these species. According to our field survey in Cat Dua Island and Hainan Island, there are many alien plants in limestone

regions. They even invade the inside of forest and have the trend to spread. In some severely destroyed regions, the alien plants appear first and become the dominant species, such as *Chromolaena odoratum* and *Bidens alba*. Why the ecosystem in limestone areas seems to be more easily invaded than in non-limestone areas? Maybe there is some relationship between alien plants and calcareous soil.

Now environment worsening has become the global problem and this is particularly serious in karst areas. It's known that economic development in most karst areas has been relatively slow compared to that of urban areas. The high rate of population growth and a rapid economic development have caused a strong pressure on the environment in general and on karst ecosystems in particular. The biodiversity on the island should be protected for future generations. Encroachment of forest for establishment of farmland and plantation leads to destruction of the forest habitat. Unsustainable harvesting of forest products have caused gradual degradation of the ecosystem. Increasing human activities resulted from such harvesting activities and tourisms will lead to indirect impact, such as invasion of alien species. It is very important especially in developing countries that public education program should be launched to raise awareness of protecting the biodiversity. Participatory approach to regulate the utilization of forest resources and tourist activities would ensure sustainable development and conservation of the limestone ecosystems. In conclusion, some suggestions on efficient management in limestone areas defined by the Cat Dua Island are as follows:

- It has to have policies and regulations with regard to acceptable activities around the protected area. It is important to educate visitors' environmental awareness and determine the number of visitors. The number of visitors should be limited in different seasons.
- Advisory groups could be established to obtain some managemental advices. Scientific advisory groups could include members from international agencies and from local experts. The international cooperation and communion between experts and governments should be strengthened through holding international meetings periodically or carrying out some cooperative projects. It is necessary to make more and more people especially local people to attend the protection activities in karst regions.
- It has to strengthen the scientific researches in karst regions. Only if we have known what and where the plants are, we can decide to how to protect them efficiently. Some basic information such as the species number, distribution, endangered reasons of rare and endangered plants should be collected, which will provide a scientific basis for future policy-making.
- It is very important to prevent environment from being polluted. Waste disposal and treatment of visitors and staff should be considered and pollution of the underground water resources should be avoided. The correlative rules should be enacted and performed faithfully.

Appendix

Checklist of Plants on the Cat Dua Island

Families are arranged by Hutchinson System, dicotyledons 1926, monocotyledons 1934; genus and species are arranged alphabetically

Annonaceae
Annona squamosa L.
Dasymaschalon rostratum Merr. et Chun
Polyalthia petelotii Merr.
Lauraceae
Cassytha filiformis L.
Litsea glutinosa (Lour.) C.B.Rob.
Ranunculaceae
Clematis uncinata Champ. et Benth.
Menispermaceae
Stephania rotunda Lour.
Tinospora sinensis (Lour.) Merr.
Aristolochiaceae
Aristolochia pierrei Lecomte
Piperaceae
Piper sintenense Hatusima
Capparidaceae
Capparis floribunda Wight
Capparis hainanensis Oliv.
Violaceae
Rinorea anguifera (Lour.) O. Ktze.
Balsaminaceae
Impatiens verrucifer Hook.f.
Cucurbitaceae
Zehneria indica (Lour.) Keraudren
Hypericaceae
Cratoxylum cochinchinense (Lour.) Bl.
Sterculiaceae
Pterospermum heterophyllum Hance
Malvaceae
Hibiscus tiliaceus L.
Euphorbiaceae
Bridelia tomentosa Bl.
Croton cascarilloides Raeusch.
Croton laevigatus Vahl
Mallotus repandus (Willd.) Müll. Arg.
Triadica rotundifolia (Hemsley) Esser
Dichapetalaceae
Dichapetalum helferianum Pierre.
Caesalpiniaceae
Bauhinia oxysepala Gagn.
Papilionaceae
Cajanus scarabaeoides (L.)Thouars
Canavalia maritima (Aubl.) Thou.
Dalbergia pinnata (Lour.) Prain
Dalbergia sp.
Derris marginata Benth.
Dunbaria henryi Y. C.Wu
Sophora tomentosa L.
Casuarinaceae
Casuarina equisetifolia L.
Ulmaceae
Celtis philippensis Blanco
Moraceae
Ficus amplissima Sm.

Ficus saxophila Bl.
Ficus superba var. *alongensis* (Gagn.) Corner
Ficus virens var. *sublanceolata* (Miq.) Corner
Urticaceae
Boehmeria zollingeriana Wedd.
Pilea peltata Hance
Pouzolzia zeylanica (L.) Benn. et R. Br.
Celastraceae
Euonymus tonkinensis Loes.
Maytenus diversifolia (Maxim.) D. Hou.
Rhamnaceae
Colubrina asiatica (L.) Brongn.
Vitaceae
Tetrastigma tonkinense Gagnep.
Tetrastigma pachyphyllum (Hemsl.) Chun
Vitis balansaeana Planch.
Rutaceae
Atalantia acuminata Huang
Atalantia sessiliflora Guill.
Glycosmis pentaphylla Corrêa
Murraya alata Drake
Murraya exotica L.
Murraya microphylla (Merr. et Chun) Swingle
Simaroubaceae
Picrasma chinensis P.Y. Chen
Sapindaceae
Allophylus viridis Radlk.
Arytera littoralis Bl.
Anacardiaceae
Pistacia weinmannifolia Poiss. ex Franch.
Rhus chinensis Mill.
Alangiaceae
Alangium salviifolium (L.f.) Wanger.
Sapotaceae
Sinosideroxylon pedunculatum (Hemsl.) H. Chung
Sinosideroxylon bonii Aubr.
Myrsinaceae
Embelia rudis Hand.-Mazz.
Oleaceae
Jasminum microcalyx Hance
Apocynaceae
Cerbera manghas L.
Asclepiadaceae
Sarcostemma brevistigma Wight & Arn.
Secamone elliptica R. Br.
Rubiaceae
Canthium umbellatum Wight
Mussaenda glabra Vahl
Mussaenda pilosissima Val.
Pavetta hongkongensis Bremek.
Spiradiclis sp.
Wendlandia sp.
Compositae
Bidens alba (L.) DC.
Chromolaena odoratum (L.) R. M. King & H. Rob.
Gynura divaricata (L.) DC.
Goodeniaceae
Scaevola sericea Vahl
Gesneriaceae
Chirita hamosa R. Br.
Verbenaceae
Callicarpa nudiflora Hook.et Arn.
Clerodendrum inerme (L.) Gaertn.
Vitex trifolia var. *simplicifolia* Cham.
Agavaceae
Dracaena cambodiana Pierre ex Gagnep.
Palmaceae
Cocos nucifera L.
Pandanaceae
Pandanus tectorius Sol.
Poaceae
Bothriochloa pertusa (L.)A.Cam.
Oplismenus compositus (L.) Beauv.
Stenotaphrum micranthum (Desv.) C. E. Hubb.

Acknowledgements

The work is supported by the National Natural Science Foundation of China (grant numbers 30270122), the Key Laboratory of Protection and Development Utilization of Tropical Crop Germplasm Resources, Ministry of Education, China (grant numbers 2010hckled-11), and the Natural Science Foundation of Hainan Province, China (grant numbers 311058).

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(Received for publication5 September 2011)

华南农业大学学报

JOURNAL OF SOUTH CHINA AGRICULTURAL UNIVERSITY

中国综合性农业科学核心期刊

ISSN 1001-411X
CODEN HNDXBH
中国·广州
GUANGZHOU CHINA

SCAU

2012

7月 第33卷 第3期
Jul. Vol.33 No.3

ISSN 1001-411X

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第33卷 第3期 2012年7月

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期刊基本参数：CN44-1110/S * 1959 * q * A4 * 156 * zh + en * P * ￥10.00 * 1600 * 32 * 2012-07

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海南俄贤岭石灰岩山地海南凤仙花所在群落植物区系及生态特征

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摘要： 通过样方调查对海南俄贤岭石灰岩山地海南凤仙花 *Impatiens hainanensis* 所在群落的植物区系及生态特征进行了分析. 结果表明，在总面积为 800 m^2 的样地中，共记录了维管植物 46 科 76 属 83 种(含种下单位)，以兰科(16 种)、水龙骨科(5 种)和大戟科(4 种)等为优势. 属的区系成分以泛热带分布(18 属)和热带亚洲(印度－马来西亚)分布(15 属)为主. 群落以灌木层(29 种)和草本层(45 种)为主，灌木层以海南大戟 *Euphorbia hainanensis* 为优势，草本层以玫瑰毛兰 *Eria rosea* 占优势；藤本层植物 9 种，以眼树莲 *Dischidia chinensis* 为优势. 生活型以矮高位芽(57 种)为主. 频度等级分布规律为 A > B > D > C > E，属于 A 级的种类最多，有 41 种，其中草本层 20 种. 与相同生境的海南大戟灌丛群落进行了比较，并对其有效保护提出了初步建议.

关键词： 海南；石灰岩；群落；海南凤仙花
中图分类号： Q948　　**文献标志码：** A　　**文章编号：** 1001-411X(2012)03-0361-07

Floristic and Ecological Characteristics of the Community with *Impatiens hainanensis* in Exianling Limestone Moutain, Hainan

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Abstract: Floristic and ecological characteristics of the community with *Impatiens hainanensis* were studied based on community investigation in Exianling limestone moutain, Hainan. The result showed there were 83 vascular species, subspecies, and varieties belonging to 76 genera and 46 families in 8 plots with a total area of 800 m^2. The dominant families were Orchidaceae(including 16 species), Polypodiaceae(5 species), and Euphorbiaceae(4 species). The distribution types of the genera in the community were mainly Pantropic(including 18 species) and Tropic Asia (India-Malasia) (15 species). The shrub layer (including 29 species) and herb layer(45 species) were the main component of the community. There were 9 species in the liana layer. The dominant species of shrub layer, herb layer, and liana layer were *Euphorbia hainanensis*, *Eria rosea*, and *Dischidia chinensis*, respectively. The life form in the community was dominated by nanophanerophytes(including 57 species). The order of the frequency distribution class was A > B > D > C > E. The A-level frequency was dominant(including 41 species). The community characteristics between *I. hainanensis* and *Eu. hainanensis* were compared. Some preliminary suggestions were also put forward on how to effectively protect *I. hainanensis*.

收稿日期： 2011-08-31
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基金项目： 海南省自然科学基金(311058)；海南大学热带作物种质资源保护与开发利用教育部重点实验室开放课题(2010hckled-11)；国家科技基础性工作专项(2008FY110400，2006FY110500-1)

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Key words: Hainan; limestone; community; *Impatiens hainanensis*

海南凤仙花 *Impatiens hainanensis* 是海南特有植物，该种由陈艺林[1]根据中国科学院华南植物研究所(即现中国科学院华南植物园)于1936年采自海南乐东报恩村(标本号: 刘心祈27038)、桃槐村(标本号: 刘心祈27493)的标本而发表. 2010年于胜祥等[2]在陈艺林的基础上对海南凤仙花的花部形态结构作了补充描述. 邢福武等[3]在20世纪90年代对海南植物区系及植物资源进行调查中发现，在海南昌江和东方等石灰岩地区山顶均有海南凤仙花的分布[3]. 作者等自2002年开始在海南石灰岩地区开展植物区系地理、群落学研究，已发表有关海南石灰岩植物分类、特有植物、外来植物、珍稀濒危植物、蕨类植物区系与资源、植被等研究结果[4-13]，期间对部分特有植物进行了前期研究[14]. 海南凤仙花在海南石灰岩地区多见于山顶裸露石灰岩缝隙，近年来由于人类活动的影响，海南凤仙花的种群数量和分布面积呈减少趋势，现已被列为海南省重点保护植物[15]. 在特殊的石灰岩生境中，海南凤仙花演化出一系列的适应机制以适应干旱环境，如肉质、膨大的根茎可以储藏大量的水分. 本研究以海南昌江俄贤岭石灰岩山地的样方调查为基础，分析了海南凤仙花所在群落的种类组成、区系成分、外貌和结构特征等，期望能为石灰岩山顶灌丛及其特有植物保护提供基础数据.

1 自然概况

海南石灰岩地区主要集中分布于该岛西部及南部，现已发现6个县(市)有石灰岩分布，包括儋州、白沙、昌江、东方、保亭、三亚等县市，其中在昌化江沿岸，昌江县七差乡王下与东方市东河镇南浪村交界处的俄贤岭是海南岛石灰岩分布面积最大，植被保存最好的地区，该地最高峰海拔达1 200 m.

海南岛石灰岩地区地处热带北缘，属于我国典型的干湿交替的热带季风气候区，由于其紧接东亚大陆南缘，受大陆气候的影响，亦具有明显的大陆性岛屿气候特点. 干湿季节明显，每年5—11月为雨季，12月至翌年4月为旱季. 年平均气温24.1～25.1 ℃，年平均降水量为1 646.9 mm，降水年际变化较大[16-17]. 海南石灰岩地区的土壤主要有棕色石灰土和黑色石灰土，前者通常分布在山体的下部坡缓、植被覆盖较好、石灰岩裸露较少的地方，后者常见于山顶石缝、石穴中，土层浅薄，有机质含量丰富，由于多分布于裸露石灰岩上，土壤比较干燥，多由植物体凋落物演变而成. 本文所研究的海南凤仙花群落位于海拔800～1 200 m的石灰岩山顶，主要由6 m以下的低矮灌丛种类组成.

2 研究方法

2.1 调查方法

在海南昌江俄贤岭石灰岩山顶(108°38′～109°17′ E，18°53′～19°30′ N)，以海南凤仙花为中心分别设置8个10 m×10 m的样方，由于海南凤仙花具有单株散生和石灰岩地区地形复杂等特点，故样方为纵向不规整排列，海拔为800～1 120 m，水平距离30～500 m.

样方内采用“每木记账法”，对高于2 m的立木进行每木调查，记录其种名、树高、胸径、冠幅. 灌木层记录种类、高度和冠幅. 草本层、藤本层记录种类、高度和盖度.

2.2 数据处理

重要值=相对频度+相对盖度+相对多度[18].

频度=某一种植物出现的样地数/所调查的样地总数.

相对频度=(某一种植物的频度/所有种的频度总和)×100%.

盖度=(地上部分垂直投影面积/样地面积)×100%.

相对盖度=(某一种植物的盖度/总盖度)×100%.

相对多度=(某一种植物的个体总数/同一生活型植物个体总数)×100%.

生活型系统参考 Raunkiaer[19]的分类方案，群落的频度划分为5个等级: A(1%～20%)、B(21%～40%)、C(41%～60%)、D(61%～80%)及E(81%～100%).

种子植物和蕨类植物属的分布区类型分别参考吴征镒等[20-22]和陆树刚[23]的划分方法.

3 结果与分析

3.1 群落的种类组成

根据在海南俄贤岭的样方调查统计，800 m^2 样地中记录到维管植物80种1变种2亚种，隶属于46科76属(表1)，其中蕨类植物6科10属12种，裸子植物1科1属1种，被子植物39科65属70种(含种下单位)，包括外来植物野茼蒿 *Crassocephalum crepidioides*. 双子叶植物在群落中占优势，有33科45属48种(含种下单位)，分别占该群落维管植物同等分类单位总数的71.74%(科)、59.21%(属)、57.83%

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(种及种下单位),单子叶植物有 6 科 20 属 22 种(含种下单位),占该群落维管植物同等分类单位总数的比例分别为 13.04%(科)、26.32%(属)、26.51%(种及种下单位).

表 1　海南俄贤岭海南凤仙花群落维管植物名录[1)]

Tab. 1　List of vascular plants in the community with *Impatiens hainanensis* in Exianling limestone moutain, Hainan

科号与科名	名称	重要值	科号与科名	名称	重要值
P. 4 卷柏科	卷柏 *Selaginella tamariscina*	4.87	229 木犀科	光蜡树 *Fraxinus griffithii*	10.13
P. 39 铁角蕨科	南方铁角蕨 *Asplenium belangeri*	7.03		青藤仔 *Jasminum nervosum*	16.40
	镰叶铁角蕨 *Asplenium falcatum*	4.69		海南木犀榄 *Olea hainanensis*	6.67
	大羽铁角蕨 *Asplenium neolaserpitiifolium*	1.94	230 夹竹桃科	鳝藤 *Anodendron affine*	17.60
P. 50 肾蕨科	肾蕨 *Nephrolepis cordifolia*	5.85	231 萝藦科	眼树莲 *Dischidia chinensis*	111.31
P. 52 骨碎补科	大叶骨碎补 *Davallia formosana*	6.43		荷秋藤 *Hoya griffithii*	12.83
P. 56 水龙骨科	抱树莲 *Drymoglossum piloselloides*	1.60		铁草鞋 *Hoya pottsii*	15.10
	伏石蕨 *Lemmaphyllum microphyllum*	1.34	232 茜草科	香港大沙叶 *Pavetta hongkongensis*	2.30
	星蕨 *Microsorum punctatum*	4.24	238 菊科	野茼蒿 *Crassocephalum crepidioides*	1.26
	海南假瘤蕨 *Phymatopteris hainanensis*	4.65		白子菜 *Gynura divaricata*	17.06
	阔鳞瘤蕨 *Phymatosorus hainanensis*	2.21		千里光 *Senecio scandens*	3.35
P. 57 槲蕨科	栎叶槲蕨 *Drynaria quercifolia*	3.25	250 茄科	海南茄 *Solanum procumbens*	2.82
G. 1 苏铁科	海南苏铁 *Cycas hainanensis*	11.62	256 苦苣苔科	烟叶唇柱苣苔 *Chirita heterotricha*	16.52
24 马兜铃科	多型叶马兜铃 *Aristolochia polymorpha*	25.43		海南蛛毛苣苔 *Paraboea hainanensis*	2.73
28 胡椒科	石蝉草 *Peperomia blanda*	3.30	257 紫葳科	美叶菜豆树 *Radermachera frondosa*	8.43
42 远志科	坝王远志 *Polygala bawanglingensis*	4.24	259 爵床科	假杜鹃 *Barleria cristata*	1.72
45 景天科	火焰草 *Sedum stellariifolium*	1.92		枪刀药 *Hypoestes purpurea*	2.97
71 凤仙花科	海南凤仙花 *Impatiens hainanensis*	12.24		海南赛爵床 *Justicia hainanensis*	1.46
104 秋海棠科	盾叶秋海棠 *Begonia peltatifolia*	19.97	264 唇形科	肉叶鞘蕊花 *Coleus carnosifolius*	3.09
128 椴树科	毛果扁担杆 *Grewia eriocarpa*	2.58	290 姜科	毛姜花 *Hedychium villosum*	1.87
136 大戟科	银叶巴豆 *Croton cascarilloides*	3.06	293 百合科	天门冬 *Asparagus cochinchinensis*	10.33
	海南大戟 *Euphorbia hainanensis*	51.48	302 天南星科	狮子尾 *Rhaphidophora hongkongensis*	15.10
	石岩枫 *Mallotus repandus*	10.76	313 龙舌兰科	海南龙血树 *Dracaena cambodiana*	13.66
	云南野桐 *Mallotus yunnanensis*	3.31	326 兰科	多花脆兰 *Acampe rigida*	5.22
147 苏木科	菱果羊蹄甲 *Bauhinia scandens* var. *horsfieldii*	71.64		芳香石豆兰 *Bulbophyllum ambrosia*	17.47
148 蝶形花科	印度崖豆藤 *Millettia pulchra*	5.90		流苏贝母兰 *Coelogyne fimbriata*	9.57
151 金缕梅科	蚊母树 *Distylium racemosum*	4.03		硬叶兰 *Cymbidium mannii*	1.60
163 壳斗科	坝王栎 *Quercus bawanglingensis*	16.98		昌江石斛 *Dendrobium changjiangense*	4.15
167 桑科	榕树 *Ficus microcarpa*	15.49		密花石斛 *Dendrobium densiflorum*	1.26
	斜叶榕 *Ficus tinctoria* subsp. *gibbosa*	8.74		玫瑰毛兰 *Eria rosea*	46.44
169 荨麻科	苎麻 *Boehmeria nivea*	7.15		流苏金石斛 *Flickingeria fimbriata*	3.42
	盾叶冷水花 *Pilea peltata*	6.44		丛生羊耳蒜 *Liparis cespitosa*	6.43
190 鼠李科	雀梅藤 *Sageretia thea*	3.06		长茎羊耳蒜 *Liparis viridiflora*	31.63
191 胡颓子科	角花胡颓子 *Elaeagnus gonyanthes*	2.30		钗子股 *Luisia morsei*	1.53
193 葡萄科	厚叶崖爬藤 *Tetrastigma pachyphyllum*	20.66		海南蝴蝶兰 *Phalaenopsis hainanensis*	1.41
194 芸香科	假黄皮 *Clausena excavata*	2.06		火焰兰 *Renanthera coccinea*	1.53
	豆叶九里香 *Murraya euchrestifolia*	4.24		寄树兰 *Robiquetia succisa*	1.75
200 槭树科	紫果槭 *Acer cordatum*	2.79		矮柱兰 *Thelasis pygmaea*	3.03
212 五加科	鹅掌藤 *Schefflera arboricola*	44.74		纯色万代兰 *Vanda subconcolor*	5.22
222 山榄科	铁榄 *Sinosideroxylon pedunculatum*	3.03	332 禾本科	水蔗草 *Apluda mutica*	9.89
223 紫金牛科	肉根紫金牛 *Ardisia crassinervosa*	19.80		簕竹 *Schizostachyum pseudolima*	10.12
228 马钱科	灰莉 *Fagraea ceilanica*	6.32			

1) 样地总面积 800 m^2; 蕨类植物按秦仁昌[24]系统,裸子植物按郑万钧[25]系统,被子植物按 Hutchinson[26-27]系统; 科号为该种植物所隶属科在各系统中的编号.

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组成群落的46科植物中,33科仅含1种,占总科数的71.74%;兰科植物较多,有16种,占总种数的19.28%;水龙骨科和大戟科分别有5种和4种.海南凤仙花所处群落的优势科见表2.

表2 海南凤仙花所在群落优势科(≥3种)

Tab.2 Dominant families in the community with *Impatiens hainanensis* (≥3 species)

科名	所含属数	占总属数比例/%	所含种数	占总种数比例/%
兰科	14	18.42	16	19.28
水龙骨科	5	6.58	5	6.02
大戟科	3	3.95	4	4.82
木犀科	3	3.95	3	3.61
萝藦科	2	2.63	3	3.61
菊科	3	3.95	3	3.61
爵床科	3	3.95	3	3.61
铁角蕨科	1	1.32	3	3.61

3.2 群落所含属的区系性质

根据吴征镒等[20-22]和陆树刚[23]对中国植物属的分布区类型划分,组成海南凤仙花所在群落的75属(除去外来的野茼蒿属 *Crassocephalum*)维管植物以泛热带分布为主,达18属,占除世界分布外属数的26.47%,包括紫金牛属 *Ardisia*、羊蹄甲属 *Bauhinia*、秋海棠属 *Begonia*、大戟属 *Euphorbia*、凤仙花属 *Impatiens* 等;其次是热带亚洲(印度-马来西亚)分布属,有15属,占除世界分布外属数的22.06%,包括唇柱苣苔属 *Chirita*、贝母兰属 *Coelogyne*、石斛属 *Dendrobium*、蛛毛苣苔属 *Paraboea*、钗子股属 *Luisia*、火焰兰属 *Renanthera* 等;北温带分布属在该群落也有少量分布,有4属,占除世界分布外属数的5.88%,包括槭属 *Acer*、胡颓子属 *Elaeagnus*、梣属 *Fraxinus* 和栎属 *Quercus* 等(表3).

表3 海南凤仙花所在群落维管植物属的区系性质

Tab.3 Distribution types of the genera in the community with *Impatiens hainanensis*

分布区类型	属数	所占比例/%
1 世界分布	7	
2 泛热带分布	18	26.47
3 热带亚洲和热带美洲间断	1	1.47
4 旧世界热带分布	10	14.71
5 热带亚洲至热带大洋洲	10	14.71
6 热带亚洲至热带非洲	6	8.82
7 热带亚洲(印度-马来西亚)分布	15	22.06
8 北温带分布	4	5.88
9 东亚和北美洲间断分布	1	1.47
12 地中海区、西亚至中亚分布	1	1.47
14 东亚(东喜马拉雅-日本)分布	2	2.94
合计	75	100.00

3.3 群落的外貌

根据 Raukiaer[19] 生活型分类系统绘制生活型谱(表4).由表4可见,海南凤仙花群落以矮高位芽为主,有57种,占总种数的68.67%,包括海南凤仙花、坝王远志 *Polygala bawanglingensis*、钗子股 *Luisia morsei*、昌江石斛 *Dendrobium changjiangense*、大叶骨碎补 *Davallia formosana*、盾叶秋海棠 *Begonia peltatifolia*、鹅掌藤 *Schefflera arboricola*、海南大戟 *Euphorbia hainanensis* 和海南茄 *Solanum procumbens* 等中层植物;其次为小高位芽和藤本高位芽,均为9种,占总种数的10.84%,小高位芽包括坝王栎 *Quercus bawanglingensis*、光蜡树 *Fraxinus griffithii*、美叶菜豆树 *Radermachera frondosa*、榕树 *Ficus microcarpa* 和铁榄 *Sinosideroxylon pedunculatum* 等上层树种,藤本高位芽包括多型叶马兜铃 *Aristolochia polymorpha*、眼树莲 *Dischidia chinensis*、菱果羊蹄甲 *Bauhinia scandens* var. *horsfieldii*、天门冬 *Asparagus cochinchinensis* 和狮子尾 *Rhaphidophora hongkongensis* 等层间植物.

表4 海南凤仙花所在群落维管植物生活型谱

Tab.4 Life form spectrum of vascular plants in the community with *Impatiens hainanensis*

生活型	种数	占总种数比例/%
小高位芽	9	10.84
矮高位芽	57	68.67
藤本高位芽	9	10.84
地上芽	5	6.02
一年生	3	3.61

3.4 群落的垂直结构

海南俄贤岭山顶的海南凤仙花所在群落以低矮灌丛为主,且分布较稀疏,灌木层植物有29种,193株.灌木层植物重要值由大到小排列见表5.灌木层高度在0.5~6.0 m之间,斜叶榕 *Ficus tinctoria* subsp. *gibbosa* 虽然相对较高,但胸径在5 cm以下,且呈匍匐抱石状.海南大戟占优势,其次是鹅掌藤、肉根紫金牛 *Ardisia crassinervosa* 和坝王栎等,青藤仔 *Jasminum nervosum*、榕树、海南龙血树 *Dracaena cambodiana* 和印度崖豆藤 *Millettia pulchra* 重要值也较大,海南茄、紫果槭 *Acer cordatum*、角花胡颓子 *Elaeagnus gonyanthes* 和假黄皮 *Clausena excavata* 等重要值相对较小.

草本层植物有45种,1 372株,其种数和株数均比灌木层多,多呈块状丛生在树干或山顶岩石缝隙荫蔽处,多具肉质器官,生命力极其顽强.草本层植物重要值由大到小排列见表6,草本层高度在0.05~1.30 m之间.以玫瑰毛兰 *Eria rosea* 为优势,其次是长茎羊耳蒜 *Liparis viridiflora*、盾叶秋海棠和芳香石

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豆兰 *Bulbophyllum ambrosia* 等,海南凤仙花和流苏贝母兰 *Coelogyne fimbriata* 重要值也较大,海南蝴蝶兰 *Phalaenopsis hainanensis*、火焰兰 *Renanthera coccinea* 和海南赛爵床 *Justicia hainanensis* 等重要值相对较小.

表 5　海南凤仙花所在群落灌木层植物的重要值

Tab. 5　Importance values of species in shrub layer in the community with *Impatiens hainanensis*

植物名称	株数	平均高度/m	相对多度/%	相对频度/%	相对盖度/%	重要值
海南大戟	54	0.50	27.98	10.39	13.11	51.48
鹅掌藤	27	1.50	13.99	10.39	20.39	44.77
肉根紫金牛	13	0.40	6.74	10.39	2.67	19.80
坝王栎	4	2.80	2.07	5.19	9.71	16.98
青藤仔	11	1.00	5.70	7.79	2.91	16.40
榕树	8	1.30	4.15	6.49	4.85	15.49
海南龙血树	9	1.20	4.66	3.90	5.10	13.66
海南苏铁	6	1.00	3.11	3.90	4.61	11.62
石岩枫	7	1.20	3.63	5.19	1.94	10.76
光蜡树	5	2.80	2.59	3.90	3.64	10.13
箣竹	10	4.00	5.18	1.30	3.64	10.12
斜叶榕	5	6.00	2.59	1.30	4.85	8.74
美叶菜豆树	5	1.90	2.59	3.90	1.94	8.43
苎麻	3	0.80	1.55	3.90	1.70	7.15
海南木犀榄	1	5.00	0.52	1.30	4.85	6.67
灰莉	5	1.30	2.59	1.30	2.43	6.32
印度崖豆藤	2	1.80	1.04	3.90	0.97	5.90
豆叶九里香	1	1.70	0.52	1.30	2.43	4.24
蚊母树	2	4.50	1.04	1.30	1.70	4.03
云南野桐	2	1.50	1.04	1.30	0.97	3.31
雀梅藤	2	1.20	1.04	1.30	0.73	3.06
银叶巴豆	2	1.50	1.04	1.30	0.73	3.06
铁榄	1	3.50	0.52	1.30	1.21	3.03
海南茄	2	1.50	1.04	1.30	0.49	2.82
紫果槭	1	1.30	0.52	1.30	0.97	2.79
毛果扁担杆	2	0.50	1.04	1.30	0.24	2.58
角花胡颓子	1	1.80	0.52	1.30	0.49	2.30
香港大沙叶	1	1.50	0.52	1.30	0.49	2.30
假黄皮	1	0.60	0.52	1.30	0.24	2.06

藤本层植物有 9 种,44 株,其种数和株数比灌木层、草本层相对较少,多缠绕、攀爬在树干或伏生在山顶石壁处. 藤本层植物重要值由大到小排列见表 7,藤本层高度在 0.6 ~ 1.5 m. 以眼树莲为优势,其次是菱果羊蹄甲、多型叶马兜铃 *Aristolochia polymorpha* 和厚叶崖爬藤 *Tetrastigma pachyphyllum* 等.

3.5　群落的频度分析

海南凤仙花所在群落频度等级分析结果见表 8. 该群落 A 级的种类最多,有 41 种,占总种数的 49.40%,

表 6　海南凤仙花所在群落草本层植物的重要值

Tab. 6　Importance values of species in herb layer in the community with *Impatiens hainanensis*

植物名称	株数	平均高度/m	相对多度/%	相对频度/%	相对盖度/%	重要值
玫瑰毛兰	340	0.30	24.78	4.00	17.66	46.44
长茎羊耳蒜	240	0.27	17.49	3.00	11.13	31.63
盾叶秋海棠	70	0.31	5.10	7.00	7.87	19.97
芳香石豆兰	130	0.17	9.48	3.00	4.99	17.47
白子菜	59	0.51	4.30	7.00	5.76	17.06
烟叶唇柱苣苔	58	0.28	4.23	5.00	7.29	16.52
海南凤仙花	16	0.39	1.17	8.00	3.07	12.24
水蕉草	45	0.87	3.28	2.00	4.61	9.89
流苏贝母兰	48	0.20	3.50	3.00	3.07	9.57
南方铁角蕨	21	0.33	1.53	3.00	2.50	7.03
盾叶冷水花	32	0.30	2.33	2.00	2.11	6.44
丛生羊耳蒜	35	0.30	2.55	1.00	2.88	6.43
大叶骨碎补	16	0.93	1.17	2.00	3.26	6.43
肾蕨	7	0.38	0.51	4.00	1.34	5.85
纯色万代兰	12	0.40	0.87	3.00	1.34	5.22
多花脆兰	12	0.43	0.87	3.00	1.34	5.22
卷柏	21	0.40	1.53	2.00	1.34	4.87
镰叶铁角蕨	10	0.30	0.73	3.00	0.96	4.69
海南假瘤蕨	10	0.45	0.73	2.00	1.92	4.65
星蕨	15	0.40	1.09	2.00	1.15	4.24
坝王远志	7	0.40	0.51	2.00	1.73	4.24
昌江石斛	30	0.30	2.19	1.00	0.96	4.15
流苏金石斛	20	0.30	1.46	1.00	0.96	3.42
千里光	8	1.05	0.58	2.00	0.77	3.35
石蝉草	10	0.15	0.73	2.00	0.58	3.30
栎叶槲蕨	4	0.58	0.29	2.00	0.96	3.25
肉叶鞘蕊花	7	0.40	0.51	2.00	0.58	3.09
矮柱兰	20	0.10	1.46	1.00	0.58	3.03
枪刀药	8	0.85	0.58	2.00	0.38	2.97
海南蛛毛苣苔	8	0.30	0.58	1.00	1.15	2.73
阔鳞瘤蕨	6	0.35	0.44	1.00	0.77	2.21
大羽铁角蕨	5	0.70	0.36	1.00	0.58	1.94
火焰草	10	0.10	0.73	1.00	0.19	1.92
毛姜花	4	1.30	0.29	1.00	0.58	1.87
寄树兰	5	0.40	0.36	1.00	0.38	1.75
假杜鹃	2	0.30	0.15	1.00	0.58	1.72
抱树莲	3	0.60	0.22	1.00	0.38	1.60
硬叶兰	3	0.50	0.22	1.00	0.38	1.60
钗子股	2	0.30	0.15	1.00	0.38	1.53
火焰兰	2	0.60	0.15	1.00	0.38	1.53
海南赛爵床	1	1.30	0.07	1.00	0.38	1.46
海南蝴蝶兰	3	0.05	0.22	1.00	0.19	1.41
伏石蕨	2	0.50	0.15	1.00	0.19	1.34
密花石斛	1	0.40	0.07	1.00	0.19	1.26
野茼蒿	1	0.30	0.07	1.00	0.19	1.26

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表7 海南凤仙花所在群落藤本层植物的重要值

Tab.7 Importance values of species in liana layer in the community with *Impatiens hainanensis*

植物名称	株数	平均高度/m	相对多度/%	相对频度/%	相对盖度/%	重要值
眼树莲	26	1.24	59.09	22.22	30.00	111.31
菱果羊蹄甲	5	1.18	11.36	27.78	32.50	71.64
多型叶马兜铃	3	1.00	6.82	11.11	7.50	25.43
厚叶崖爬藤	2	1.10	4.55	11.11	5.00	20.66
鳝藤	2	0.80	4.55	5.56	7.50	17.60
狮子尾	2	0.60	4.55	5.56	5.00	15.10
铁草鞋	2	0.80	4.55	5.56	5.00	15.10
荷秋藤	1	1.50	2.27	5.56	5.00	12.83
天门冬	1	0.60	2.27	5.56	2.50	10.33

表8 海南凤仙花所在群落不同层次各频度等级的种类统计

Tab.8 Statistics of frequency class in the community with *Impatiens hainanensis*

层次	各频度等级的种数/种				
	A	B	C	D	E
灌木层	16	8	2	3	0
草本层	20	19	2	3	1
藤本层	5	2	1	1	0
合计	41	29	5	7	1

主要集中在草本层,有20种;B级的种类有29种,占总种数的34.94%;E级仅海南凤仙花1种.灌木层以A级的种类最多,有16种,占总种数的19.28%,包括豆叶九里香 *Murraya euchrestifolia*、海南茄、灰莉 *Fagraea ceilanica*、雀梅藤 *Sageretia thea*、铁榄和云南野桐 *Mallotus yunnanensis* 等.草本层以A级的种类最多,有20种,占总种数的24.10%,包括矮柱兰 *Thelasis pygmaea*、钗子股、海南蛛毛苣苔 *Paraboea hainanensis*、火焰草和毛姜花 *Hedychium villosum* 等;其次是B级,有19种,占总种数的22.89%,包括多花脆兰 *Acampe rigida*、芳香石豆兰、镰叶铁角蕨 *Asplenium falcatum* 和南方铁角蕨 *Asplenium belangeri* 等.藤本层以A级的种类最多,有5种,占总种数的6.02%,包括荷秋藤 *Hoya griffithii*、狮子尾和天门冬等.该群落的频度等级分布规律为A>B>D>C>E,可见大部分种类出现的频度较低.

3.6 群落中海南凤仙花种群大小及分布特征

海南凤仙花在800 m^2 样地群落中记录有16株,占群落中草本植物总株数的1.17%;重要值为12.24,在草本层中排在第7位,低于玫瑰毛兰(重要值为46.44,下同)、长茎羊耳蒜(31.63)、盾叶秋海棠(19.97)、芳香石豆兰(17.47)、白子菜 *Gynura divaricata*(17.06)及烟叶唇柱苣苔 *Chirita heterotricha*(16.52).

海南凤仙花单株散生于俄贤岭裸露石灰岩山顶,个体间距在10~500 m,调查中较少见到幼苗.

4 讨论与结论

海南凤仙花所在群落800 m^2 样地中记录到46科76属83种(包括种下单位).单种科有33科,优势科包括兰科(16种)、水龙骨科(5种)和大戟科(4种)等.属的区系成分以泛热带分布为主(18属),其次是热带亚洲(印度-马来西亚)分布属(15属),也有少量温带性质成分(4属).该群落以矮高位芽为主(57种),其次是小高位芽和藤本高位芽(各9种).群落结构分层不明显,缺少乔木层,灌木层植物有29种,以海南大戟为优势,其次是鹅掌藤、肉根紫金牛和坝王栎等;草本层植物有45种,以玫瑰毛兰为优势,其次是长茎羊耳蒜、盾叶秋海棠和芳香石豆兰等;藤本层植物有9种,以眼树莲为优势,其次是菱果羊蹄甲、多型叶马兜铃和厚叶崖爬藤等.海南凤仙花群落的频度等级分布规律为A>B>D>C>E,属于A级的种类最多,有41种,其中草本层20种;B级的种类有29种;E级仅海南凤仙花1种.

海南凤仙花所在群落植物分布稀疏,种类较少,为低矮灌丛,这可能与其处在热带石灰岩裸露山顶土壤浅薄、高温、风大等环境因素有关.该群落优势类群多数个体附生在树干或岩石缝隙,以灌木和草本植物为主,群落外貌属于石灰岩灌丛类型[28],这与云南西双版纳石灰岩山顶矮林外貌相近,但稍有不同[29].与海南俄贤岭石灰岩特有植物海南大戟灌丛群落[14]生境相同,样方种类、物种数量、优势科、区系性质、群落结构等均相似;灌木层优势种海南大戟、鹅掌藤均排在前2位,海南大戟群落青藤仔、雀梅藤排在第3、4位,而海南凤仙花群落排在第3、4位的是肉根紫金牛和坝王栎;矮高位芽在海南凤仙花群落中所占比例明显高于海南大戟群落,且后者存在中高位芽植物,其小高位芽植物所占比例也较高;海南凤仙花群落频度以A级为主,而海南大戟则以B级为主,缺少A级,表明前者个体在群落中的均匀程度低于后者.

海南凤仙花目前仅在海南昌江、东方、乐东、白沙等地发现有分布,野外保存数量甚为稀少,分布区狭窄、群落结构单一等特点对其实现可持续天然更新带来一定难度.此外,海南俄贤岭位于少数民族聚

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集地区,经济、教育尚为落后,药材采集和木材偷盗目前仍无法杜绝,早前收集石斛类药材和花梨木 *Dalbergia odorifera* 导致山顶矮林植物遭受了较为严重的破坏. 海南俄贤岭省级自然保护区的成立对海南凤仙花等珍稀植物的就地保护起到了很好的促进作用,但仍需继续加强监管,处理好与周边社区的关系,切实协调好保护与发展的矛盾. 对海南凤仙花的研究工作仍有待进一步深入,其生态适应性、生殖生物学、保护生物学、种质资源学等方面均有迫切需要解决的问题,但在科研取材时也需特别注意保护好野外植株,尽量不要挖取,避免对其造成破坏.

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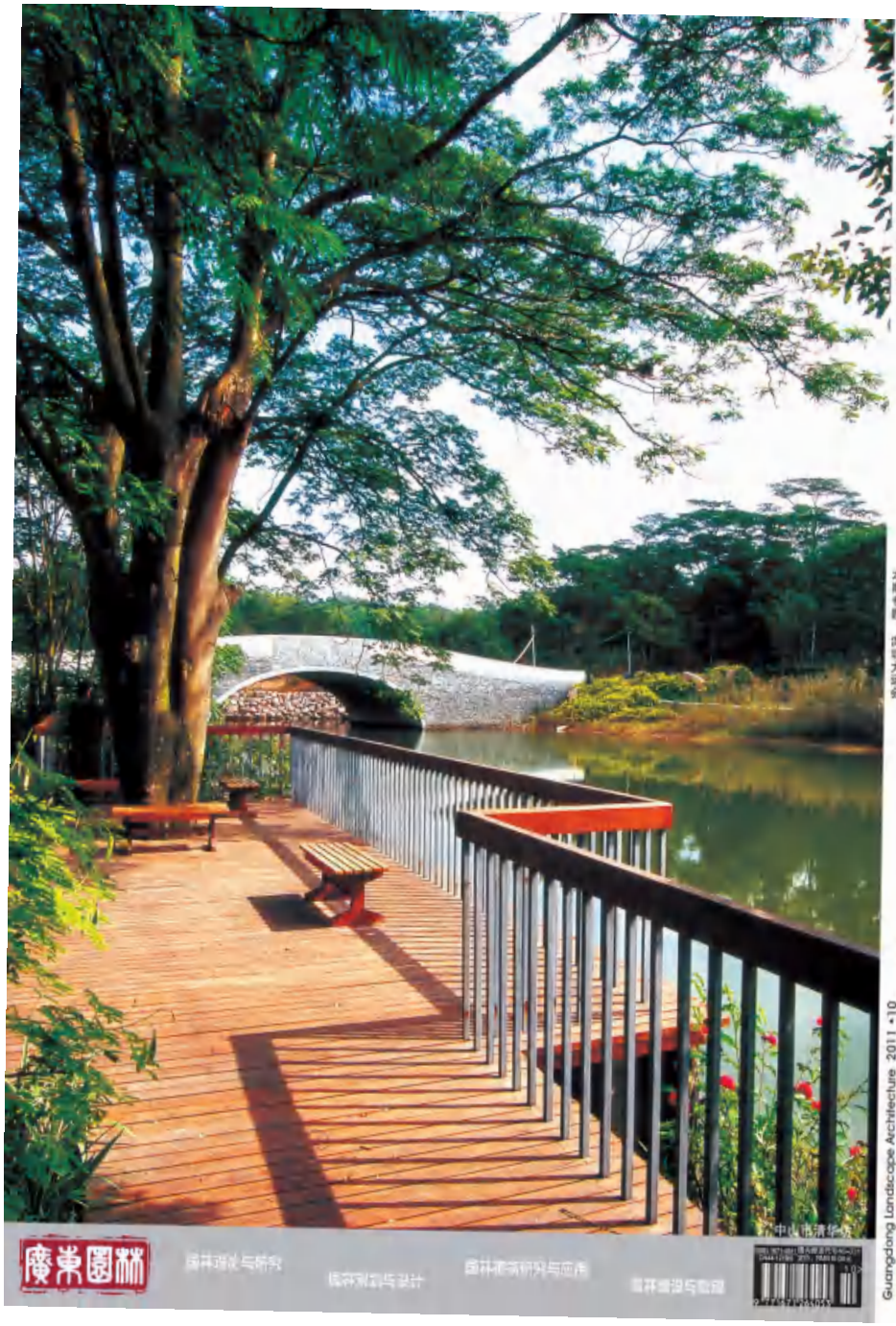
华南农业大学学报
Huanan Nongye Daxue Xuebao
(季刊,1959 年创刊,1980 年复刊)
第 33 卷第 3 期　2012 年 7 月

Journal of South China Agricultural University
(Quarterly, Started 1959, Resumed 1980)
Vol. 33 No. 3 Jul. 2012

主管单位:华南农业大学
主办单位:华南农业大学
主　　编:陈晓阳
编辑出版:华南农业大学学报编辑部
(广州五山,邮政编码:510642)
网　　址:http://hnnyzr.alljournalsystem.com
电子邮件:journal@scau.edu.cn
电　　话:(020)85280069
印刷单位:广州市锐先印刷有限公司
发行订购:华南农业大学学报编辑部
国外发行:中国国际图书贸易总公司
(中国国际书店)北京 399 信箱

Responsible Institution:South China Agricultural University
Sponsor: South China Agricultural University
Chief Editor:CHEN Xiaoyang
Edited and Published by Editorial Department, Journal of South China Agricultural University
Address:Wushan, Guangzhou, 510642, China
Website:http://hnnyzr.alljournalsystem.com
E-mail:journal@scau.edu.cn
Tel: (86-20)85280069
Distributed by China International Book Trading Corporation(P. O. Box 399 Beijing, China)

公开发行　　刊号:ISSN 1001-411X / CN 44-1110/S　　定价:10.00 元



廣東園林 双月刊 2011年 第5期 总第144期

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1979年创刊 Vol. 33总第144期 双月刊

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东莞园林植物及其应用现状研究 *

A Study on Application of the Landscape Plants in Dongguan City

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摘要：文章实地调查了东莞市 58 个代表性园林绿地中园林植物种类及其配置现状，共记录了 810 种（含种下单位）维管植物，隶属于 136 科、437 属。其中，外来植物占植物总种数 53.21%，仅 10.12% 为东莞原生植物。从植物种类来看，东莞园林植物以乔木树种最丰富，占总种数的 41.73%，其次为草本植物，约占 32.59%，藤本植物较少；从观赏特性来看，东莞园林植物以观形植物为主，占总种数的 55.80%；彩叶植物也较丰富，占总种数的 20.12%；观果和香花类植物相对较少。通过分析园林植物组成特点，文章探讨了东莞园林绿地植物应用特点及存在问题，并提出改进建议。

关键词：东莞；园林绿地；植物配置；应用现状；广东园林
中图分类号：S731.2
文献标识码：A
文章编号：1671-2641（2011）05-0059-07
收稿日期：2010-11-30
修回日期：2011-05-05

Abstract: A total of 810 vascular species of landscape plants belonging to 136 families and 437 genera were recorded after field survey on the 58 representative green-lands in Dongguan City. 53.21% are exotic and only 10.12% among these species are native. In habitus of plant species, 41.73% are trees and 32.59% are herbal plants in the Landscape Plants in Dongguan. And climbers are a fat lot. In terms of aesthetic enjoyment, 55.80% of the plants possess elegant shape and 20.12% are color foliage. The plants with ornamental fruits and scented flowers are less. Through the analysis of the plant composition, the species application status and deficiencies of the landscape plants in Dongguan City were discussed. Some suggestions about the application of landscape plants were put forward.

Key words : Dongguan; Green-land; Landscape plants; Applications status;Guangdong landscape architecture

东莞市是广东省城市化建设和工业化发展较快的城市之一。东莞市政府在城市建设过程中也非常重视城市园林绿地建设，并取得了显著成果。但目前有关东莞市园林植物方面的研究较少，仅见东莞古树、行道树评价等方面的研究报告[1~8]。本文在东莞园林植物资源调查的基础上，分析了东莞市园林绿地植物资源的利用状况，拟为东莞市及其邻近地区的城乡园林绿化建设与可持续发展提供参考资料。

1 研究地概况

东莞市（北纬 22°39′~23°09′，东经 113°31′~114°15′）位于广东省中南部，东江下游，南邻珠江口，地势东南高西北低，西北部是东江三角洲河网区，北部和西南部为冲积平原。东莞市陆地面积约 2465 km^2，年平均气温 22.1℃，年平均降水量 1800 mm，属亚热带季风气候，日照充足，雨量充沛，季风明显。地带性土壤类型为赤红壤，发育母岩主要有花岗岩、砂页岩、沉积岩等[9]。

2 研究内容与方法

在文献资料收集的基础上，2007 年 8 月至 2008 年 6 月期间，在东莞市选择了 58 个代表性园林绿地进行了实地调查。调查点遍及东莞市区各镇，绿地类型包括公园绿地（人民公园、黄旗山城市公园、黄旗山、金鳌洲公园、坝头公园、东莞可园、虎英郊野公园、榴花公园、长安郊野公园、塘厦公园、福神岗公园、体育公园、明珠花园、海月岩公园、麻涌、东莞市区等），广场绿地（旗峰广场、市行政广场、长安广场、桥头广场等），单位附属绿地（旧市府大院、桥头镇政府大院、东莞中学等），居住区绿地（新世纪豪园、东骏豪苑、新世纪丽江豪园、月湖居、愉景花园、星河传说、李城山庄、莲花山庄、三正半山豪苑、银湖山庄、名仕居、海逸豪庭、莲湖度假村、凯达华庭、正丰豪苑等），道路绿地（东莞大道全段、东江大道细村段、东江大道可园段、樟村段、塘厦迎宾路、长青路带状公园、东城中路、东城东路等），酒店绿地（长安国际酒店、三正半山酒店、嘉华大酒店、喜来登大酒店等），湿地与河涌（三百亩莲湖、莲湖公园、石排湿地公园、企石东江金海岸体育长廊、石龙金沙湾、石碣滨江公园、

* 基金项目：东莞市林业局“东莞植物资源调查”项目资助。

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高埗亲水公园、中堂滨江公园）。调查内容包括园林植物的种类、生长状况、配置方式和应用情况等信息。

3 结果与分析

3.1 东莞园林植物的种类和习性

在所调查的东莞市 58 个园林绿地中，共记录了 810 种维管植物，隶属于 136 科 437 属（表 1）。其中蕨类植物有 9 种，隶属于 6 科 7 属；裸子植物有 26 种及种下单位，隶属于 7 科 15 属；被子植物 775 种及种下单位，隶属于 123 科 415 属。

东莞园林绿地所应用的植物以乔木种类为主，占总种数的 41.73%；其次是草本植物，占总种数的 32.59%；藤本植物种类相对较少，仅占总种数的 4.44%。在乔木植物中，92.90% 的种类为被子植物，裸子植物只有 22 种，占乔木种数 6.51%（表 2）。

3.2 东莞园林常见乔木及其主要配置方式

在东莞园林绿地中，共记录了 22 种（含种下单位）常见乔木树种（表 3），其出现频率均在 30% 以上，出现频率排在前四位的分别是鸡蛋花、垂叶榕、木棉和凤凰木。

3.3 东莞园林常见灌木及其主要配置方式

在东莞园林绿地中共记录了 23 种（含种下单位）常见灌木类园林植物，主要配置方式有列植、对植和丛植（表 4）。出现频率排在前两位的分别是苏铁、含笑，其余种类出现的频率均低于 30%。

3.4 东莞园林常见草本植物及其主要配置方式

在东莞园林绿地中，共记录了 44 种常见草本植物种类（含种下单位）（表 5）。陆域绿地中常见草本植物主要有肾蕨、三色堇、长寿花、大叶红草、千日红、紫萼距花和蔓花生等。水域环境应用植物主要为荷花和睡莲等。配置方式主要为群植和丛植。

3.5 东莞园林常见竹类植物及其主要配置方式

东莞常见观赏竹类植物有 10 种（含种下单位）（表 6）。出现频率最高的种类依次为黄金间碧玉竹、大佛肚竹和小琴丝竹。种植方式有列植、散植和丛植。

3.6 东莞园林常见藤本植物及其主要配置方式

东莞园林中所应用的藤本植物较少，在调查样地中仅记录了 11 种（含种下单位）（表 7）。它们均为垂直绿化的良好材料，应用较广的种类为宝巾、花叶常春藤、金银花和炮仗花。除金银花和首冠藤为乡土植物外，其余均为外来引种或栽培植物。藤本植物的种植方式主要有散植和丛植。

3.7 东莞园林常见棕榈植物及其主要配置方式

棕榈科植物是具有热带风情的特色植物，在东莞园林中主要用作新建道路和广场绿化，常见有 21 种（含种下单位）（表 8），多为外来引进种类。

3.8 东莞园林的乡土植物与外来植物

本文“乡土植物”采用广义概念，即指原产于中国的植物。根据调查数据统计，在东莞园林绿地中所应用的 810 种园林植物中，53.21% 为外来植物，只有 10.12% 的植物为东莞原生植物（表 9）。

东莞园林植物以常绿植物为主，约占总种数的 90%，落叶植物仅占总种数的 10%。东莞园林注重各类观赏植物的应用。整体来看，各类观赏植物在东莞园林中的应用有以下特点：1）以观形植物为主，占总

表 1 东莞市园林植物树种科、属、种统计表

类别		科数	属数	种数（含种下等级）	占总种数比率（%）
蕨类植物		6	7	9	1.11
裸子植物		7	15	26	3.21
被子植物	双子叶植物	100	316	583	71.98
	单子叶植物	23	99	192	23.70
合计		136	437	810	100

表 2 东莞市园林植物的习性

类别	乔木种类	灌木种类	草本种类	藤本种类	合计
蕨类植物	2	0	7	0	9
裸子植物	22	4	0	0	26
被子植物	314	168	257	36	775
合 计	338	172	264	36	810
占总种数比率（%）	41.73	21.23	32.59	4.44	–

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表 3 东莞园林常见乔木的出现频率及主要配置方式

中文名	学名	科名	出现频率 (%)	配置方式
鸡蛋花	*Plumeria rubra 'Acutifolia'*	夹竹桃科	64.91	孤植、对植、丛植
垂叶榕	*Ficus benjamina*	桑科	63.16	孤植、列植、对植、丛植
木棉	*Bombax ceiba*	木棉科	56.14	孤植、对植
凤凰木	*Delonix regia*	苏木科	54.39	孤植、对植、丛植
樟树	*Cinnamomum camphora*	樟科	49.12	孤植、对植、列植
罗汉松	*Podocarpus macrophyllus*	罗汉松科	47.37	孤植、对植、列植
大叶紫薇	*Lagerstroemia speciosa*	千屈菜科	47.37	孤植、列植、对植、丛植
秋枫	*Bischofia javanica*	大戟科	47.37	孤植、列植
榕树	*Ficus microcarpa*	桑科	47.37	孤植、列植、对植、丛植
糖胶树	*Alstonia scholaris*	夹竹桃科	47.37	孤植、列植、对植、丛植
小叶榄仁	*Terminalia mantaly*	使君子科	45.62	孤植、列植、对植、丛植
尖叶杜英	*Elaeocarpus apiculatus*	杜英科	45.62	孤植、列植、对植
水石榕	*E. hainanensis*	杜英科	36.84	孤植、列植、丛植
白兰	*Michelia alba*	木兰科	45.61	孤植、列植、对植
蒲桃	*Syzygium jambos*	桃金娘科	42.11	孤植、列植、对植
阴香	*C. burmanii*	樟科	40.35	孤植、列植、对植、丛植
异叶南洋杉	*Araucaria heterophylla*	南洋杉科	38.60	孤植、列植、对植、丛植
垂柳	*Salix babylonica*	杨柳科	38.60	列植、丛植
紫檀	*Pterocarpus indicus*	蝶形花科	36.84	列植、对植
非洲楝	*Khaya senegalensis*	楝科	36.84	孤植、列植、对植
高山榕	*F. altissima*	桑科	35.09	孤植、列植、对植
芒果	*Mangifera indica*	漆树科	35.09	孤植、列植、对植

表 4 东莞园林常见灌木的出现频率（≥ 5%）及主要配置方式

中文名	学名	科名	出现频率 (%)	配置方式
苏铁	*Cycas revoluta*	苏铁科	70.18	孤植、列植
含笑	*M. figo*	木兰科	54.39	列植、丛植
海桐及其栽培变种	*Pittosporum tobira,* and its cultivars	海桐花科	29.82	列植、丛植
巴西野牡丹	*Tibouchina semidecandra*	野牡丹科	22.81	列植、群植、丛植
朱槿及其栽培变种	*Hibiscus rosa-sinensis,* and its cultivars	锦葵科	21.05	列植、群植、丛植
悬铃花	*Malvaviscus arboreus*	锦葵科	12.28	列植、群植、丛植
红桑及其栽培变种	*Acalypha wilkesiana,* and its cultivars	大戟科	12.28	列植、群植、丛植
变叶木及其栽培变种	*Codiaeum variegatum,* and its cultivars	大戟科	10.53	列植、群植、丛植
红背桂	*Excoecaria cochinchinensis*	大戟科	7.25	列植、群植、丛植
朱樱花	*Calliandra haematocephala*	含羞草科	5.26	列植、群植、丛植

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表 5 东莞园林常见草本植物的出现频率（≥ 5%）及主要配置方式

中文名	学名	科名	出现频率 (%)	配置方式
肾蕨	*Nephrolepis auriculata*	肾蕨科	50.88	群植、丛植
荷花及其栽培变种	*Nelumbo nucifera,* and its cultivars	睡莲科	28.07	群植、丛植
睡莲及其栽培变种	*Nymphaea tetragona* ,and its cultivars	睡莲科	19.3	群植、丛植
三色堇	*Viola tricolor,* and its variety	堇菜科	12.28	群植、丛植
长寿花	*Kalanchoe blossfeldiana*	景天科	12.28	群植、丛植
大叶红草	*Alternanthera dentata* ‘Ruliginosa’	苋科	8.77	群植、丛植
白苋草	*A. ficoides* 'Variegata'	苋科	8.77	群植、丛植
美洲虾钳菜及其栽培变种	*A. paronychioides,* and its cultivars	苋科	8.77	群植、丛植
凤尾鸡冠花	*Celosia cristata* ‘Plumosa’	苋科	7.02	群植、丛植
千日红	*Gomphrena globosa,* and its formae	苋科	7.02	群植、丛植
紫萼距花	*Cuphea articulata*	千屈菜科	5.26	群植、丛植

表 6 东莞园林常用竹类植物的出现频率（≥ 5%）及其配置方式

中文名	学名	出现频率 (%)	配置方式
黄金间碧玉竹	*Bambusa vulgaris* cv. Vittata	19.3	列植、群植、丛植
大佛肚竹	*B. vulgaris* 'Wamin'	14.04	列植、群植、丛植
小琴丝竹	*B. multiplex* 'Stripestem'	12.28	列植、群植、丛植
撑篙竹	*B. pervariabilis*	7.02	列植、群植、丛植
凤尾竹	*B. multiplex* 'Fernleaf'	5.26	列植、群植、丛植
黄金丽竹	*Schizostachyum brachycladum*	5.26	列植、群植、丛植

表 7 东莞园林常用藤本植物的出现频率（≥ 5%）及其配置方式

中文名	学名	科名	出现频率 (%)	配置方式
宝巾	*Bougainvillea glabra*	紫茉莉科	49.12	列植、丛植、群植
红毛宝巾	*Bougainvillea spectabilis* 'Laleritia'	紫茉莉科	8.77	列植、丛植、群植
花叶常春藤	*Hedera canariensis* 'Variegata'	五加科	24.56	列植、丛植
金银花	*Lonicera japonica*	忍冬科	21.05	列植、丛植、群植
炮仗花	*Pyrostegia venusta*	紫葳科	19.3	列植、丛植、群植
紫藤	*Wisteria sinensis*	蝶形花科	10.53	丛植、群植
绿萝	*Epipremnum Pinnatum*	天南星科	8.77	列植、丛植
异叶爬山虎	*Parthenocissus dalzielii*	葡萄科	5.26	列植、丛植、群植
红文藤	*Mondevilla×amabilis* 'Alice Du Pont'	夹竹桃科	5.26	丛植、群植

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表 8 东莞园林常用棕榈科植物的出现频率（≥ 5%）及其配置方式

中文名	学名	出现频率 (%)	配置方式
* 散尾葵	*Chrysalidocarpus lutescens*	66.67	列植、群植
蒲葵	*Livistona chinensis*	57.89	列植、对植、群植
* 大王椰子	*Roystonea regia*	54.39	列植、对植、群植
* 软叶刺葵	*Phoenix roebelenii*	45.62	列植、对植、群植
棕竹	*Rhapis excelsa*	43.86	列植、群植
* 短穗鱼尾葵	*Caryota mitis*	36.84	列植、群植
* 油棕	*Elaeis guineensis*	36.84	列植、对植、群植
* 国王椰子	*Ravenea rivularis*	29.82	列植、对植、群植
* 三药槟榔	*Areca triandra*	28.07	列植、群植
* 假槟榔	*Archontophoenix alexandrae*	26.32	列植、对植、群植
* 加那利海枣	*Phoenix canariensis*	26.32	列植、群植、孤植
* 酒瓶椰子	*Hyophorbe lagenicaulis*	24.56	列植、群植、孤植
* 丝葵	*Washingtonia filifera*	22.81	列植、群植、孤植
* 细叶棕竹	*R. gracilis*	19.3	列植、群植
* 银海枣	*P. sylvestris*	17.54	列植、群植、孤植
* 金山葵	*Syagrus romanzoffiana*	14.04	列植、群植、对植
* 三角椰子	*Neodypsis decaryi*	12.28	列植、群植
* 狐尾椰子	*Wodyetia bifurcata*	12.28	列植、群植
* 霸王棕	*Bismarckia nobilis*	8.77	列植、群植、孤植
* 观音棕竹	*R. humilis*	8.77	列植、群植
* 海枣	*P. dactylifera*	7.02	列植、群植

表 9 东莞园林的乡土植物与外来植物统计表

类别	原产地	种及种下单位数量	占总种数比例 %
本地植物	东莞	82	10.12
	东莞以外国内其他地区	297	36.67
外来植物	中国以外地区	431	53.21

种数的 55.80%；2）具有较丰富的彩叶（绿色以外）植物，占总种数的 20.12%；3）观花植物约占总种数的 17.9%，以小乔木和花灌木为主，花色以白色、红色和黄色为主，分别占观花植物的 40.0%、24.8% 和 35.2%，观果植物占总种数的 9.14%，香花类植物占总种数的 7.16%。

3.10 东莞园林植物的生长和病虫害危害情况

在东莞园林绿地中，大多数种类生长表现良好，但也有一些种类生长一般，个别种类生长较差，如荷花玉兰 *Magnolia grandiflora*、阳桃 *Averrhoa carambola* 和椰子 *Cocos nucifera* 等。导致生长不良的原因包括生长环境不适宜、养护管理措施不到位和病虫害危害等。有一些种类病虫害比较严重，如苏铁、白兰、阴香、紫薇、水翁、海南蒲桃 *Syzygium cumini*、榄仁树 *Terminalia catappa*、山杜英、黄槿、秋枫、刺桐及酒瓶椰子等。

3.11 东莞不同绿地类型园林植物应用特点

此次调查的 58 处绿地按其功能等可划分为不同类型，包括公园绿

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表 10 东莞不同绿地类型园林植物应用比较

序号	绿地类型	调查样数	植物种数变化范围（平均物种数 ± 变异系数）
1	公园绿地（含郊野公园）	16	17–268（74 ± 41）
2	居住区绿地	15	40–144（98 ± 42）
3	酒店附属绿地	4	38–99（68 ± 27）
4	道路绿地	8	6–93（59 ± 32）
5	广场绿地	4	22–79（51 ± 34）
6	单位附属绿地	3	26–44（45 ± 19）
7	湿地与河涌绿地	8	28–63（43 ± 18）
总计		58	6–268（63 ± 19）

地、广场绿地、道路绿地、居住区绿地、单位附属绿地、酒店附属绿地、湿地与河涌绿地等 7 种类型。整体来看，居住区绿地所应用的植物种类最丰富，其次是公园绿地和酒店附属绿地，道路绿地和广场绿地的物种较丰富，单位绿地、湿地与河涌绿地所应用的种类相对较少（表 10）。

东莞的公园绿地和广场绿地通常占地面积较大，自然环境条件较好，为许多园林植物的生长提供了良好的生态条件，因此物种丰富度较高。公园绿地多为树型美观、枝繁叶茂、花色鲜艳的景观植物，如凤凰木、秋枫、糖胶树、朱缨花、千日红、紫薇 *Lagerstroemia indica*、翅荚决明、洋紫荆 *Bauhinia blakeana*、刺桐 *Erythrina variegata*、橡胶榕 *Ficus elastica* 等较丰富。郊野公园均临山而建，多保存次生林恢复的乡土植物，如山苍子 *Litsea cubeba*、荷木 *Schima superba*、野牡丹 *Melastoma candidum*、山乌桕 *Sapium discolor* 等优良乡土观花、观叶植物；另有早期种植的速生经济树种，如柠檬桉 *Eucalyptus citriodora*、大叶桉 *E. robusta*、枫香 *Liquidambar formosana*、大叶相思 *Acacia auriculiformis* 及马尾松 *Pinus massoniana* 等。

道路绿地既要考虑到为行人遮荫，也涉及交通安全问题，因此所用乔木种类多为树体高大、树形通直、枝繁叶茂、枝下高较高的树种，阴香、榕树和凤凰木等是比较常见的道路绿地树种；下层多种植叶色、花色富于变化的灌木和时花，如海桐、朱槿、红花檵木、美洲虾钳菜、矮牵牛和沿阶草等。

东莞的居住区绿地多具有物种丰富、景观效果好、注重应用树形优美和色彩艳丽的观花植物的特点，居住区应用较多的树种有榕树、大叶紫薇、尖叶杜英、九里香、桂花等。别墅区多有私家花园，多种植名贵树种及果树，如罗汉松、黄皮 *Clausena lansium*、龙眼 *Dimocarpus longan*、荔枝 *Litchi chinensis* 及柑橘 *Citrus reticulata* 等。

湿地与河涌绿地多种植水生及滨水植物，如浮水植物睡莲 *Nymphaea tetragona*、水金英 *Hydrocleys nymphoides*、挺水植物荷花 *Nelumbo nucifera*、东方泽泻 *Alisma orientale*、水竹芋 *Thalia dealbata*，水黄皮 *Pongamia pinnata* 和垂柳等喜湿树木也常见应用。但与其他陆域绿地相比，湿地与河涌绿地植物种类丰富度较低。

本文调查的单位附属绿地包括东莞中学和政府大院，这些绿地以樟树、小叶榄仁、含笑及朱槿等遮荫效果好、花形美观芳香、无毒无刺且虫害少的植物较为常见。与其他绿地相比，物种相对较少。

东莞许多酒店附属绿地的绿地都非常注重环境的绿化。为了提供高贵、舒适的住宿和商务环境，星级酒店多种植名贵、奇特、外来热带树种，同时也有少量野外采挖、高价购进的乡土树木，如罗汉松、黑桫椤 *Alsophila podophylla*、金花茶 *Camellia nitidissima* 及五月茶 *Antidesma bunius* 等。

4 讨论

4.1 东莞园林植物种类及其应用特点

4.1.1 植物种类较为丰富，群落结构层次较丰富 东莞园林绿地植物丰富，在调查区共记录了 810 种（含种下单位）。应用频率较高的约有 200 种，以大戟科、苏木科、含羞草科、蝶形花科、棕榈科等热带、亚热带常绿树种较为丰富。在园林植物群落中注重不同习性植物的配置，通过中型乔木与灌木和草本的搭配，形成乔、灌、草相结合的多层植物群落结构。与邻近的广州市、佛山市、中山市和江门市等地相比，东莞市园林绿地所应用的植物种类丰富度低于广州市（1007 种）[10] 和中山市（962 种）[11]，但高于佛山市（338 种）[12 ~ 13] 和江门市（311 种）[14]。东莞市乔灌草种数比例为 1.66∶0.65∶1，乔木比例高于广州市（1.09∶0.67∶1），灌木比例与广州市 [10] 相近。而佛山市具有明显高的乔灌比（3.47∶1.57∶1）[12 ~ 13]。

4.1.2 植物配置形式多样，亚热带特色明显 东莞园林绿地的植物配置灵活多样，结合了西方规则式种植和东方自然式种植的特点。植物的配置能依据不同的地形和植物生态习性，按照适地适树的原则进行。园林绿地的植物配置既有鲜明的亚热带地域性特色，也有不同于小区或路段的特色变化。

4.1.3 乡土植物与外来植物并用，观

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赏效果好 东莞市园林绿地的植物丰富多样，既有观赏特点高的外来植物，近来也注重对乡土植物的应用，如榕树、秋枫、木棉、水石榕、尖叶杜英、山杜英、假苹婆 *Sterculia lanceolata* 和苹婆 *S. nobilis* 等具有典型南亚热带特色的乡土植物应用逐渐增加，这种中西结合的物种配置方式取得良好效果。

4.1.4 棕榈科植物较多 东莞园林绿地的热带、亚热带地域性特色也表现在棕榈科植物的应用。在道路、小区和公共服务区中具有较丰富的棕榈科植物，比较常见的种类有大王椰子、霸王棕、华盛顿葵、金山葵、国王椰子等，这些植物大都生长良好，在园林绿地中有群植、列植或孤植等种植方式，所营造的景观效果均能凸显热带特色。

4.2 东莞园林植物种类及其应用不足之处与建议

4.2.1 园林绿地绿化水平参差不齐 东莞市整体绿化效果较好，但不同镇区的绿化水平存在差异。从植物多样性应用状况来看，由于自然条件和管理水平的不同，不同的绿地类型物种丰富度存在差异。整体来看，以公园绿地、居住区绿地和酒店附属绿地的物种较为丰富，广场绿地和道路绿地居中，单位附属绿地和湿地与河涌绿地的植物丰富度相对较低。从不同镇区来看，经济发达镇区的主干道、公园、居住小区等地的园林植物多样性较高，绿化效果也较好；经济实力稍弱的镇区绿地植物多样性较低，绿化效果也欠佳，特别是厂区、街道的绿化有待加强。

4.2.2 部分绿地园林植物的配置欠合理 东莞园林植物种植中乔、灌、草的应用和配置比例不太合理，主要体现在草地面积较大等方面。许多街道、住宅区、单位附属绿地、公共绿地的绿化空间较小，有效解决老城区绿化空间不足的重要途径是加强立体绿化。东莞对攀缘植物的应用较少，有待进一步发掘。

4.2.3 绿化形式单一，地方特色不够凸显 东莞市园林植物种类虽然较多，但应用较单一化。大量使用外来棕榈科植物使得东莞植物地方特色日益淡化。东莞近年来的园林绿化中热衷使用大树移植，材料多在野外直接挖取，这将对自然生态系统造成破坏。

4.2.4 外来植物使用仍过多，乡土植物有待开发 乡土植物和外来植物比例不协调，东莞市绿化乔木中使用频率高的多为外来树种；东莞市拥有丰富的乡土植物资源，多数种类可用于园林绿化，乡土植物开发利用仍有待进一步开展。今后有必要加大对东莞乡土植物的生态学特性研究，加强对优良观赏植物筛选和培育研究，为优良乡土植物的保护开发、引种驯化和推广利用提供基础资料和理论依据。

致谢：本研究实地调查得到华南植物园邢福武教授和东莞市林科所朱剑云博士、刘颂颂博士和莫罗坚的大力支持，华南农业大学林学院黄久香副教授以及何卓彦、翟翠花、胡竞恺、胡新月等硕士研究生参与了野外调查和室内数据处理，在此一并感谢。

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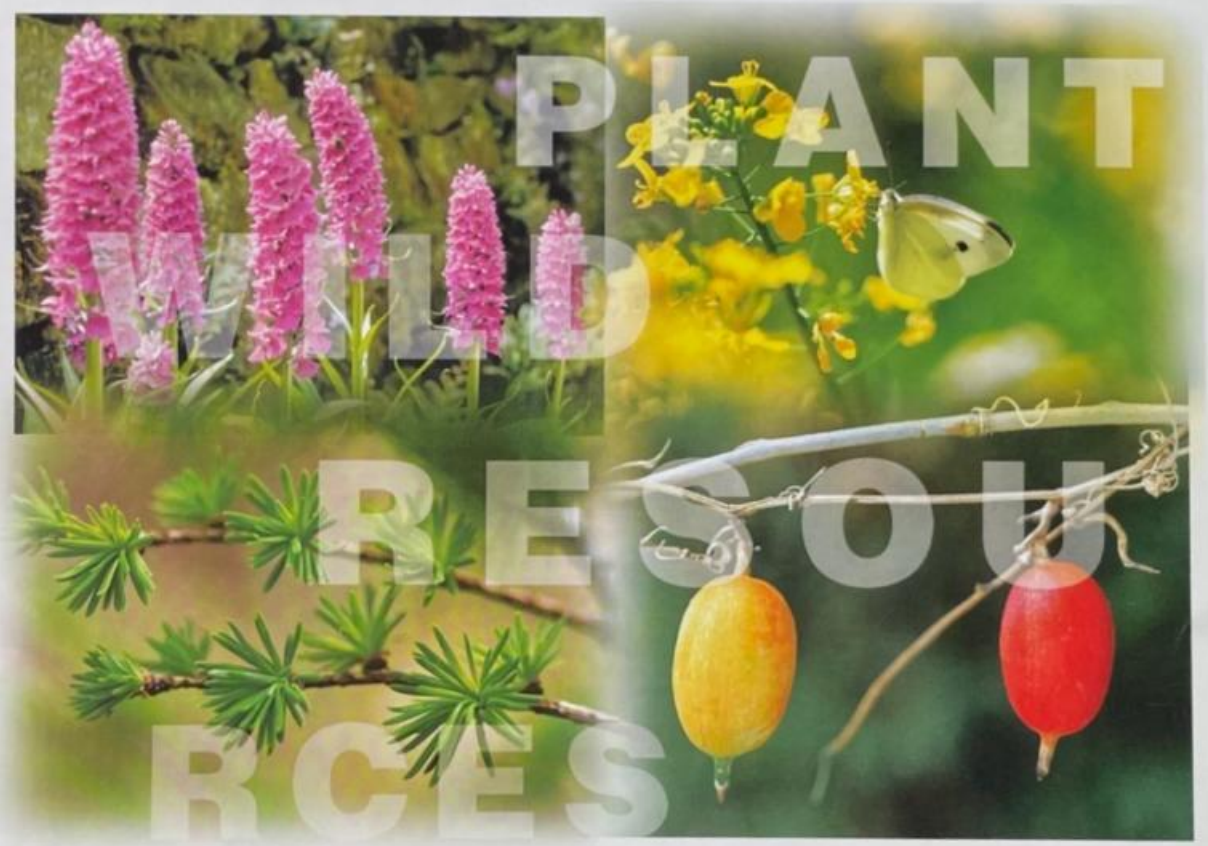
中国科学引文数据库来源期刊
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ISSN 1006-9690
CN 32-1381/Q

第30卷 第5期
Vol.30 No.5

中国野生植物资源

Chinese Wild Plant Resources



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2011

ISSN 1006-9690
10>
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主 管：中华全国供销合作总社
主 办：南京野生植物综合利用研究院
协 办：戈宝绿业（深圳）有限公司
汕头市友情精细化工实业有限公司
中国自然资源学会天然药物资源专业委员会

中国野生植物资源

第30卷 第5期 2011年10月 总第140期

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doi: 10.3969/j.issn.1006 - 9690.2011.05.002

中国鹅绒藤属(萝藦科)植物研究进展

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摘 要 从分类历史、地理分布、实验生物学研究等方面综述了中国鹅绒藤属(萝藦科)植物的研究进展,并就该属植物分类、实验生物学、种质资源保护与开发利用等未来研究方向和重点提出了建议。

关键词 萝藦科;鹅绒藤属;中国

中图分类号: Q949.95 **文献标识码:** A **文章编号:** 1006 - 9690(2011)05 - 0007 - 07

Research Advances of *Cynanchum* L. (Asclepiadaceae) in China

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Abstract Classification, geographical distribution, and experimental biology of *Cynanchum* L. (Asclepiadaceae) in China were reviewed. Some advices were proposed on classification, experimental biology, and protection and utilization of germplasm resources of *Cynanchum* in China.

Key words Asclepiadaceae; *Cynanchum*; China

鹅绒藤属(*Cynanchum* L.)又名白前属、牛皮消属,隶属于萝藦科(Asclepiadaceae),是该科中包含种类最多的属,全球约 200 种,分布范围广泛,非洲、美洲、欧洲和亚洲均有分布;中国有 57 种,在全国大部分省区都有分布,主要分布在西南各省区[1-2]。鹅绒藤属植物具有较大的经济价值,大部分种类可以入药,具有抗肿瘤、免疫调节以及抗氧化等功效。有关鹅绒藤属植物的分类、化学成分、生药资源、药理等长期以来都是植物分类学、药用植物学、植物化学等学科研究的焦点之一,不断有相关研究报道[3-7]。然而,鹅绒藤属植物的分类相对比较复杂,不少类群的归属还存在争议,对已知类群的资源本底状况也还不甚清楚,以致对该属植物的分类和资源开发利用造成混乱和困难。为更好地认识和开发利用国产鹅绒藤属植物,笔者对原产于中国的鹅绒藤属植物从分类历史、地理分布、实验生物学研究等方面进行初步总结。

1 分类历史

鹅绒藤属是瑞典植物学家林奈 1753 年以 *Cynanchum acutum* L. 为模式种建立的,迄今已有 258 年的历史,属名"*Cynanchum*"是由希腊语"kyon"和"ancho"组合变化而成,前者是"犬"的意思,后者是"绞杀"的意思[8],组合是指本属植物大部分为藤本植物,且多含有毒汁液,对动物有毒杀作用。鹅绒藤属建立至今已发表的属下分类群名称有近千个,其中合法名称就有 300 多个,属及其下种类的分类有些仍存在争议,如 *Endotropis*、*Vincetoxicum* 等最初是作为属存在的,蒋英和李秉滔等认为这些属的副花冠基本具有共同特点,存在少许变异和过渡类型,故主张将 *Endotropis*、*Vincetoxicum* 等作为鹅绒藤属(*Cynanchum*)下的组(Sectio)来处理[1-2]。对国产鹅绒藤属植物分类的首部总结性专著出版于

收稿日期: 2010 - 11 - 05
基金项目: 国家自然科学基金项目(31000095)、国家科技基础性工作专项项目(2008FY110400 和 2006FY110500)、广东省大学生创新实验项目(LX005)。
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1977年，是由蒋英和李秉滔教授主编的《中国植物志(第六十三卷)》，书中收录了分布于我国的53种及12变种鹅绒藤属植物，属内分7个组级单位，即鹅绒藤组(Sect. *Cynanchum*)、牛皮消组(Sect. *Endotropis*)、豹药藤组(Sect. *Cryptoglossum*)、催吐白前组(Sect. *Vincetoxicum*)、地梢瓜组(Sect. *Rhodostegiella*)、隔山消组(Sect. *Seutera*)、青羊参组(Sect. *Cyathella*)等[2]。李德铢、邱声祥等曾利用化学方法对鹅绒藤属及其近缘属植物进行分类研究，主张将*Seutera*、*Rhodostegiella*、*Cyathella*、*Vincetoxicum*恢复到属的等级地位，而不是作为鹅绒藤属内的组[3-4]。

自《中国植物志(第六十三卷)》出版后近20年，我国李秉滔教授与美国密苏里植物园Michael和Stevens于1995年共同出版*Flora of China*(Vol. 16)，书中对中国鹅绒藤属植物第二次进行了系统总结，收录了56种以及1亚种和1变种中国产的鹅绒藤属植物[1]。*Flora of China*(Vol. 16)相对《中国植物志(第六十三卷)》鹅绒藤属植物学名变动较大[1-2,5]，学名发生改变的有23种，主要变化有戟叶鹅绒藤(*C. sibiricum* Willdenow)降级为亚种，学名为*C. acutum* L. subsp. *sibiricum*(Willdenow) K. H. Rechinger；羊角子草(*C. cathayense* Tsiang & Zhang)被归并到戟叶鹅绒藤[*C. acutum* Linnaeus subsp. *sibiricum*(Willdenow) K. H. Rechinger]中；白花四川鹅绒藤(*C. szechuanense* var. *albescens* Tsiang & Zhang)被归并到四川鹅绒藤(*C. szechuanense* Tsiang & Zhang)中；丽江牛皮消(*C. likiangense* W. T. Wang ex Tsiang & P. T. Li)被归并到白牛皮消(*C. lysimachioides* Tsiang & P. T. Li)中；西藏牛皮消(*C. saccatum* W. T. Wang ex Tsiang & P. T. Li)被归并到牛皮消(*C. auriculatum* Royle ex Wight)中；紫花合掌消(*C. amplexicaule* var. *castaneum* Makino)被归并到合掌消[*C. amplexicaule*(Siebold & Zuccarini) Hemsley]中；椭圆叶白前[*C. balfourianum*(Schlechter) Tsiang & Zhang]、木里白前(*C. muliense* Tsiang)、石棉白前(*C. forrestii* var. *stenolobum* Tsiang & Zhang)、卵叶白前(*C. steppicola* Handel-Mazzetti)、康定白前(*C. limprichtii* Schlechter)均被归并到大理白前(*C. forrestii* Schlechter)中；潮风草[*C. asyrifolium*(Franch. et Sav.) Matsum.]被归并到潮风草(*C. acuminatifolium* Hemsley)中，但*Flora of China*(Vol. 16)中漏此异名；华北白前[*C. hancockianum*(Maximowicz) Iljinski]学名改变为*C. mongolicum*(Maximowicz) Hemsley；富宁白前(*C. verticillatum* var. *arenicola* Tsiang & Zhang)被归并到轮叶白前(*C. verticillatum* Hemsley)中；老瓜头(*C. komarovii* Iljinski)被归并到华北白前[*C. mongolicum*(Maximowicz) Hemsley]；细梗白前(*C. gracilipes* Tsiang & Zhang)被归并到太行白前(*C. taihangense* Tsiang & Zhang)中；雀瓢[*C. thesioides*(Freyn) K. Schum var. *australe*(Maxim.) Tsiang et P. T. Li]被归并到地梢瓜[*C. thesioides*(Freyn) K. Schum]中；卵叶杯冠藤[*C. formosanum*(Maximowicz) Hemsley var. *ovalifolium* Tsiang & P. T. Li]被归并到台湾杯冠藤[*C. formosanum*(Maximowicz) Hemsley]；美翼杯冠藤(*C. callialata* Ham. ex Wight)学名改为*C. callialatum* Buchanan-Hamilton ex Wight，其中种加词有变化；翅果杯冠藤(*C. alatum* Wight & Arnott)被归并到美翼杯冠藤(*C. callialatum* Buchanan-Hamilton ex Wight)中；催吐白前*C. vincetoxicum*(L.) Pers. 被认为可能鉴定错误，疑似*C. inamoenum*(Maximowicz) Loesener。另外，*Flora of China*(Vol. 16)收入了自《中国植物志(第六十三卷)》出版后发表的新种或新组合15个，它们是短柱豹药藤(*C. longipedunculatum* M. G. Gilbert & P. T. Li)、短冠豹药藤(*C. brevicoronatum* M. G. Gilbert & P. T. Li)、小花杯冠藤(*C. duclouxii* M. G. Gilbert & P. T. Li)、尖叶杯冠藤(*C. sinoracemosum* M. G. Gilbert & P. T. Li)、景东杯冠藤(*C. kintungense* Tsiang)、大花刺瓜(*C. megalanthum* M. G. Gilbert & P. T. Li)、宁蒗杯冠藤(*C. kingdonwardii* M. G. Gilbert & P. T. Li)、巴塘白前(*C. batangense* P. T. Li)、折冠牛皮消(*C. boudieri* H. Léveillé & Vaniot)、粉绿白前(*C. canescens*(Willdenow) K. Schumann)、钟冠白前(*C. bicampanulatum* M. G. Gilbert & P. T. Li)、高冠白前(*C. rockii* M. G. Gilbert & P. T. Li)、启无白前(*C. wangii* P. T. Li & W. Kittredge)、平山白前(*C. pingshanicum* M. G. Gilbert & P. T. Li)和线萼白前(*C. linearisepalum* P. T. Li)等。

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1998 年陈锡沐等对 *Flora of China*(Vol. 16)和《中国植物志(第六十三卷)》萝藦科部分进行了比较,其中包括两者对鹅绒藤属植物分类处理的比较[5]。

1999 年《中国高等植物(第九卷)》出版,书中收录我国鹅绒藤属植物 27 种,每种均配有黑白线条图,植物名称沿用 *Flora of China*(Vol. 16)所做处理[9]。

此后近 12 年时间内,我国有关鹅绒藤属植物分类的研究工作鲜见发表,各地方植物志中鹅绒藤属部分的分类处理多以 *Flora of China*(Vol. 16)为准。

2　地理分布

我国鹅绒藤属的地理分布见表 1[1-2,9-11]。由表中统计数据可见,鹅绒藤属植物分布于我国各省区,以西南各省区分布最为集中,其中以四川省分布的种类最多,达 29 种,占中国鹅绒藤属植物种及种下单位总数的 50%,其次是云南,达 25 种,占总数的 43%。华中地区的湖南、湖北也分布有较多的鹅绒藤属植物,分别有 16 种和 15 种,占总数的 28%和 26%。有些种类仅分布于我国少数地区,是我国特有植物,中国特有的鹅绒藤属植物有 36 种,占总数的 62%,它们分别是小叶鹅绒藤(*C. anthonyanum*)、巴塘白前(*C. batangense*)、钟冠白前(*C. bicampanulatum*)、秦岭藤白前(*C. biondioides*)、短冠豹药藤(*C. brevicoronatum*)、蔓剪草(*C. chekiangense*)、豹药藤(*C. decipiens*)、小花杯冠藤(*C. duclouxii*)、台湾杯冠藤(*C. formosanum*)、大理白前(*C. forrestii*)、峨眉牛皮消(*C. giraldii*)、白前(*C. glaucescens*)、水白前(*C. hydrophilum*)、海南杯冠藤(*C. insulanum*)、线叶杯冠藤(*C. insulanum* var. *lineare*)、宁蒗杯冠藤(*C. kingdonwardii*)、景东杯冠藤(*C. kintungense*)、广西杯冠藤(*C. kwangsiense*)、线萼白前(*C. linearisepalum*)、短柱豹药藤(*C. longipedunculatum*)、白牛皮消(*C. lysimachioides*)、华北白前(*C. mongolicum*)、毛白前(*C. mooreanum*)、朱砂藤(*C. officinale*)、青羊参(*C. otophyllum*)、平山白前(*C. pingshanicum*)、荷花柳(*C. riparium*)、高冠白前(*C. rockii*)、尖叶杯冠藤(*C. sinoracemosum*)、柳叶白前(*C. stauntonii*)、狭叶白前(*C. stenophyllum*)、四川鹅绒藤(*C. szechuanense*)、太行白前(*C. taihangense*)、变色白前(*C. versicolor*)、轮叶白前(*C. verticillatum*)和启无白前(*C. wangii*)。

3　实验生物学研究

中国鹅绒藤属的实验生物学研究主要集中在化学成分和药理研究方面[3-4,6-7,12],其他方面的研究很少涉及。

鹅绒藤属植物由于大多数具有较高的药用价值,应用历史悠久,对其化学成分的研究也早在 1875 年就已开始,Butlerow 从本属的模式植物 *C. acutum* 中分离出白薇醇[12]。鹅绒藤属植物的化学成分包括 C_{21} 甾体皂甙、生物碱、三萜类化合物、黄酮类化合物、苯类衍生物、糖类以及脂肪酸、脂肪酸酯、植物甾醇和小分子芳香族化合物,以 C_{21} 甾体皂甙为主[7,12]。中国鹅绒藤属的化学成分研究始于 20 世纪 80 年代,1983 年开始木全章等陆续从青羊参(*C. otophyllum*)中分离出青羊参苷甲和乙等化学成分[13,15]。随后邱声祥等 1989 年从变色白前(*C. versicolor*)中分离出变色白前苷,吴振洁等从竹灵消(*C. inamoenum*)中分离出白薇苷;彭军鹏等 1990 年从华北白前(*C. mongolicum*)中分离出 7-脱甲氧基娃儿藤次碱[12,14]。至今已提取过化学成分的中国鹅绒藤属植物包括潮风草(*C. acuminatifolium*)、白薇、白首乌(*C. bungei*)、鹅绒藤(*C. chinense*)、牛皮消、大理白前、白前(*C. glaucescens*)、竹灵消、华北白前、白牛皮消(*C. lysimachioides*)、青羊参、徐长卿(*C. paniculatum*)、戟叶鹅绒藤(*C. acutum* subsp. *sibiricum*)、地梢瓜(*C. thesioides*)、柳叶白前、变色白前、昆明杯冠藤(*C. wallichii*)和隔山消(*C. wilfordii*)等[12-27]。

鹅绒藤属植物的药理研究主要集中在免疫调节、抗肿瘤、抗癫痫、消炎镇痛、强心、抗血栓形成等方面,开展过药理研究的该属植物有白首乌、牛皮消、变色白前、竹灵消、华北白前、豹药藤(*C. decipiens*)、西藏牛皮消、青羊参、鹅绒藤、柳叶白前和徐长卿等[6-7,12,38-43]。

鹅绒藤属形态结构方面的研究工作较少,目前仅见黄久香等在其博士学位论文中对鹅绒藤属刺瓜、牛皮消的叶表皮进行过光学显微镜观察,但结果

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表1 中国鹅绒藤属植物地理分布总览

中文名	学名	黑	吉	辽	冀	晋	蒙	陕	甘	宁	青	新	苏	浙	皖	鲁	赣	闽	鄂	湘	豫	粤	桂	琼	港	澳	台	川	滇	黔	藏
潮风草	*Cynanchum acuminatifolium*			*	*	*									*	*															
戟叶鹅绒藤	*C. acutum* subsp. *sibiricum*				*		*		*	*		*																			*
合掌消	*C. amplexicaule*		*	*	*	*	*		*	*	*					*			*	*	*		*								
小叶鹅绒藤	*C. anthonyanum*																											*	*		
白薇	*C. atratum*	*	*	*	*	*	*	*					*			*	*	*		*	*	*	*					*	*	*	
牛皮消	*C. auriculatum*																		*	*		*									
巴塘白前	*C. batangense*																				*										
钟冠白前	*C. bicampanulatum*								*																			*			
秦岭藤白前	*C. biondioides*																					*									
折冠牛皮消	*C. boudieri*			*			*	*	*	*	*	*			*	*	*			*	*	*	*	*							
短冠豹药藤	*C. brevicoronatum*																		*												
白首乌	*C. bungei*			*		*				*					*		*			*											
美翼杯冠藤	*C. callialatum*																					*					*				
粉绿白前	*C. canescens*																										*	*		*	
蔓剪草	*C. chekiangense*												*				*	*	*	*											
鹅绒藤	*C. chinense*		*	*	*	*		*			*				*	*	*	*	*												
刺瓜	*C. corymbosum*																*		*	*		*			*	*	*				
豹药藤	*C. decipiens*																			*								*	*	*	
小花杯冠藤	*C. duclouxii*																												*		
山白前	*C. fordii*																*	*	*	*							*				
台湾杯冠藤	*C. formosanum*																										*				
大理白前	*C. forrestii*							*																	*	*	*	*			
峨眉牛皮消	*C. giraldii*						*	*											*						*						
白前	*C. glaucescens*											*	*		*	*		*	*		*				*						
西藏鹅绒藤	*C. heydei*																													*	
水白前	*C. hydrophilum*																										*				
竹灵消	*C. inamoenum*			*	*	*		*	*	*	*	*	*	*	*	*	*	*						*							
海南杯冠藤	*C. insulanum*																					*	*	*	*						
线叶杯冠藤	*C. insulanum* var. *lineare*																					*		*							
宁蒗杯冠藤	*C. kingdonwardii*																												*		
景东杯冠藤	*C. kintungense*																					*					*	*	*	*	

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续表 1

中文名	学名	黑	吉	辽	冀	晋	蒙	陕	甘	宁	青	新	苏	浙	皖	鲁	赣	闽	鄂	湘	豫	粤	桂	琼	港	澳	台	川	滇	黔	藏
广西杯冠藤	*C. kwangsiense*																						*								
线萼白前	*C. linearisepalum*																											*			
短柱豹药藤	*C. longipedunculatum*																	*										*			
白牛皮消	*C. lysimachioides*																											*			
大花刺瓜	*C. megalanthum*																											*			
华北白前	*C. mongolicum*			*	*	*	*	*	*	*																*					
毛白前	*C. mooreanum*												*	*		*	*	*	*	*	*	*									
朱砂藤	*C. officinale*						*	*					*			*	*	*			*					*	*	*			
青羊参	*C. otophyllum*																	*	*			*	*					*	*	*	
徐长卿	*C. paniculatum*			*	*	*	*	*	*				*	*	*	*	*	*	*	*	*	*		*		*		*	*	*	*
平山白前	*C. pingshanicum*																											*			
紫花鹅绒藤	*C. purpureum*			*		*																									
荷花柳	*C. riparium*																			*											
高冠白前	*C. rockii*																										*				
尖叶杯冠藤	*C. sinoracemosum*																										*	*			
柳叶白前	*C. stauntonii*							*			*	*	*		*	*		*	*	*	*					*					
狭叶白前	*C. stenophyllum*																	*								*		*			
镇江白前	*C. sublanceolatum*											*																			
四川鹅绒藤	*C. szechuanense*																										*	*			
太行白前	*C. taihangense*				*								*																		
地梢瓜	*C. thesioides*	*	*	*	*	*	*	*	*	*			*	*		*	*														
变色白前	*C. versicolor*	*	*	*							*	*		*	*	*	*							*							
轮叶白前	*C. verticillatum*																	*			*	*				*	*	*			
蔓白前	*C. volubile*	*																													
昆明杯冠藤	*C. wallichii*																											*			
启无白前	*C. wangii*																											*			
隔山消	*C. wilfordii*		*		*		*	*	*				*		*	*	*						*	*	*	*					
合计种数		4	6	10	12	9	7	11	14	3	3	2	11	9	9	11	7	8	15	16	13	13	15	2	3	0	3	29	25	12	10

注：* 表示有分布

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未正式发表。本文作者2010年对13种及1变种鹅绒藤属植物的叶表皮进行过扫描电镜观察[44]，并对广东及香港、澳门鹅绒藤属药用植物资源进行初步总结[45]。

4 结 语

中国萝藦科(包括鹅绒藤属)植物分类的总结性专著*Flora of China*(Vol. 16)出版迄今已有16年时间，期间有关萝藦科植物分类的研究工作较少，基本处于停滞状态，专著和研究论文等文献也少见出版或发表。前期的分类研究工作主要是依据宏观形态学特征，缺乏实验学科的综合证据，这也使得萝藦科植物的很多分类难题悬而未决，如鹅绒藤属内的分组或分属的问题。有关鹅绒藤属化学成分的研究也集中在少数种类的C_{21}甾苷类化合物。针对目前我国鹅绒藤属植物的研究现状，建议今后应开展或加强以下几方面的研究工作。

4.1 继续加强我国鹅绒藤属植物资源的本底调查研究

尽管我国有关鹅绒藤属的植物志中英文版都已出版，但由于以前野外和室内实验条件的限制，至今仍存在一些野外调查的薄弱和盲点地区，包括一些行政区划的交界处，因为这些地方通常是山脉中的山脊地带，山高路远，人迹罕至，植被破坏较轻，今后应着重加强对这些地区的调查研究。我国鹅绒藤属植物集中分布的西南地区(四川、云南、贵州和西藏)、华中地区(湖北、湖南和河南)以及我国生物多样性丰富的华南地区(海南、广东和广西)也应是调查的重点地区。有必要组织全国或地区性的野外资源调查和分类研究专项，调查研究内容应包括种群数量、地理分布、生境、生存现状评估等，力争摸清我国鹅绒藤属植物资源现状。

4.2 充分重视我国鹅绒藤属植物分类人才的培养

《中国植物志》历经四代人近半个世纪的共同努力才得以编撰完成，*Flora of China*的编撰同样也汇聚了数代科学家的心血，这些专著的编写为我国培养了一大批植物分类学人才。夹竹桃科和萝藦科植物分类专家蒋英和李秉滔教授也是在编写《中国植物志(第六十三卷)》的过程中逐渐成长起来的。蒋英教授研究夹竹桃科和萝藦科植物始于20世纪60年代，当时李秉滔教授是其学生兼助手，两人合作于1977年出版了夹竹桃科和萝藦科植物分类专著——《中国植物志(第六十三卷)》。蒋英教授1982年逝世，随后李秉滔教授接手挑起了夹竹桃科和萝藦科植物分类的重担，对这两科植物进行了深入、系统的整理，1995年与美国密苏里植物园两位植物学家合作出版了*Flora of China*(Vol. 16)，李秉滔教授至今已75岁高龄，仍在潜心从事他钟爱的分类学事业。然而，自李秉滔教授对鹅绒藤属植物有专攻后，国内至今尚未见中青年继续从事鹅绒藤属植物的系统研究。这与当前国际植物经典分类学普遍存在不景气、科研经费申请困难等有着密切关系。鹅绒藤属植物的一些疑难物种多、分类处理争议大，这些问题的解决都有待进一步深入研究，因此当前加强我国鹅绒藤属植物分类人才的培养工作势在必行。

4.3 深入开展我国鹅绒藤属植物实验学科研究

我国鹅绒藤属植物的分类和系统学研究集中在解放初期和改革开放前期，由于当时经济和技术条件有限，我国鹅绒藤属植物的分类采用经典分类方法，主要依据外部形态结构。随着实验技术的广泛应用，鹅绒藤属植物的显微结构、胚胎学、孢粉学、细胞学、分子生物学、生物化学、生药学、药理学以及繁殖生物学等实验学科的研究有待深入开展。实验学科的研究结果将为鹅绒藤属中疑难类群的分类提供更多参考依据。

4.4 重视我国鹅绒藤属植物的野外种质资源保护和栽培驯化研究

鹅绒藤属植物有些种类对生境要求较高，在野外并不多见，但目前我们使用的科研和入药材料均直接来源于野外自然种群，这种利用方式对鹅绒藤属植物资源具有较大的破坏作用，而且是不可持续的。当今植物迁地保护和人工繁殖技术已日趋成熟，我们在加强鹅绒藤属植物就地保护的同时，可以开展该属植物的迁地保育工作，建立种质资源保存库，这种可持续的保护方式也将为鹅绒藤属植物的科学研究和开发利用提供实验材料和场所。

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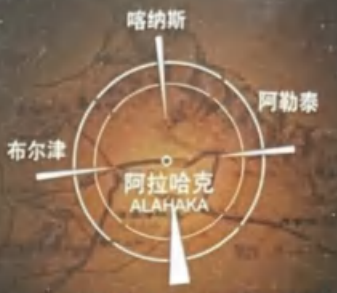
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E-mail:yszw2009@163.com　　电话：(025)85472153　　定价：5.00元

中国园林

国家中文核心期刊　中国科技核心期刊

Chinese Landscape Architecture

秦雅生

中国风景园林学会主办

IFLA 国际风景园林师联合会合作刊物

本期主题

滨水空间规划设计

Planning and Design of Waterfront Space

07 2011

Vol.27/187



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期刊基本参数:
CN11-2165/TU*1984*m*A4*104*zh*P* ¥ 28.00* *20*2011-07
Vol.27 / 187 / Monthly 总27卷 187期 每月15日出版
Http://www.jcbla.com

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中国园林

《中国园林》创刊于1985年

2011.07 Vol.27 / 187 / Monthly

本期主题：滨水空间规划设计

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刊社地址：北京市海淀区甘家口21号楼708室、711室

邮政编码：100037

总　　机：010-8838 2517 / 6831 8322 / 6834 8041

分　　机：

编辑部：816 / 817 / 818 / 821 / 822 / 823 / 825 / 828

办公室：826 / 6833 9217（传真）

电子信箱：jcla@china.com（编辑）zgyl@china.com（制作）zgylgg@china.com（广告）lareIease@china.com（发行）

国内发行：北京报刊发行局

订　　阅：全国各地邮局

邮发代号：82-217

国外发行：中国国际图书贸易总公司

代　　号：BM4577

定　　价：28.00元

出版日期：每月15日

国内统一连续出版物号：CN 11-2165/TU

国际标准连续出版物号：ISSN 1000-6664

广告许可证号：京海工商广字第0193号

印刷单位：北京方嘉彩色印刷有限责任公司

地　　址：北京市西直门外交大东路31号电子楼9层

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Tel (Switch Board): 010-8838 2517 / 6831 8322 / 6834 8041

Ext.: Editorial Department: 816/818/821/822/823/828

Design & Production Department: 817/825

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E-mail: jcla@china.com (Editor)

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Domestic Distributor: Beijing Newspaper & Periodicals Distribution Bureau

Subscription: Local Post Offices

Postal Distribution Number: 82-217

Overseas Distributor: China International Book Trading Corporation (P.O.Box399, Beijing, China)

Code No. BM4577

Price: 28.00RMB

Publishing Time: Monthly 15th

Domestic Unified Number: CN 11-2165/TU

International Standard Serial Number: ISSN 1000-6664

Advertisement Permit Number: Guang No. 0193, Beijing Haigong Administration of Industry and Commerce

Printing: Beijing Foundart Colour Printing Co.,Ltd.

Postal Address: 9/F, Electronics Building, No.31 Jiaoda East Rd, Xizhimenwai, Beijing 100044, China

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中国园林网站：http://www.jchla.com

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摘　要：通过对海南特有野生植物资源的实地考察和文献查阅，初步统计了海南特有野生花卉约320种，隶属于69科182属，主要为茜草科(32种)、樟科(27种)、竹亚科(16种)、桃金娘科(13种)、兰科(13种)、莎草科(11种)、蝶形花科(11种)和萝藦科(9种)等所含种类。对海南特有野生植物资源的种类、重要类群与观赏特性等进行了综述，最后就其资源保护与利用提出了建议。

关 键 词：园林植物；海南；特有植物；植物资源
文章编号：1000-6664(2011)07-0072-07
中图分类号：S 688　　**文献标志码：**A
收稿日期：2010-11-08；　**修回日期：**2011-02-18
基金项目：教育部博士点基金项目(编号20104601110002)和海南省自然科学基金(编号310025)、海南大学研究生教育教学改革研究项目(编号yjg0114)共同资助

Abstract: Based on the literature review and field investigation, the results show that there are 320 species wild flower resources endemic to Hainan Island. These species belong to 69 families and 182 genera, and the dominant families include Rubiaceae (32 species), Lauraceae (27 species), Bambusaceae (16 species), Myrtaceae(13 species), Orchidaceae (13 species), Cyperaceae (11 species), Papilionaceae (11 species) and Asclepiadaceae (9 species) et al.. The species, distribution, important groups and ornamental characters of wild flower resources endemic to Hainan Island were summarized. The suggestions on protecting and utilizing the wild flower resources endemic to Hainan Island were also proposed.

Key words: landscape plants; Hainan; endemic species; plant resource

特有现象是种系分化的结果，其形成机制是多方面的，包括地貌因子、土壤因子、气候因子、边缘效应、海洋岛屿隔离等外部因素以及自然杂交、自身遗传变异等内部因素的综合作用[1-2]。特有植物多为不同基质的指示植物和先锋植物，对于研究物种分化、特殊环境中植物的适应性等科学问题提供了很好的材料。此外，由于特有植物表现出与环境变化极为强烈的依赖关系，且很多地方的特有植物同时也是珍稀濒危植物，因此特有现象的研究对于生物多样性的保护也具有重要意义。

海南岛(18° 10′ ~20° 10′ N，108° 37′ ~111° 03′ E)面积约3.4万km^2，是我国仅次于台湾的第二大岛屿。全岛气候温和，年平均气温22~26℃，终年无霜雪，雨量充沛，年平均降雨量为1 500~2 000mm，属热带季风气候[3]。第四纪后多次地质运动为海南岛岛屿生物地理中特有生物现象的形成起到了重要作用[4]。海南生物资源丰富，该岛现已记录的野生维管束植物约有4 000种[5-6]，其中海南特有种子植物约397种，隶属于74科215属[7-8]，约占全岛维管束植物总种数的9.9%，主要是茜草科(33种及种下单位，下同)、樟科(27种)、禾本科(26种)、兰科(23种)和壳斗科(23种)所含属种，其中耳草属(*Hedyotis*，11种及种下单位)、簕竹属(*Bambusa*，10种及种下单位)所含海南特有种最多[6-8]。海南特有植物集中分布在吊罗山(163种及种下单位，下同)、尖峰岭(157种)、霸王岭(126种)和鹦哥岭(107种)等林区[6-15]。

由于特有植物是某一地区独有的生物资源，多数具有较高的观赏价值，因此是不可多得的野生花卉资源，为资源开发

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利用提供了宝贵的基因库。本文野生花卉采用广义概念，即指花、果、叶、株型和其他所有具观赏价值的野生植物[16]。海南特有野生花卉即指局限分布于海南且具有观赏价值的野生植物。根据文献资料[4-15]和笔者实地考察，海南特有野生花卉现统计约有320种，隶属于69科182属，以茜草科(32种)、樟科(27种)、竹亚科(16种)、桃金娘科(13种)、兰科(13种)、莎草科(11种)、蝶形花科(11种)和萝藦科(9种)等所含种类为主(表1)。

1 海南特有野生花卉物种多样性

海南特有野生花卉生活型多样，以灌木类最为丰富(96种)，草本类其次(86种)，乔木类位居第三(84种)，藤本和攀援灌木类相对较少(54种)。

1.1 乔木类

主要见于海南中部和西南部热带雨林山地、沟谷地区，包括长柄冬青(学名见表1，下同)、保亭冬青、海南幌伞枫、十蕊大参、海南厚壳树、海南柿、海南猴欢喜、海南黄檀、海南黄杞、白背黄肉楠、保亭黄肉楠、皱皮油丹、保亭琼楠、东方琼楠、尖峰润楠、梨润楠、海南新木姜子、保亭新木姜子、乐东油果樟、石碌含笑、海南梧桐、保亭梭罗、海南蒲桃、海南厚皮香、海南大头茶、海南油杉、吊罗坭竹、琼梅、海南韶子、海南紫荆木和琼刺榄等84种。

1.2 灌木类

主要见于海南热带雨林林下或山顶灌丛，也见于低海拔次生林或人工林坡地，包括海南蕊木、吊罗山萝芙木、保亭树参、矮琼棕、海南轴榈、海南黄杨、吊罗裸实、东方裸实、葫芦苏铁、海南苏铁、陈氏铁芄菜、海南叶下珠、平基紫珠、海南染木树、琼岛染木树、海南黄皮、柃叶山矾和窄叶菁花等96种。

1.3 草本类

主要见于海南热带雨林林下阴湿处、树干上或石灰岩地区山顶干旱处，包括海南秋英爵床、糙叶山蓝、海南叉柱花、保亭叉柱花、海南菊、海南凤仙花、海南割鸡芒、海南大戟、海南秋海棠、盾叶苣苔、昌江蛛毛苣苔、海南黄芩、保亭花、海南兰花蕉、海南石豆兰、牛角兰、华石斛、海南锚柱兰、海南鹤顶兰、坝王远志、海南远志、海南耳草、海南蛇根草和海南假砂仁等86种。

1.4 藤本和攀援灌木类

主要见于海南热带雨林林缘、路旁等向阳处，包括狭瓣鹰爪花、荟蔓藤、海南匙羹藤、厚花球兰、崖县球兰、白水藤、海南弓果藤、紫叶娃儿藤、短叶省藤、多刺鸡藤、黄毛马兜铃、多型叶马兜铃、海南忍冬、古山龙、海南地不容、小叶地不容、海南青牛胆、壮丽玉叶金花、海南玉叶金花、乐东玉叶金花、膜叶玉叶金花和细花百部等54种。

2 海南特有野生花卉生态学特性

海南特有野生花卉按照生长环境不同可分为土生、石生和附生类，缺少水生类，其中以土生类最为丰富(302种)，石生类其次(10种)，附生类相对较少(8种)。

2.1 土生类

大部分特有植物属于此类(302种)，生于土山或石山土壤之中，如长柄冬青、海南幌伞枫、十蕊大参、单叶豆、崖柿、海南柿、海南蕊木、吊罗山萝芙木等，也包括少数寄生植物，如石山蛇菰等。

2.2 石生类

主要是指生长于石灰岩地区裸露山顶的植物(10种)，包括海南凤仙花、东方裸实、葫芦苏铁、海南大戟和坝王远志等。

2.3 附生类

指附生于热带雨林树干上的植物(8种)，主要是一些蕨类和兰科植物，包括海南石豆兰、乐东石豆兰、牛角兰、华石斛、海南大苞兰、镰叶盆距兰、芳香白点兰和裂唇羊耳蒜等。

3 海南特有野生花卉观赏特性

3.1 观花类

主要观赏花的形状、颜色、气味等特性。白色花系如抱茎短蕊茶、海南大头茶、保亭梭罗、剑叶梭罗、长柄梭罗、海南流苏树、烟叶唇柱苣苔、海南菊、海南鹤顶兰和华石斛等；橙色色花系如美丽火桐等，粉红色花系如枝毛野牡丹、海南锦香草、毛锦香草和窄叶锦香草等；黄色花系如黄花马铃苣苔等；紫色花系如糙叶山蓝等；花形奇特如狭瓣鹰爪花、毛叶鹰爪花、海南玉叶金花、膜叶玉叶金花、厚花球兰、崖县球兰和海南半边莲等；花芳香者如石碌含笑、芳香白点兰等153种。

3.2 观果类

主要观赏果实的形状、颜色等特性。果形奇特如钱木、东方瓜馥木、皱皮油丹、梨润楠、黄毛马兜铃、南粤马兜铃、海南线果兜铃、多毛山柑、山柑、海南叶下珠、单花水油甘、海南猪屎豆、崖州猪屎豆、疏节槐、短柄鸡眼藤、海南巴戟、海南弓果藤和紫叶娃儿藤等；果色鲜艳如海南尧花、大叶尧花、保亭冬青、红果黄檀、吊罗裸实、东方裸实、平基紫珠、红腺紫珠、小花肖菝葜、崖柿、五蒂柿和密鳞紫金牛等；果内有红色假种皮如海南卫矛、保亭卫矛和单叶豆等219种。

3.3 观叶类

主要观赏叶的形状、颜色、变异等特性。叶形奇特如多型叶马兜铃、保亭树参、十蕊大参、海南轴榈、海南秋海棠、侯

氏秋海棠、保亭秋海棠和海南蝙蝠草等；叶有彩纹如保亭金线兰等；叶有毛被如绢毛木兰和盾叶苣苔等37种。

3.4 观全株类

主要观赏植株的形状等特性。乔木如白背黄肉楠、保亭黄肉楠、尖峰润楠、海南新木姜子、保亭新木姜子和海南幌伞枫等；灌木如葫芦苏铁、海南苏铁、假赤楠、陈氏铁苋菜和海南大戟等；草本如坝王远志、海南远志、海南凤仙花、大众耳草、海南耳草、革叶山姜、黎婆花、海南千年健、落檐和海南兰花蕉等；藤本如海南地不容、小叶地不容、海南青牛胆和牛角兰等308种。

4 海南特有野生花卉推介

4.1 兰科(Orchidaceae)植物

兰科植物株型优雅，花形奇特，是深受人们喜爱的花卉，海南是我国兰科植物集中分布地之一，生长众多的兰科植物，特有的兰科植物包括保亭金线兰、海南金线兰、多枝拟兰、海南石豆兰、乐东石豆兰、五指山石豆兰、牛角兰、海南沼兰、琼岛沼兰、华石斛、海南锚柱兰、镰叶盆距兰、裂唇羊耳蒜、拟石斛、海南鹤顶兰、海南大苞兰、东方毛叶兰等，其中保亭金线兰、海南鹤顶兰主要分布在保亭、琼中等地，海南金线兰、多枝拟兰、海南锚柱兰主要分布在乐东等地，海南石豆兰、海南沼兰、琼岛沼兰主要分布在保亭、琼中等地，乐东石豆兰、牛角兰、华石斛主要分布在昌江、乐东、保亭、琼中、白沙等地，五指山石豆兰主要分布在五指山等地，镰叶盆距兰主要分布在定安、琼海、琼中、陵水等地，裂唇羊耳蒜主要分布在保亭、陵水等地，拟石斛主要分布在昌江、乐东、琼中等地，海南大苞兰主要分布在琼中等地，东方毛叶兰主要分布在东方等地。

4.2 苦苣苔科(Gesneriaceae)植物

苦苣苔科植物花形美观，多数种类具有很高的观赏价值，但只有少数被开发利用。海南特有的苦苣苔科植物包括扁蒴苣苔、烟叶唇柱苣苔、盾叶苣苔、毛花马铃苣苔、黄花马铃苣苔、昌江蛛毛苣苔和海南蛛毛苣苔等，其中扁蒴苣苔主要分布在陵水，烟叶唇柱苣苔、盾叶苣苔、黄花马铃苣苔主要分布在昌江、乐东、陵水、五指山、琼中、白沙等地，毛花马铃苣苔主要分布在琼中、白沙等地，昌江蛛毛苣苔主要分布在昌江、东方石灰岩地区，海南蛛毛苣苔主要分布在乐东等地。

4.3 球兰属(*Hoya* spp.)植物

萝藦科球兰属植物花冠肉质，辐射状，花粉块边缘有透明的薄膜，给人晶莹剔透的感觉，具有较高观赏价值。海南特有球兰属植物包括厚花球兰和崖县球兰，其中厚花球兰主要分布在万宁、昌江等地，崖县球兰主要分布在昌江、乐东、陵水和三亚等地。

4.4 弓果藤属(*Toxocarpus* spp.)植物

萝藦科弓果藤属植物果期蓇葖果不同种类成不同角度叉开，种子有种毛，具有较高观赏价值。海南特有弓果藤属植物包括海南弓果藤、平滑弓果藤和广花弓果藤，其中海南弓果藤主要分布在昌江、乐东、陵水等地，平滑弓果藤主要分布在白沙等地区，广花弓果藤主要分布在乐东等地。

4.5 冬青属(*Ilex* spp.)植物

冬青科冬青属植物叶色翠绿，果实成熟时果多色艳且可食，通常为红色，是极佳的观果植物，海南特有冬青属植物包括长柄冬青、秀英冬青、保亭冬青、洼皮冬青和石枚冬青，其中长柄冬青主要分布在昌江、乐东、陵水等地，秀英冬青主要分布在琼海、万宁和保亭等地，保亭冬青和石枚冬青主要分布在陵水、保亭等地，洼皮冬青主要分布在昌江、乐东、陵水和琼中等地。

4.6 紫金牛属(*Ardisia* spp.)植物

紫金牛科紫金牛属植物叶片通常有不透明腺点，叶片边缘也常有腺点，果实成熟后常为红色，鲜艳可爱。海南特有紫金牛属植物包括保亭紫金牛、密鳞紫金牛、轮叶紫金牛、细孔紫金牛、弯梗紫金牛，其中保亭紫金牛主要分布在保亭、琼中、白沙等地，密鳞紫金主要分布在昌江、乐东、保亭、琼中等地，轮叶紫金牛主要分布在昌江、乐东、琼中等地，细孔紫金牛主要分布在乐东等地，弯梗紫金牛主要分布在琼中、白沙等地。

4.7 蒲桃属(*Syzygium* spp.)植物

桃金娘科蒲桃属植物嫩叶常带红色，花果繁多，果实成熟后多为紫红色。该属植物主要分布于亚洲热带地区，我国华南为主要分布地区。海南蒲桃属植物较多，海南特有的蒲桃属植物就有9种，包括假赤楠、散点蒲桃、海南蒲桃、万宁蒲桃、褐背蒲桃、尖峰蒲桃、皱萼蒲桃、纤枝蒲桃和方枝蒲桃等，其中假赤楠主要分布在保亭、陵水等地，散点蒲桃、纤枝蒲桃主要分布在昌江、乐东、琼中、白沙等地，海南蒲桃主要分布在琼中等地，万宁蒲桃主要分布在万宁、昌江、乐东等地，褐背蒲桃主要分布在昌江、乐东等地，尖峰蒲桃主要分布在乐东等地，皱萼蒲桃主要分布在昌江、保亭、乐东等地，方枝蒲桃主要分布在昌江、乐东、保亭、琼中、白沙等地。

4.8 竹亚科(Bambusoideae)植物

禾本科竹亚科植物分布广泛，海南拥有丰富的竹类资源，与海南的热带气候相适应，多具丛生、攀援等特性，海南特有的竹亚科植物包括射毛悬竹、孟竹、妈竹、褐毛青皮竹、吊罗坭竹、蓬莱黄竹、光鞘石竹、马岭竹、黄竹仔、石竹仔、响子竹、海南箭竹、藤单竹、细柄少穗竹、林竹仔、毛秆少穗竹等，这些竹类植物多生长在热带雨林林窗、林缘、低海拔灌丛、溪旁、路旁、村边等地，生境较为多样，

表1　　海南特有野生花卉资源特性一览表

中文名	学名	生活型	生长习性	观赏部位
葫芦苏铁	*Cycas changjiangensis*	灌木	石生	全株
海南苏铁	*Cycas hainanensis*	灌木	土生	全株
三亚苏铁	*Cycas shanyagensis*	灌木	土生	全株
海南油杉	*Keteleeria hainanensis*	乔木	土生	全株、果
绢毛木兰	*Magnolia albosericea*	乔木	土生	全株、叶、花
石碌含笑	*Michelia shiluensis*	乔木	土生	全株、花
狭瓣鹰爪花	*Artabotrys hainanensis*	攀援灌木	土生	花、果
毛叶鹰爪花	*Artabotrys pilosus*	攀援灌木	土生	花、果
钱木	*Chieniodendron hainanense*	乔木	土生	全株、花、果
东方瓜馥木	*Fissistigma tungfangense*	攀援灌木	土生	花、果
白背黄肉楠	*Actinodaphne glaucina*	乔木	土生	全株、果
保亭黄肉楠	*Actinodaphne paotingensis*	乔木	土生	全株、果
皱皮油丹	*Alseodaphne rugosa*	乔木	土生	全株、果
山潺	*Beilschmiedia appendiculata*	乔木	土生	全株、果
保亭琼楠	*Beilschmiedia baotingensis*	乔木	土生	全株、果
短叶琼楠	*Beilschmiedia brevifolia*	乔木	土生	全株、果
长柄琼楠	*Beilschmiedia longepetiolata*	乔木	土生	全株、果
肉柄琼楠	*Beilschmiedia macropoda*	乔木	土生	全株、果
锈叶琼楠	*Beilschmiedia obconica*	乔木	土生	全株、果
东方琼楠	*Beilschmiedia tungfangensis*	乔木	土生	全株、果
钝叶厚壳桂	*Cryptocarya impressinervia*	乔木	土生	全株、果
鸡卵槁	*Cryptocarya leiana*	乔木	土生	全株、果
长序厚壳桂	*Cryptocarya metcalfiana*	乔木	土生	全株、果
红柄厚壳桂	*Cryptocarya tsangii*	乔木	土生	全株、果
莲桂	*Dehaasia hainanensis*	乔木	土生	全株、果
土楠	*Endiandra hainanensis*	乔木	土生	全株、果
海南山胡椒	*Lindera robusta*	乔木	土生	全株、果
海南木姜子	*Litsea litseaefolia*	乔木	土生	全株、果
琼南木姜子	*Litsea verticillifolia*	乔木	土生	全株、果
尖峰润楠	*Machilus monticola*	乔木	土生	全株、果
梨润楠	*Machilus pomifera*	乔木	土生	全株、果
海南新木姜子	*Neolitsea hainanensis*	乔木	土生	全株、果
保亭新木姜子	*Neolitsea howii*	乔木	土生	全株、果
钝叶新木姜子	*Neolitsea obtusifolia*	乔木	土生	全株、果
茶槁楠	*Phoebe hainanensis*	乔木	土生	全株、果
油果樟	*Syndiclis chinensis*	乔木	土生	全株、果
乐东油果樟	*Syndiclis lotungensis*	乔木	土生	全株、果
海南铁线莲	*Clematis hainanensis*	草质藤本	土生	叶、果
少叶野木瓜	*Stauntonia oligophylla*	木质藤本	土生	叶、果
古山龙	*Arcangelisia gusanlung*	木质藤本	土生	叶、果
海南地不容	*Stephania hainanensis*	木质藤本	土生	全株、块根、叶
小叶地不容	*Stephania succifera*	木质藤本	土生	全株、块根、叶
海南青牛胆	*Tinospora hainanensis*	木质藤本	土生	叶
黄毛马兜铃	*Aristolochia fulvicoma*	木质藤本	土生	花、果
南粤马兜铃	*Aristolochia howii*	木质藤本	土生	花、果
多型叶马兜铃	*Aristolochia polymorpha*	木质藤本	石生	叶、花、果
海南线果兜铃	*Thottea hainanensis*	木质藤本	土生	花、果
嵌果胡椒	*Piper infossibaccatum*	木质藤本	土生	叶、果
陵水胡椒	*Piper lingshuiense*	木质藤本	土生	叶、果
斜叶蒟	*Piper senporeiense*	木质藤本	土生	叶、果
多毛山柑	*Capparis dasyphylla*	攀援灌木	土生	花、果
山柑	*Capparis hainanensis*	攀援灌木	土生	花、果
坝王远志	*Polygala bawanglingensis*	草本至亚灌木	石生	全株、花、果
海南远志	*Polygala hainanensis*	草本至亚灌木	土生	全株、花、果
海岛远志	*Polygala wuzhishanensis*	草本至亚灌木	土生	全株、花、果
海南凤仙花	*Impatiens hainanensis*	草本	石生	全株、叶、花、果
窄叶菡花	*Wikstroemia chuii*	灌木	土生	全株、果
海南菡花	*Wikstroemia hainanensis*	灌木	土生	全株、果
大叶菡花	*Wikstroemia liangii*	灌木	土生	全株、果
狭叶天料木	*Homalium stenophyllum*	乔木	土生	全株、花
海南秋海棠	*Begonia hainanensis*	草本	土生	全株、叶、花、果
侯氏秋海棠	*Begonia howii*	草本	土生	全株、叶、花、果
盾叶秋海棠	*Begonia peltatifolia*	草本	石生	全株、叶、花、果
保亭秋海棠	*Begonia sublongipes*	草本	土生	全株、叶、花、果
狭叶杨桐	*Adinandra angustifolia*	灌木或小乔木	土生	全株、果
无腺杨桐	*Adinandra epunctata*	灌木或小乔木	土生	全株、果
保亭杨桐	*Adinandra howii*	灌木或小乔木	土生	全株、果
抱茎短蕊茶	*Camellia amplexifolia*	灌木或小乔木	土生	全株、花、果
细花短蕊茶	*Camellia parviflora*	灌木或小乔木	土生	全株、花、果
腺叶离蕊茶	*Camellia paucipunctata*	灌木或小乔木	土生	全株、花、果
黄花短蕊茶	*Camellia xanthochroma*	灌木或小乔木	土生	全株、花、果
海南柃	*Eurya hainanensis*	灌木或小乔木	土生	全株、果
卵叶柃	*Eurya ovatifolia*	灌木或小乔木	土生	全株、果
五柱柃	*Eurya pentagyna*	灌木或小乔木	土生	全株、果
海南大头茶	*Gordonia hainanensis*	乔木	土生	全株、花、果
海南厚皮香	*Ternstroemia hainanensis*	乔木	土生	全株、花、果
白毛子楝树	*Decaspermum albociliatum*	灌木	土生	全株、果
琼南子楝树	*Decaspermum austrohainanicum*	灌木	土生	全株、果
海南子楝树	*Decaspermum hainanense*	乔木	土生	全株、果
圆枝子楝树	*Decaspermum teretis*	乔木	土生	全株、果
假赤楠	*Syzygium buxifolioideum*	灌木	土生	全株、花、果
散点蒲桃	*Syzygium conspersipunctatum*	乔木	土生	全株、花、果
海南蒲桃	*Syzygium hainanense*	乔木	土生	全株、花、果
万宁蒲桃	*Syzygium howii*	灌木或小乔木	土生	全株、花、果
褐背蒲桃	*Syzygium infrarubiginosum*	乔木	土生	全株、花、果
尖峰蒲桃	*Syzygium jienfunicum*	乔木	土生	全株、花、果
皱萼蒲桃	*Syzygium rysopodum*	乔木	土生	全株、花、果
纤枝蒲桃	*Syzygium stenocladum*	乔木	土生	全株、花、果
方枝蒲桃	*Syzygium tephrodes*	灌木或小乔木	土生	全株、花、果
附生美丁花	*Medinilla arboricola*	攀援灌木	土生	全株、花
枝毛野牡丹	*Melastoma dendrisetosum*	灌木	土生	全株、花、果
海南锦香草	*Phyllagathis hainanensis*	灌木	土生	全株、花
毛锦香草	*Phyllagathis melastomatoides*	灌木	土生	全株、花
窄叶锦香草	*Phyllagathis stenophylla*	灌木	土生	全株、花
红毛卷花丹	*Scorpiothyrsus erythrotrichus*	灌木	土生	全株、花
黄毛卷花丹	*Scorpiothyrsus xanthostictus*	灌木	土生	全株、花
海南桑叶草	*Sonerila hainanensis*	草本	土生	全株、花、果
海南猴欢喜	*Sloanea hainanensis*	乔木	土生	全株、果
海南梧桐	*Firmiana hainanensis*	乔木	土生	全株、花、果
美丽火桐	*Grewia chuniana*	乔木	土生	全株、叶、花
保亭梭罗	*Reevesia botingensis*	乔木	土生	全株、花、果
剑叶梭罗	*Reevesia lancifolia*	乔木	土生	全株、花、果
长柄梭罗	*Reevesia longipetiolata*	乔木	土生	全株、花、果
陈氏铁苋菜	*Acalypha chuniana*	灌木	土生	全株、花、果
海南铁苋菜	*Acalypha hainanensis*	灌木	土生	全株、花、果
光果巴豆	*Croton chunianus*	灌木	土生	全株、果
宽昭巴豆	*Croton howii*	灌木	土生	全株、果
海南巴豆	*Croton laui*	灌木	土生	全株、果
长柄海南核果木	*Drypetes hainanensis*	乔木	土生	全株、果

续表1　　海南特有野生花卉资源特性一览表

海南大戟	*Euphorbia hainanensis*	灌木	石生	全株、叶、花、果
海南雀舌木	*Leptopus hainanensis*	灌木	土生	全株、果
海南叶下珠	*Phyllanthus hainanensis*	灌木	土生	全株、果
单花水油甘	*Phyllanthus nanellus*	草本	土生	全株、果
剑叶三宝木	*Trigonostemon xyphophylloides*	灌木	土生	全株、果
海南常山	*Dichroa mollissima*	灌木	土生	全株、花
裂叶悬钩子	*Rubus howii*	攀援灌木	土生	全株、叶、花、果
海南蝙蝠草	*Christia hainanensis*	草本	土生	全株、叶、花、果
海南猪屎豆	*Crotalaria hainanensis*	草本	土生	全株、叶、花、果
尖峰猪屎豆	*Crotalaria jianfengensis*	草本	土生	全株、叶、花、果
崖州猪屎豆	*Crotalaria yaihsienensis*	草本	土生	全株、叶、花、果
海南黄檀	*Dalbergia hainanensis*	乔木	土生	全株、果
白沙黄檀	*Dalbergia peishaensis*	灌木	土生	全株、果
红果黄檀	*Dalbergia tsoi*	灌木	土生	全株、果
短枝鱼藤	*Derris breviramosa*	灌木	土生	全株、果
海南鱼藤	*Derris hainanensis*	灌木	土生	全株、果
滨海木蓝	*Indigofera litoralis*	草本	土生	全株、花
疏节槐	*Sophora praetorulosa*	亚灌木	土生	全株、果
山铜材	*Chunia bucklandioides*	乔木	土生	全株、叶、果
柳叶假蚊母树	*Distyliopsis salicifolia*	灌木	土生	全株、果
海南黄杨	*Buxus hainanensis*	灌木	土生	全株、果
毛枝黄杨	*Buxus pubiramea*	灌木	土生	全株、果
小齿冷水花	*Pilea subedentata*	草本	土生	全株、叶
长柄冬青	*Ilex dolichopoda*	乔木	土生	全株、果
秀英冬青	*Ilex huiana*	灌木	土生	全株、果
保亭冬青	*Ilex liangii*	灌木或小乔木	土生	全株、果
洼皮冬青	*Ilex nuculicava*	乔木	土生	全株、果
石枚冬青	*Ilex shimeica*	乔木	土生	全株、果
海南卫矛	*Euonymus hainanensis*	灌木	土生	全株、果
保亭卫矛	*Euonymus potingensis*	灌木或小乔木	土生	全株、果
海南沟瓣	*Glyptopetalum fengii*	灌木	土生	全株、果
吊罗裸实	*Gymnosporia tiaoloshanensis*	攀援灌木	土生	全株、果
东方裸实	*Gymnosporia dongfangensis*	攀援灌木	石生	全株、果
海南美登木	*Maytenus hainanensis*	攀援灌木	土生	全株、果
隐脉假卫矛	*Microtropis obscurinervia*	灌木	土生	全株、果
密花五层龙	*Salacia confertiflora*	攀援灌木	土生	全株、果
海南五层龙	*Salacia hainanensis*	攀援灌木	土生	全株、果
假柴龙树	*Nothapodytes obtusifolia*	灌木或小乔木	土生	全株、果
东方肖榄	*Platea parvifolia*	乔木	土生	全株、果
石山蛇菰	*Balanophora saxicola*	草本	土生	全株
海南鼠李	*Rhamnus hainanensis*	灌木	土生	全株、果
狭叶乌蔹莓	*Cayratia lanceolata*	草质藤本	土生	全株、叶、果
过山崖爬藤	*Tetrastigma pseudocruciatum*	木质藤本	土生	全株、叶、果
海南黄皮	*Clausena hainanensis*	小乔木	土生、石生	全株、果
蜜茱萸	*Melicope patulinervia*	灌木	土生	全株、果
单叶异木患	*Allophylus repandifolius*	灌木	土生	全株、果
毛叶异木患	*Allophylus trichophyllus*	灌木	土生	全株、叶、果
鳞花木	*Lepisanthes hainanensis*	乔木	土生	全株、果
赛木患	*Lepisanthes oligophylla*	灌木或小乔木	土生	全株、果
爪耳木	*Sapindaceae unilocularis*	灌木	土生	全株、果
海南柄果木	*Mischocarpus hainanensis*	灌木	土生	全株、果
海南韶子	*Nephelium topengii*	乔木	土生	全株、果
单叶豆	*Ellipanthus glabrifolius*	乔木	土生	全株、果
保亭树参	*Dendropanax oligodontus*	灌木	土生	全株、叶
海南幌伞枫	*Heteropanax hainanensis*	乔木	土生	全株、叶
十蕊大参	*Macropanax decandrus*	乔木	土生	全株、叶
海南越橘	*Vaccinium hainanense*	灌木	土生	全株、花、果
崖柿	*Diospyros chunii*	灌木或小乔木	土生	全株、果
五蒂柿	*Diospyros corallina*	乔木	土生	全株、果
海南柿	*Diospyros hainanensis*	乔木	土生	全株、果
琼南柿	*Diospyros howii*	乔木	土生	全株、果
囊萼柿	*Diospyros inflata*	乔木	土生	全株、果
琼岛柿	*Diospyros maclurei*	乔木	土生	全株、果
海南紫荆木	*Madhuca hainanensis*	乔木	土生	全株、果
琼刺榄	*Xantolis longispinosa*	灌木或乔木	土生	全株、果
保亭紫金牛	*Ardisia baotingensis*	灌木	土生	全株、果
密鳞紫金牛	*Ardisia densilepidotula*	乔木	土生	全株、叶、果
轮叶紫金牛	*Ardisia ordinata*	灌木	土生	全株、果
细孔紫金牛	*Ardisia porifera*	灌木	土生	全株、果
弯梗紫金牛	*Ardisia retroflexa*	灌木	土生	全株、果
拟杜茎山	*Maesa consanguinea*	灌木	土生	全株、果
厚叶山矾	*Symplocos crassilimba*	乔木	土生	全株、花、果
柃叶山矾	*Symplocos euryoides*	灌木	土生	全株、花、果
单花山矾	*Symplocos ovatilobata*	乔木	土生	全株、花、果
海南流苏树	*Chionanthus hainanensis*	灌木或乔木	土生	全株、花、果
白皮素馨	*Jasminum rehderianum*	攀援灌木	土生	全株、花、果
狭叶木犀榄	*Olea neriifolia*	灌木	土生	全株、花、果
小叶木犀榄	*Olea parvilimba*	乔木	土生	全株、花、果
海南蕊木	*Kopsia hainanensis*	灌木	土生	全株、花、果
吊罗山萝芙木	*Rauvolfia tiaolushanensis*	灌木	土生	全株、花、果
荟蔓藤	*Cosmostigma hainanense*	草质藤本	土生	全株、花、果
海南匙羹藤	*Gymnema hainanense*	木质藤本	土生	全株、果
厚花球兰	*Hoya dasyantha*	草质藤本	土生	全株、花、果
崖县球兰	*Hoya liangii*	草质藤本	土生	全株、花、果
白水藤	*Pentastelma auritum*	草质藤本	土生	全株、花、果
海南弓果藤	*Toxocarpus hainanensis*	木质藤本	土生	全株、果
平滑弓果藤	*Toxocarpus laevigatus*	木质藤本	土生	全株、果
广花弓果藤	*Toxocarpus patens*	木质藤本	土生	全株、果
紫叶娃儿藤	*Tylophora picta*	木质藤本	土生	全株、果
异色雪花	*Argostemma discolor*	草本	土生	全株、花、果
海南雪花	*Argostemma hainanicum*	草本	土生	全株、花、果
木瓜榄	*Ceriscoides howii*	灌木	土生	全株、花、果
海南虎刺	*Damnacanthus hainanensis*	木质藤本	土生	全株、花、果
保亭耳草	*Hedyotis baotingensis*	草本	土生	全株、花
中华耳草	*Hedyotis cathayana*	草本	土生	全株、花
少卿耳草	*Hedyotis cheniana*	草本	土生	全株、花
大众耳草	*Hedyotis communis*	草本	土生	全株、花
闭花耳草	*Hedyotis cryptantha*	草本	土生	全株、花
海南耳草	*Hedyotis hainanensis*	草本	土生	全株、花
粉毛耳草	*Hedyotis minutopuberula*	草本	土生	全株、花
延龄耳草	*Hedyotis paridifolia*	草本	土生	全株、花
顶花耳草	*Hedyotis terminaliflora*	草本	土生	全株、花
五指山耳草	*Hedyotis wuzhishanensis*	草本	土生	全株、花
崖州耳草	*Hedyotis yazhouensis*	草本	土生	全株、花
黄果粗叶木	*Lasianthus calycinus*	灌木	土生	全株、花、果
瘤果粗叶木	*Lasianthus verrucosus*	灌木	土生	全株、花、果
琼梅	*Meyna hainanensis*	灌木或小乔木	土生	全株、花、果
短柄鸡眼藤	*Morinda brevipes*	攀援灌木	土生	全株、果
海南巴戟	*Morinda hainanensis*	攀援灌木	土生	全株、果
壮丽玉叶金花	*Mussaenda antiloga*	攀援灌木	土生	全株、花

续表1　　海南特有野生花卉资源特性一览表

海南玉叶金花	*Mussaenda hainanensis*	攀援灌木	土生	全株、花
乐东玉叶金花	*Mussaenda lotungensis*	攀援灌木	土生	全株、花
膜叶玉叶金花	*Mussaenda membranifolia*	攀援灌木	土生	全株、花
海南腺萼木	*Mycetia hainanensis*	亚灌木	土生	全株、花
海南蛇根草	*Ophiorrhiza hainanensis*	草本	土生	全株、花
溪畔蛇根草	*Ophiorrhiza humilis*	草本	土生	全株、花
海南九节	*Psychotria hainanensis*	灌木	土生	全株、花、果
海南染木树	*Saprosma hainanensis*	灌木	土生	全株、花、果
琼岛染木树	*Saprosma merrillii*	灌木	土生	全株、花、果
崖州乌口树	*Tarenna laui*	灌木	土生	全株、花、果
海南水锦树	*Wendlandia merrilliana*	灌木	土生	全株、叶、花
海南忍冬	*Lonicera calvescens*	木质藤本	土生	全株、花、果
刺冠菊	*Calotis caespitosa*	草本	土生	全株、花
海南菊	*Hainanecio hainanensis*	草本	土生	全株、花
海南半边莲	*Lobelia hainanensis*	草本	土生	全株、花
昌江厚壳树	*Ehretia changjiangensis*	攀援灌木	石生	全株、花
海南厚壳树	*Ehretia hainanensis*	乔木	土生	全株、花
疏花丁公藤	*Erycibe oligantha*	草质藤本	土生	全株、花
曲毛母草	*Lindernia cyrtotricha*	草本	土生	全株、花
扁蒴苣苔	*Cathayanthe biflora*	草本	土生	全株、花
烟叶唇柱苣苔	*Chirita heterotricha*	草本	土生	全株、花
盾叶苣苔	*Metapetrocosmea peltata*	草本	土生、石生	全株、花
毛花马铃苣苔	*Oreocharis dasyantha*	草本	土生	全株、花
黄花马铃苣苔	*Oreocharis flavida*	草本	土生	全株、花
昌江蛛毛苣苔	*Paraboea changjiangensis*	草本	石生	全株、花
海南蛛毛苣苔	*Paraboea hainanensis*	草本	土生	全株、花
海南秋英爵床	*Cosmianthemum viridiuliflorum*	草本	土生	全株、花、果
糙叶山蓝	*Peristrophe strigosa*	草本	土生	全株、花、果
海南叉柱花	*Staurogyne hainanensis*	草本	土生	全株、花、果
保亭叉柱花	*Staurogyne paotingensis*	草本	土生	全株、花、果
狭叶叉柱花	*Staurogyne stenophylla*	草本	土生	全株、花、果
琼海叉柱花	*Staurogyne strigosa*	草本	土生	全株、花、果
平基紫珠	*Callicarpa basitruncata*	灌木	土生	全株、花、果
红腺紫珠	*Callicarpa erythrosticta*	灌木	土生	全株、花、果
海南臭黄荆	*Premna hainanensis*	灌木	土生	全株、花、果
海南锥花	*Gomphostemma hainanense*	草本	土生	全株、花
海南黄芩	*Scutellaria hainanensis*	草本	土生	全株、花、果
保亭花	*Wenchengia alternifolia*	亚灌木	土生	全株、花
硬叶谷精草	*Eriocaulon sclerophyllum*	草本	土生	全株、花
海南兰花蕉	*Orchidantha insularis*	草本	土生	全株、花
革叶山姜	*Alpinia coriacea*	草本	土生	全株、花、果
海南假砂仁	*Amomum chinense*	草本	土生	全株、花、果
海南万寿竹	*Disporum hainanense*	草本	土生	全株、花、果
小花肖菝葜	*Heterosmilax micrandra*	攀援灌木	土生	全株、花、果
黎婆花	*Arisaema hainanense*	草本	土生	全株、花、果
海南千年健	*Homalomena hainanensis*	草本	土生	全株、花、果
落檐	*Schismatoglottis hainanensis*	草本	土生	全株、花、果
细花百部	*Stemona parviflora*	木质藤本	土生	全株、花、果
短叶省藤	*Calamus egregius*	木质藤本	土生	全株、果
裂苞省藤	*Calamus multispicatus*	木质藤本	土生	全株、果
单叶省藤	*Calamus simplicifolius*	木质藤本	土生	全株、果
多刺鸡藤	*Calamus tetradactyloides*	木质藤本	土生	全株、果
琼棕	*Chuniophoenix hainanensis*	乔木	土生	全株、叶、果
矮琼棕	*Chuniophoenix humilis*	灌木	土生	全株、叶、果
海南轴榈	*Licuala hainanensis*	灌木	土生	全株、叶、果
保亭金线兰	*Anoectochilus baotingensis*	草本	土生	全株、叶、花
多枝拟兰	*Apostasia ramifera*	草本	土生	全株、叶、花
海南石豆兰	*Bulbophyllum hainanense*	草本	附生	全株、花
乐东石豆兰	*Bulbophyllum ledungense*	草本	附生	全株、花
牛角兰	*Ceratostylis hainanensis*	草本	附生	全株、茎、花
华石斛	*Dendrobium sinense*	草本	附生	全株、花
海南锚柱兰	*Didymoplexiella hainanensis*	草本	土生	全株、花
镰叶盆距兰	*Gastrochilus acinacifolius*	草本	附生	全株、花
裂唇羊耳蒜	*Liparis fissilabris*	草本	附生	全株、花
拟石斛	*Oxystophyllum changjiangense*	草本	附生	全株、花
海南鹤顶兰	*Phaius hainanensis*	草本	土生	全株、花
海南大苞兰	*Sunipia hainanensis*	草本	附生	全株、花
东方毛叶兰	*Trichotosia dongfangensis*	草本	附生	全株、花
芳香白点兰	*Thrixspermum odoratum*	草本	附生	全株、花
扁茎苔草	*Carex planiscapa*	草本	土生	全株
线茎苔草	*Carex tsoi*	草本	土生	全株
东方苔草	*Carex tungfangensis*	草本	土生	全株
澄迈飘拂草	*Fimbristylis chingmaiensis*	草本	土生	全株
长柄果飘拂草	*Fimbristylis longistipitata*	草本	土生	全株
海南割鸡芒	*Hypolytrum hainanense*	草本	土生	全株
少穗割鸡芒	*Hypolytrum paucistrobiliferum*	草本	土生	全株
多花剑叶莎	*Machaerina myriantha*	草本	土生	全株
海南砖子蕾	*Mariscus hainanensis*	草本	土生	全株
单子砖子苗	*Mariscus monospermus*	草本	土生	全株
陈氏蔗草	*Scirpus chunianus*	草本	土生	全株
射毛悬竹	*Ampelocalamus actinotrichus*	灌木状	土生	全株
孟竹	*Bambusa bicicatricata*	乔木状	土生	全株
妈竹	*Bambusa boniopsis*	乔木状	土生	全株
吊罗坭竹	*Bambusa diaoluoshanensis*	乔木状	土生	全株
蓬莱黄竹	*Bambusa duriuscula*	乔木状	土生	全株
光鞘石竹	*Bambusa glabro–vagina*	乔木状	土生	全株
黎庵高竹	*Bambusa insularis*	乔木状	土生	全株
马岭竹	*Bambusa malingensis*	乔木状	土生	全株
黄竹仔	*Bambusa mutabilis*	乔木状	土生	全株
石竹仔	*Bambusa piscatorum*	乔木状	土生	全株
响子竹	*Monocladus levigatus*	乔木状	土生	全株
海南箭竹	*Fargesia hainanensis*	乔木状	土生	全株
藤单竹	*Bambusa hainanensis*	藤本状	土生	全株
细柄少穗竹	*Oligostachyum gracilipes*	灌木状	土生	全株
林仔竹	*Oligostachyum nuspiculum*	灌木状	土生	全株
毛稃少穗竹	*Oligostachyum scopulum*	灌木状	土生	全株
高画眉草	*Eragrostis alta*	草本	土生	全株、果
海南画眉草	*Eragrostis hainanensis*	草本	土生	全株、果
红脉画眉草	*Eragrostis rufinerva*	草本	土生	全株、果
微药金茅	*Eulalia micranthera*	草本	土生	全株
黄穗茅	*Imperata flavida*	草本	土生	全株
二芒金发草	*Pogonatherum biaristatum*	草本	土生	全株
刺毛头黍	*Setiacis diffusa*	草本	土生	全株

注：裸子植物按郑万钧系统(1978年)，被子植物按哈钦松系统(双子叶植物1926年，单子叶植物1934年)。属和种的排列按拉丁名首字母顺序排列。

常成片生长。

5 海南野生花卉资源的保护、开发与利用

特有植物分布具有极强的地域性，体现了该地区地质、气候、人文等特点。海南特有植物丰富，有强烈的热带特色，是我国难得的资源宝库，但目前对特有植物的深入研究与开发利用仍未引起足够重视。针对目前海南特有野生花卉的研究与利用现状，建议今后应开展或加强以下几方面的工作。

5.1 继续加强海南特有野生花卉资源的本底调查

海南野生植物数量至今仍没有确切答案，海南特有植物的数量也一直在增长中。随着调查的深入，海南野生植物和特有植物的数量仍将增加。海南特有野生花卉资源的地理分布、生境、生存现状及资源储藏量将是今后调查研究工作的重点。

5.2 深入了解海南特有野生花卉资源的生物学特性

目前对海南特有野生花卉资源的实验学科研究仅局限在少数类群的少数种类，如兰科、苏铁科植物，而对绝大多数特有植物的生物学特性缺乏认识，从而使引种繁殖带有盲目性，造成植物资源的极大破坏和浪费。对海南特有野生花卉开展生长发育、传粉、繁殖等生物学特性全面观测，并运用现代生物学技术进行快速繁殖将会对其资源保护与利用起到积极的促进作用。

5.3 大力推进海南特有野生花卉资源的引种栽培和驯化研究

植物特有现象与其珍稀濒危程度密切相关，多数特有植物也是珍稀濒危植物，两者在植物多样性研究和保护中同样具有优先地位。由于特有植物的形成与长期的演化适应和地理分异有关，对环境变化反应敏感，有着极为强烈的依赖关系，因此将来对特有植物资源研究与利用中务必注意对其生境和植株的重点保护。

特有植物野外种群个体数量往往较少，这也给其保护与利用带来一定困难，对于种群个体数量极少的物种应采取就地保护，而对种群个体数量较多的物种可在就地保护的基础上开展迁地保育工作，建立种质资源保存库，同时开展人工繁殖研究。

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(编辑/王媛媛)

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在混凝土上播种造林

——植被恢复与环境的生态性治理

案例说明

工程地点：河南省新乡市 / **施工时间**：2008年5月 / **边坡原貌**：混凝土喷锚坡面，坡度65° ~85° 之间。
植物配置：刺槐、盐肤木、火炬树、苦楝、臭椿、马棘、紫穗槐、胡枝子和黑麦草等。

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中国园林 Chinese Landscape Architecture
ISSN 1000-6664
CN 11-2165/TU
邮发代号：82-217
定 价：28.00元
ISSN 1000-6664
07
9 771000 666039

华南园林树木

Ornamental Trees in Southern China









图1 荷花玉兰的花和叶
图2 荷花玉兰的果实
图3 海南木莲的花和叶
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摄影 / 陈定如

广东园林 双月刊33卷 第2期

Guangdong Landscape Architecture 2011 • 04

ISSN 1671-2641 2011年04月出版
CN44-1219/S 定价：RMB15.00元

9 771671 264053 04

广东园林

广东园林学会主办
2011 2
1979年创刊
Vol. 33总第141期 双月刊

Guangdong Landscape Architecture



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适合园林应用的三种乌桕属乡土观赏植物

Three Indigenous Ornamental *Sapium* Plants for Landscape Application

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摘要：乌桕属植物在我国分布广泛，具有较高的经济价值和观赏价值。文章从形态特征、分布、习性、繁殖、观赏价值、应用特点等方面，介绍了适合在园林中推广应用的乌桕属三种植物。

关键词：山乌桕；圆叶乌桕；乌桕；特性；园林应用；广东园林
中图分类号：S688
文献标识码：A
文章编号：1671-2641(2011)02-0071-03
收稿日期：2010-04-26
修回日期：2010-05-13

Abstract: The *Sapium* plants have important economic and ornamental value and widely distribute in China. The morphological characteristic, distribution, habit, reproduction, ornamental value and application features of three species of *Triadica* were introduced in this paper.

Key words: *Triadica cochinchinensis; Triadica rotundifolia; Triadica sebifera;* Habit; Landscape application;Guangdong landscape architecture

乌桕属隶属大戟科（Euphorbiaceae），属的大小因其学名的改变而不同。《中国植物志（第四十四卷第三分册）》中记载，乌桕属（*Sapium*）全世界有120种，主要分布于热带地区，其中南美洲最多，中国有9种，分布于东南至西南丘陵地区，分为雌雄同序组（Sect. Triadica）、雌雄异序组（Sect. Falconeria）和拟乌桕组（Sect. Parasapium）[1]。而在*Flora of China*(Vol.11)中，将乌桕属细分为乌桕属（*Triadica*）、异序乌桕属（*Falconeria*）、浆果乌桕属（*Balakata*）、齿叶乌桕属（*Shirakiopsis*）和白木乌桕属（*Neoshirakia*），其中乌桕属（*Triadica*）包含3种，分布于亚洲东部和南部[2]。

乌桕属（*Triadica*）植物具有较高的经济价值，种子外被蜡质假种皮可作为制造蜡烛、肥皂等的工业原料，种子富含油脂可榨油制油漆，根皮、叶还可入药治水肿、蛔虫等疾病。此外，乌桕属植物也具有较高的观赏价值，树体优雅，叶形奇特，叶色富于变化。乌桕属包括山乌桕（*Triadica cochinchinensis* Loureiro）、圆叶乌桕[*T. rotundifolia* (Hemsley) Esser]和乌桕[*T. sebifera* (Linn.) Small]等3种，三者间叶形各有特点，区别较大（图1）。这3种植物在我国都有分布，作为优良的乡土植物，适合在园林中开发应用，在此对其进行推介。

1 山乌桕

山乌桕别名红心乌桕、红叶乌桕、膜叶乌桕，在《中国植物志（第四十四卷第三分册）》中，其学名为*Sapium discolor* (Champ. ex Benth.) Muell. Arg.。小乔木，高3～12 m，枝条灰褐色。单叶互生，叶片椭圆形或长卵形，纸质，长4～10 cm，宽2～5 cm，先端短渐尖或钝，基部楔形，全缘；叶柄纤细，长2～8 cm，顶端有2枚腺体。花单性，雌雄同株，总状花序顶生，密生黄色小花；雌雄花同在一花序上，但有时仅具雄花，



图1 三种乌桕属植物叶形比较

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图 2　山乌桕的果序



图 3　圆叶乌桕的果序



图 4　圆叶乌桕秋季的叶片

无花瓣及花盘；雄蕊 2，很少有 3 枚；雌花生于花序的近基部，子房 3 室，柱头 3 裂，向外反卷。蒴果黑色，球形，直径 1.0 ～ 1.5 cm；种子近球形，外被薄蜡质假种皮。花期 4 ～ 6 月，果期 8 ～ 10 月[1、3]（图 2）。

山乌桕在我国主要分布于西南、华南、华东等省区，在东南亚其他国家也有分布。模式标本采自广东南部。

山乌桕适应性强，喜生于山谷或山坡混交林中，喜土层深厚、湿润的土壤，较耐旱。可用播种繁殖，播种前需去除假种皮。

山乌桕树干通直，枝繁叶茂，叶形秀丽，质地柔软，叶色绿中带红，果实成熟后裂开露出白色假种皮，春季的嫩叶和秋季的成熟叶片也呈现红色，适合种于阴坡、山谷等稍阴湿处作园景树、行道树等，可丛植、列植或孤植。

2　圆叶乌桕

圆叶乌桕别名雁来红、大叶乌桕，在《中国植物志（第四十四卷第三分册）》中，其学名为 *Sapium rotundifolium* Hemsley。灌木至小乔木，高 3 ～ 12 m。叶互生，革质，近圆形，长 5 ～ 11 cm，宽 6 ～ 12 cm，顶端圆，稀凸尖，有时有浅内凹，基部圆、截平至微心形，全缘，腹面绿色，背面苍白色；中脉在背面显著凸起，网脉和边脉明显；叶柄稍粗壮，长 3 ～ 8 cm，顶端具 2 枚腺体。花单性，雌雄同株，密集成顶生的总状花序，雌花生于花序轴下部，雄花生于花序轴上部或有时整个花序全为雄花。蒴果近球形，直径约 2 cm；种子扁球形，外被蜡质假种皮。花期 4 ～ 6 月，果期 8 ～ 10 月[1、3]（图 3）。

圆叶乌桕在我国主要分布于西南、华南和华中，越南北部也有分布。模式标本采自广东。

圆叶乌桕喜生于阳光充足的石灰岩山地，是钙质土的指示植物，较耐旱。可用播种繁殖，播种前也需去除假种皮。

圆叶乌桕树姿优美，叶形大而奇特，质地厚实，叶色在春季、秋季均呈现红色（图 4），适合种植于假山、矿区、路旁等干旱环境，特别是石灰岩地区，作为园景树、庭荫树或行道树，可丛植、列植或孤植。

3　乌桕

乌桕别名腊子树、柏子树，在《中国植物志（第四十四卷第三分册）》中，其学名为 *Sapium sebiferum* (Linn.) Roxb.。落叶乔木，高达 15 m，树皮有纵裂纹，枝条广展（图 5）。单叶互生，叶片菱形至菱状卵形，纸质，长和宽均约 3 ～ 9 cm，先端渐尖或长尖，基部阔楔形或钝，全缘，两面无毛，秋天变成红色；叶柄细长，长 2.5 ～ 6.0 cm，顶端有 1 对腺体。花单性，雌雄同株，为顶生的总状花序，雌花常生于花序轴最下部，雄花序生于花序轴上部或有时整个花序全为雄花。蒴果梨状球形，成熟时黑色，直径 1.0 ～ 1.5 cm；种子扁球形，黑色，

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图 5　乌桕植株



图 6　乌桕的果枝

外被白色、蜡质假种皮。花期 4 ～ 8 月，果期 10 ～ 11 月[1、3]（图 6）。

乌桕在我国主要分布于黄河以南各省区，北达陕西、甘肃，日本、越南与印度也有分布，现全球多数地方有栽培。模式标本采自广州近郊。

乌桕适应性强，生长速度快，喜生于旷野、岸边或疏林中，较耐寒、耐旱、耐水湿，对土壤要求不严，酸性土、钙质土及稍盐碱土均能生长。以播种繁殖为主，播种前需去除蜡质假种皮；也可嫁接繁殖。注意防治小地老虎、脐蠕等地下害虫和毒蛾、蚜虫等地上害虫[4]。

乌桕在我国栽培和应用的历史悠久，据史料记载已有 1500 多年的历史[5]。乌桕种子富含油脂，是重要的工业原料植物；从其假种皮中提取的类可可脂，是生产巧克力和糖果的重要原料。乌桕叶形奇特、清秀，果实成熟后开裂露出白色的假种皮，而且乌桕对工业有毒气体抗性强，叶片具杀虫作用，春季长出的嫩叶和秋季叶片掉落前均呈现红色，适合种植于工厂、矿区、森林公园、河岸、池畔等地方，作行道树、园景树或护坡树，可丛植、列植或孤植。

在我国乌桕属植物作为药材、工业等经济用途历史悠久，但在园林中应用较少。乌桕被开发利用时间相对最长、范围最广，近年来山乌桕也逐渐被应用到园林绿化中，而圆叶乌桕至今仍未见被应用。乌桕属植物具有株形美观、叶形秀丽、叶色富于变化、适应性强、分布范围广、繁殖容易、生长速度快等特点，是我国园林中值得进一步开发利用的优良乡土植物。但是需要注意的是，乌桕属植物的叶片、果实均有一定的毒性，具杀虫功效，因此尽量不要应用于幼儿园、小学以及养殖场等儿童、家禽聚集的场所，以免发生误食中毒事故。

基金项目：广东省自然科学基金项目 (8451064201001149)、国家科技基础性工作专项项目 (2008FY110400 和 2006FY110500-1) 和华南农业大学校长基金项目 (2007K034)。

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■ 审稿编辑：刘海涛　冯志坚

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华南园林树木

Ornamental Trees in Southern China








图1 中国无忧树的花序和花
图2 海南红豆的花序和花
图3 海南红豆的叶、果实和种子
图4 火焰木的花序和花
图5 火焰木的枝叶、花序和果实
图6 炮仗花的花

摄影 / 陈定如

广东园林 双月刊33卷 第1期

Guangdong Landscape Architecture 2011 • 02

广东园林学会主办

广东园林

Guangdong Landscape Architecture

2011 1

1979年创刊 Vol. 33总第140期 双月刊



园林理论与研究
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ISSN 1671-2641 2011年02月出版
CN44-1219/S 定价：RMB15.00元



《广东园林》2011 年 第 1 期

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79 《广东园林》2011 年征稿简约

80 欢迎订阅 2011 年《广东园林》杂志

封面 惠州西湖

封底 华南园林树木

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2 种石灰岩特有植物的特性及园林应用

Characteristic, Landscaping Value, and Application of Two Endemic Species in Limestone Regions

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摘要：圆叶乌桕（*Triadica rotundifolia*）和报春苣苔（*Primulina tabacum*）是石灰岩特有植物，具有较高的学术、观赏和经济价值。文章从形态特征、分布、生态习性及繁殖等方面对圆叶乌桕和报春苣苔进行介绍，并阐述其园林观赏及应用价值。

关键词：圆叶乌桕；报春苣苔；石灰岩；特有植物；园林应用；广东园林
中图分类号：S688
文献标识号：A
文章编号：1671-2641(2011)01-0052-03
收稿日期：2010-03-29
修回日期：2010-05-27

Abstract: *Triadica rotundifolia* and *Primulina* tabacum are the endemic species in limestone regions in China. The two species have important academic, ornamental, and economic value. Their characteristics, distribution, habits, reproduction, landscaping value and application were introduced in this paper.

Key words: *Triadica rotundifolia*; *Primulina tabacum*; Limestone; Endemic species; Landscaping application; Guangdong landscape architure

石灰岩植物区系以含有丰富的喜钙植物为特征，历来受到植物学家的关注。我国大部分省区都有石灰岩分布，其中以华南、西南最为集中，主要包括贵州、广西、广东等省区。石灰岩特有植物不仅是研究物种形成、植物适应石灰岩地区地表水缺乏和土层浅薄等干旱环境下生存策略的良好材料，也可作为石灰岩基质园林造景中首选植物素材，具有较高的园林观赏与应用价值。文章简介石灰岩特有植物圆叶乌桕（*Triadica rotundifolia* (Hemsley) Esser）和报春苣苔（*Primulina tabacum* Hance）的形态特征、分布、生态习性、园林观赏和应用价值等，借此抛砖引玉，希望引起园林界对石灰岩特有植物研究和应用的重视，逐步形成既保护好又合理开发利用好的可持续发展模式。

1 圆叶乌桕和报春苣苔的形态特征

1.1 圆叶乌桕

大戟科乌桕属，1891 年 Hemsl. 根据采自广东的标本发表于《林奈学会植物学杂志》（*Botanical Journal of the Linnean Society*）第 26 卷 445 页，使用的学名是 *Sapium rotundifolium* Hemsley，属名“Sapium”是来源于拉丁词“sapinus”，意为一种松或枞，种加词“rotundifolium”是“圆叶的”，指圆叶乌桕叶片近圆形。*Sapium rotundifolium* 这一学名在中国植物志第四十四卷中得到沿用，2002 年 Esser 将 Sapium 中的一些种类组合到 *Triadica* 下，*Sapium rotundifolium* 作为 *Triadica rotundifolia* 的基本异名，2008 年 Flora of China(Vol.11) 接受这一分类处理，因此，圆叶乌桕最新的学名为 *Triadica rotundifolia* (Hemsley) Esser[1~3]。

灌木或乔木，高 3～12 m，叶互生，革质，近圆形，顶端圆，稀凸尖，有时有浅内凹，基部圆、截平至微心形，全缘，腹面绿色，背面苍白色；中脉在背面显著凸起，网脉和边脉明显；叶柄长 3～8 cm，顶端具 2 枚腺体（图 1）。花单性，雌雄同株，密集成顶生的总状花序，雌花生于花序轴下部，雄花生于花序轴上部或有时整个花序全为雄花。蒴果近球形，直径约 2 cm，种子扁球形，外被蜡质假种皮。花期 4～6 月；果期 8～10 月[1、2]。

1.2 报春苣苔

隶属于苦苣苔科报春苣苔属，1883 年 Hance 根据采自广东连州的标本发表于《植物学杂志》（*Botanical Journal*）第 21 卷 169 页，属名“Primulina”是由“Primula”（“报春花属”）和后缀“ina”（“相似”）组成，是指报春苣苔属与报春花属植物形态特征相似，种加词“tabacum”是“烟草”，指植株具有烟草气味[3~5]。

多年生草本。叶集生于植株基部，叶片圆卵形或正三角形，顶端微尖，基部浅心形，边缘浅波状或羽状浅裂，两面均被短柔毛；叶柄长 2～14 cm，边缘有波状翅（图 2）。花冠紫色，具细长花冠筒，稍二唇形，上唇 2 深裂，下唇 3 深裂；3～9 朵小花组成伞状聚伞花序（图 3）。蒴果长椭圆状球形，种子暗紫色，表面有瘤状突起。花期 6～9 月；果期 11 月至翌年 1 月[4、5]。



图 1 圆叶乌桕亮绿色的革质成熟叶片



图 2 报春苣苔植株

2 圆叶乌桕和报春苣苔的分布及生态习性

2.1 圆叶乌桕

圆叶乌桕在我国主要分布于广东、广西、云南、贵州和湖南等石灰岩地区，从海拔 50 ～ 600 m 均有分布，越南北部石灰岩地区也有分布。作者近年来，在中国科学院华南植物园邢福武研究员和华南农业大学庄雪影教授的指导下开展圆叶乌桕野外调查，发现广州石灰岩地区有一天然种群，约有 20 株，但此种群目前面临炸山采石、毁林开荒等人为威胁，应引起相关部门的重视。

圆叶乌桕喜阳光充足的石灰岩山地，是钙质土指示植物。多见于石灰岩地区陡峭石缝，根系发达，生命力强，伴生植物主要有青檀（*Pteroceltis tatarinowii*）、大叶土蜜树（*Bridelia fordii*）、中南鱼藤（*Derris fordii*）、铁灵花（*Celtis philippensis* var. *consimilis*）、八角枫（*Alangium chinense*）、竹叶花椒（*Zanthoxylum armatum*）、铁榄（*Sinosideroxylon pedunculatum*）、广东紫薇（*Lagerstroemia fordii*）和尾叶远志（*Polygala caudata*）等。作者 2009 年曾将圆叶乌桕引种于华南农业大学经济林苗圃，目前生长良好，可见其适应性较强，在非石灰岩地区也可以人工种植成活。

2.2 报春苣苔

报春苣苔是我国特有植物，仅见于广东连州、阳山和湖南宁远，生于海拔 100 ～ 300 m 处。分布相对集中，往往成片生长，但数量不多，每种群数量为 50 ～ 120 株，现被列为国家一级重点保护植物，也是国际自然保护联盟（IUCN）确认的濒危植物。

报春苣苔喜生于石灰岩崖壁，多见于洞口阴湿、土层稀薄之处，根系浅（图 4）。主要伴生植物有白垩铁线蕨（*Adiantum leveillei*）、半边铁角蕨（*Asplenium unilaterale*）、岩凤尾蕨（*Pteris deltodon*）、糙叶楼梯草（*Elatostema scabrum*）、对生耳蕨（*Polystichum deltodon*）、天仙果（*Ficus erecta*）和印度崖豆藤（*Millettia pulchra*）等。报春苣苔植株非常娇嫩，极易折断、破碎，适应性较弱，人工移植不易成活。

3 圆叶乌桕和报春苣苔的繁殖

圆叶乌桕的繁殖目前还未见报道，但同属的乌桕（*Triadica sebifera*）和山乌桕（*T. cochinchinensis*）利用播种、扦插、嫁接、组织培养繁殖方法均取得成功，特别是乌桕的繁殖技术相对较为成熟，在园林绿化和经济林种植中已广泛利用。圆叶乌桕种子因含有白色蜡质假种皮，播种繁殖前应去掉以提高发芽率，无性繁殖宜于春季选取茎尖或腋芽等。2009 年春季作者曾从广东石灰岩地区将两棵圆叶乌桕引种于苗圃，目前均生长良好，表现出较强的适应性。

报春苣苔自 20 世纪 90 年代被重新发现以来，已引起了政府和相关科研院所的高度关注。中国科学院华南植物园自 2002 年，开始研究报春苣苔的繁殖技术，结果证明报春苣苔种子萌发等传统方式的人工繁殖较为困难。2009 年，利用克隆技术繁殖成功并进行了回归种植实验，这一技术已获得国家发明专利授权。报春苣苔繁殖中保持阴湿环境至关重要，苔藓作为护理保湿植物，可提高报春苣苔的野外存活率和生长速度。



图 3 报春苣苔深紫色的花朵



图 4 报春苣苔的生长环境

4 圆叶乌桕和报春苣苔的价值和应用

4.1 价值

圆叶乌桕和报春苣苔均为石灰岩特有植物，对研究石灰岩这一特殊基质适生植物与种植技术具有较高理论和生产实践意义。圆叶乌桕和报春苣苔也具有较高的观赏价值，圆叶乌桕树形美观，叶近圆形，叶色变化多样，春、夏季为绿色，秋、冬季则变为暗红色；报春苣苔全株小巧玲珑，花色亮丽。此外，圆叶乌桕的种子含油量高，可以作为工业用油或医药化工的重要原料。

4.2 园林应用

石灰岩特有植物是经过长期自然选择、物种分化形成的珍贵资源，其中很多是珍稀濒危植物，并且具有较高观赏价值。圆叶乌桕生性强健，耐瘠薄，管理粗放，适合种植在园林绿地向阳砂壤土，可以孤植、片植或列植，奇特的叶形和丰富的叶色将为园林景观增色不少，并能吸引人们的注意。报春苣苔对其生长环境要求较高，适合种植在园林石灰岩假山阴湿处，培养基质以砂壤为佳，务必保持较高的空气湿度。

目前，在园林绿化中对石灰岩特有植物的应用较少，这不仅与社会对石灰岩特有植物的认识和重视不足有很大关系，也与石灰岩特有植物的种质资源、繁殖与栽培技术等基础研究薄弱有关。作者拟在对石灰岩特有植物适应性研究的基础上，继续深入探究其特有机理，特别是其形态和生理上的变异性及规律，为石灰岩特有植物的繁育及其在林业和园林中的推广应用提供理论依据。

基金项目：广东省自然科学基金（8451064201001149）、华南农业大学校长基金（2007K034）、广东省林业科技创新专项资金（2008KJCX010 和 2009KJCX014）。

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■ 审稿编辑：刘海涛 赵小兰

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Article

Delineating the Area for Sustainable Cultivation of *Morinda officinalis* Based on the MaxEnt Model

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Abstract: *Morinda officinalis*, a traditional medicinal plant in southern China, has a well-established cultivation history in Zhaoqing and Yunfu City of the Guangdong Province, China, contributing significantly to the local economy. Inadequate cultivation practices of *Morinda officinalis* may heighten the risk of landslide occurrences due to its specific growth and harvesting characteristics. This issue presents a challenge to the sustainable advancement of agriculture and forestry in the area, underscoring the necessity for scholarly intervention to address and devise effective remedies. This research utilized the MaxEnt model to assess landslide susceptibility and habitat suitability for *Morinda officinalis*, aiming to delineate appropriate cultivation zones amidst changing climatic conditions. The findings indicate that the model demonstrated a high level of accuracy, achieving combined AUC values of 0.802 for landslide susceptibility and 0.861 for habitat suitability evaluations, meeting the criteria for classification as "highly accurate". Regions such as the Yun'an District, Luoding City, and the Xinxing District in Yunfu City were identified as having a low landslide risk and being highly conducive to *Morinda officinalis* cultivation under current climate conditions. Future projections indicate an anticipated expansion of the species' distribution area between 2021 and 2040 under different climate scenarios, with subsequent variations. Spatial analysis unveiled a notable trend in the research area, indicating greater suitability for cultivation in the southern region compared to the northern region. This suggests that Yunfu City holds promise for facilitating the cultivation of *Morinda officinalis* more effectively than Zhaoqing City. This research offers a practical approach for promoting the sustainable growth of the regional *Morinda officinalis* industry, while also serving as a valuable resource for other economic crops encountering comparable developmental obstacles.

Keywords: sustainable cultivation; *Morinda officinalis*; habitat suitability; landslide susceptibility; MaxEnt model; climate change

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Citation: Liang, J.; Tang, G.; Qin, X. Delineating the Area for Sustainable Cultivation of *Morinda officinalis* Based on the MaxEnt Model. *Agronomy* **2024**, *14*, 1134. https://doi.org/10.3390/agronomy14061134

Academic Editor: Mark P. Widrlechner

Received: 22 April 2024
Revised: 22 May 2024
Accepted: 24 May 2024
Published: 26 May 2024

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1. Introduction

Morinda officinalis, a perennial vine plant belonging to the Morinda genus of the Rubiaceae family, is acknowledged as a traditional southern medicinal herb in China, renowned for its therapeutic attributes in enhancing kidney Yang and fortifying muscles and bones by harnessing the potency of its succulent roots [1]. In contemporary times, the escalating demand for *Morinda officinalis* has resulted in their excessive exploitation, consequently depleting the available raw materials. However, current research in the academic community on *Morinda officinalis* mainly focuses on its chemical composition [2–4], genetic diversity [5], etc. Only a small number of scholars have conducted research on its germplasm resource protection [6], and there is almost no related research on plant ecology.

The regions of Zhaoqing City and Yunfu City in the Guangdong Province offer conducive environmental conditions for the cultivation of *Morinda officinalis*. Deqing County and the Gaoyao District of Zhaoqing City are recognized as the principal cultivation regions for *Morinda officinalis*, boasting a cultivation legacy of more than 270 years [7]. The

expansion of the *Morinda officinalis* industry has had a substantial positive impact on the local economy, as evidenced by the example of Zhaoqing City where the cultivating area reached 40,900 hm^2 and the output value amounted to CNY 884 million by 2020 [7,8]. The development of the southern medicinal industry chain, spearheaded by *Morinda officinalis*, has yielded substantial economic gains and promising growth prospects, playing a crucial role in driving agricultural transformation, upgrading, and poverty alleviation among local farmers, thereby contributing to their prosperity.

However, based on our field investigations and discussions with native farmers, it has been noted that the development of the *Morinda officinalis* industry in the designated area has faced a period of stagnation in recent years. The local governments of the Fengkai County, Guangning County, and Yunan County have actively discouraged the growth of *Morinda officinalis* due to the potential hazards linked with unscientific cultivation methods, such as soil erosion and landslide incidents [9,10]. These practices can result in ecological harm and pose risks to human lives.

Due to its drought tolerance and susceptibility to waterlogging, *Morinda officinalis* is commonly cultivated by local farmers through a practice of continuous deforestation. This method involves uprooting trees with their roots from sunny slopes in the autumn, followed by deep soil excavation for subsequent cultivating. The deep-rooted characteristics of *Morinda officinalis* can result in substantial harm to surrounding vegetation during the harvesting process, consequently contributing to soil erosion on inclines and elevating the likelihood of landslides. Numerous regions within Zhaoqing City and Yunfu City exhibit susceptibility to moderate-to-high occurrences of geological disasters [11], underscoring the significance of implementing efficient measures for geological disaster prevention. The extensive and irregular cultivation of *Morinda officinalis* may heighten the susceptibility to landslide disasters. Therefore, the conflict arising from the economic advantages of cultivating *Morinda officinalis* and the environmental hazards linked to its cultivation requires urgent attention from the academic community to seek resolution.

The use of species distribution models (SDMs) to forecast suitable habitats for species has become an important tool for developing effective management and control strategies. SDMs use statistical techniques to link species distribution data with relevant environmental factors, helping to understand how a species' range is influenced by its environment and predict changes in distribution under different climate conditions [12,13]. One popular SDM, MaxEnt, is based on the maximum entropy theory and is known for its reliable performance, high accuracy, and low susceptibility to sampling biases [14]. As a result, the MaxEnt model has been increasingly adopted recently due to its easy-to-use interface and strong predictive abilities in ecology fields [14–18]. It is important to highlight that a number of researchers have recently begun employing the Maximum Entropy (MaxEnt) model for evaluating landslide susceptibility, yielding favorable outcomes in simulation studies [19–21].

Based on the above, the authors propose a solution to the challenges associated with the sustainable cultivation of *Morinda officinalis*, which entails the scientific selection of cultivating locations considering the probability of landslide occurrences and the plant's habitat suitability by applying the optimized MaxEnt model. We conducted two experiments to assess the habitat suitability and evaluate the landslide susceptibility of *Morinda officinalis* in Zhaoqing City and Yunfu City. By superimposing the outcomes of these experiments, the research aimed to assess the suitability of cultivating *Morinda officinalis* in Zhaoqing and Yunfu City, taking into consideration the impacts of climate change. The aim of the study was to identify cultivation areas characterized by a low landslide risk and high suitability for the growth of *Morinda officinalis*.

Through our investigation, we have identified the sustainable distribution range of *Morinda officinalis* within the study region, considering factors such as susceptibility to landslides and habitat suitability amidst the backdrop of climate change. This finding can be utilized by local *Morinda officinalis* cultivators and relevant authorities to enhance sustainable cultivation practices, aiding in the informed selection of planting sites and the

development of pertinent strategies to address existing challenges in the *Morinda officinalis* industry. Furthermore, the methodology employed in this study can be extrapolated to similar investigations concerning economic crops globally, particularly those grappling with the balance between ecological preservation and economic viability, with the aim of fostering the sustainable advancement of such crops.

2. Materials and Methods

2.1. Study Area Overview

The research area includes Zhaoqing City and Yunfu City in the Guangdong Province, located in the central and western regions along the middle reaches of the Xijiang River, with a total area of 22,676.16 km^2. The climate in this region is defined by mild winters and hot summers, accompanied by significant rainfall throughout the same seasons. The average annual temperature is 22.4 °C and the average annual precipitation is 1651.3 mm. This region is classified under the South Asian tropical monsoon climate category, characterized by ample sunlight, warmth, and water resources [22].

The main economic crops in the research area are mainly Chinese medicinal herbs, including *Morinda officinalis*, *Polygonum multiflorum*, *Citrus medica*, and *Cinnamomum cassia*. In addition, there are also specialty economic crops such as *Dendrobium officinale* and *Euryale ferox* [23].

The region's topography is primarily characterized by low mountains and hills, with a restricted and sporadic plain terrain. The study area is geologically situated within the South China fold system and is in close proximity to the Pacific Volcanic Seismic Belt. Numerous large and small northeast fault zones are prevalent in the region, resulting in relatively frequent geological occurrences like landslides and collapses [11,24].

The soil composition in the area consists mainly of mountain yellow and red soil types, which are highly suitable for the cultivation of *Morinda officinalis* [7]. According to the description of the yellow and red soils in the study area in the Chinese Soil Database (http://vdb3.soil.csdb.cn/, accessed on 13 October 2023), the soil texture is sandy loam, acidic in nature, with parent material being weathered granite alluvium and residual material. The soil layer is deep, suitable for the growth of economic crops and trees such as evergreen coniferous and broad-leaved forests. However, the soil contains a lot of sand, and after vegetation destruction, it is prone to soil erosion.

2.2. Research Method and Study Area Overview

2.2.1. Scenarios Setting

In this study, a collection of seven unique climate scenarios have been utilized, incorporating three scenarios derived from the shared socio-economic pathways outlined by the 6th International Coupled Model Comparison Program (CMIP6) for future climate projections [25]. The scenarios are elaborated in Table 1. The atmospheric circulation model employed is the second-generation National Climate Center Medium-Resolution Climate System Model (BCC-CSM2-M2), recognized for its improved precision in reproducing temperature and precipitation distributions in China [26].

Table 1. Three kinds of shared socio-economic pathways.

Scenario	Description
SSP1-2.6	Sustainable Path Scenario updates the RCP2.6 scenario by setting the radiative forcing at 2.6 W/m^2 in 2100.
SSP2-4.5	Medium development path scenario involves updating the RCP4.5 scenario to achieve a radiative forcing of 4.5 W/m^2 by 2100.
SSP5-8.5	The conventional development path scenario, which updates the RCP8.5 scenario and sets the radiative forcing at 8.5 W/m^2 in 2100.

2.2.2. Model Parameter Setting and Optimization

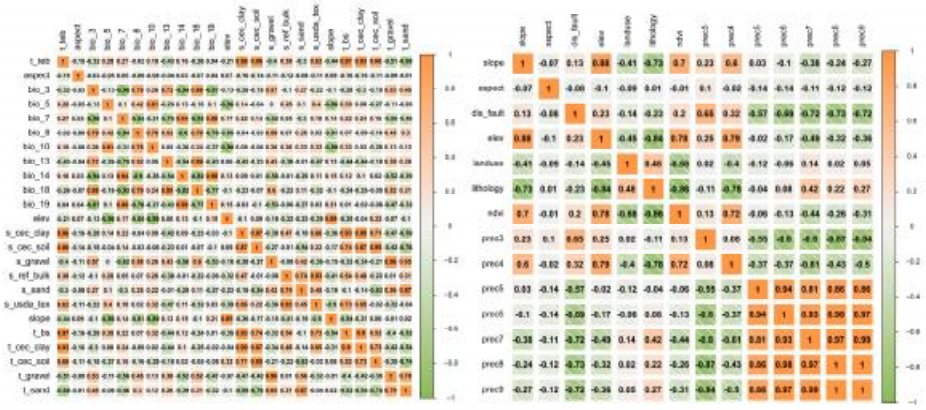
The MaxEnt model was utilized to simulate the habitat suitability and landslide susceptibility of *Morinda officinalis* in Zhaoqing City and Yunfu City. The model configuration involved allocating 75% of distribution points to the training set, 25% to the test set, and

employing the Bootstrap method for validation [27]. Each process was repeated 40 times to assess the predictive accuracy of the model using the Receiver Operating Characteristic (ROC) curve. The significance of environmental variables was evaluated utilizing the Jackknife method, with the default settings being retained for the remaining parameters.

The distribution points were segmented into two groups utilizing the "Kuemn" package (Version 2019)in the R language. Then, 75% of the random sample data were assigned to the training set, while the remaining 25% were allocated to the test set. The regularization multiplier (RM) and feature combinations (FC) were evaluated using the MaxEnt software(Version 3.4.1). The parameters were optimized by adjusting the RM within the range of 0.1 to 4, with increments of 0.1. A comprehensive set of regularization frequency multipliers comprising 40 variations and 29 feature combinations were established, encompassing Linear (L), Quadratic (Q), Hinge (H), Product (P), and Threshold (T) modifications. The Kuemn language package was utilized to evaluate 1160 different parameter combinations. The model's performance was assessed by the minimum information criterion AICc value, which was utilized to evaluate the Area under the Receiver Operating Characteristic (ROC) curve. The AUC difference test was employed to assess the adequacy and intricacy of the model. The model exhibiting the lowest Akaike Information Criterion corrected (AICc) value (AICc = 0) was considered the most appropriate for the development of the MaxEnt model [28].

2.2.3. Variables' Collinearity Test

To address the challenge of overfitting in model simulations caused by autocorrelation among environmental variables, all environmental variables were initially included in the MaxEnt model for simulation. Variables that showed no significant impact on the model (as indicated by a contribution rate of 0) were subsequently removed from the simulation results. The residual environmental variables were subsequently imported into the SPSS software(Version 17)for further analysis. The presence of multicollinearity among variables was evaluated through the utilization of the Pearson correlation coefficient (r) [29]. In instances where sets of variables exhibited a strong correlation ($|r| > 0.8$), only the variable with the highest contribution rate was selected for inclusion in the final model implementation. Figure 1 shows the correlation analysis performed in the two subexperiments that constitute this study.



(**a**) (**b**)

Figure 1. Experimental collinearity test of landslide susceptibility evaluation (**a**) and habitat suitability evaluation of *Morinda officinalis* (**b**).

2.2.4. Accuracy Evaluation Method

The Receiver Operating Characteristic (ROC) curve functions as a metric for assessing the accuracy of model predictions. The area enclosed by the Receiver Operating Characteristic (ROC) curve and the *x*-axis is commonly referred to as the Area Under the ROC Curve (AUC) value, which serves as a key indicator of the optimal model accuracy [30].

The Area Under the Curve (AUC) value is a scalar that ranges from 0 to 1. Values closer to 1 suggest higher predictive accuracy [31]. Typically, an AUC value ranging from 0.7 to 0.8 is classified as "relatively accurate", values between 0.8 and 0.9 are deemed "very accurate", and those surpassing 0.9 are denoted as "highly accurate" [32].

2.2.5. Technical Route

This study comprises two experiments: the analysis of landslide susceptibility in Zhaoqing City and Yunfu City in the Guangdong Province (Experiment 1), and the assessment of habitat suitability for *Morinda officinalis* (Experiment 2). In experiment 2, particular attention is given to considering the ecological differences present among different populations of *Morinda officinalis* in order to improve the scientific evaluation of the suitability of habitats for this species. The inclusion of distribution data for *Morinda officinalis* across China is utilized to evaluate the appropriateness of habitats. Subsequently, the masking extraction tool in ArcGIS is used to extract the results of the habitat suitability assessment based on the scope of the study area. Upon analyzing the results of both experiments, a superposition analysis was conducted to determine the geographic distribution of regions exhibiting high habitat suitability and low susceptibility to landslides for *Morinda officinalis*. The technical methodology utilized is depicted in Figure 2.

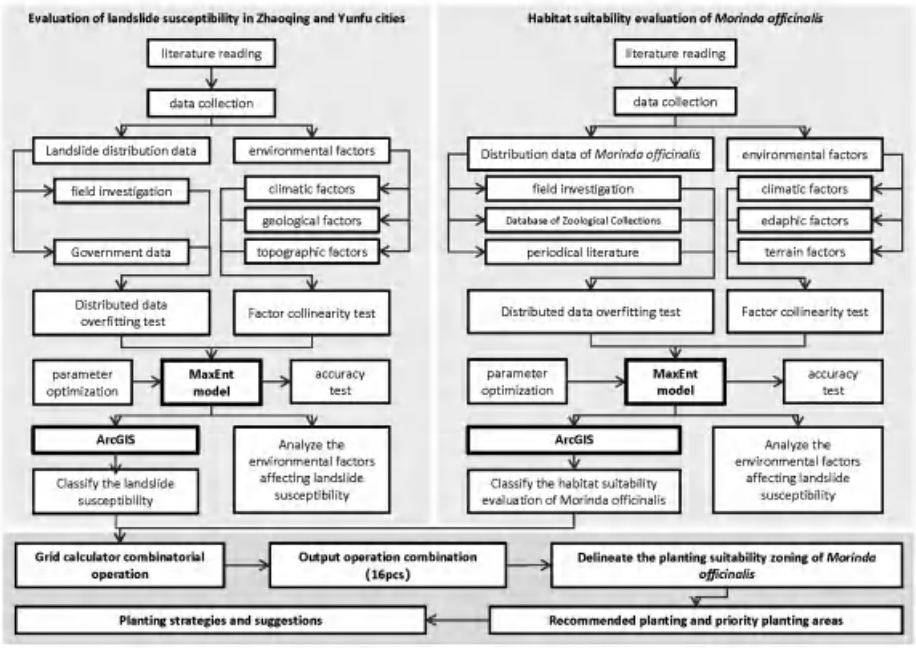


Figure 2. Technical route of this study.

2.3. Data Sources

2.3.1. Landslide Data and Morinda Officinalis Distribution Data

The landslide disaster data utilized in this study were obtained from the Zhaoqing Natural Resources Bureau and Yunfu Natural Resources Bureau of the Guangdong Province through official channels, comprising a total of 134 records. The data encompassed details such as the geographical coordinates of the landslide locations, their severity classification, and the count of individuals at risk. A dataset comprising 88 data points on the distribution of *Morinda officinalis* was compiled from diverse sources, which were collected from all over China. These sources included field surveys that documented GPS coordinates, literature reviews from databases like CNKI and Wanfang, as well as shared databases such as the Global Biodiversity Information Database (GBIF, http://www.gbif.org/, accessed on 13 October 2023), China Digital Herbarium (CVH: https://www.cvh.ac.cn/, accessed on 13 October 2023), and the National Specimen Sharing Platform (NSII: http://www.nsii.org.cn/, accessed on 17 October 2023). To address the potential issue of model overfitting due

to sampling biases and dense local data points, we utilized the ENMtools software(Version 1.3) package to perform an overfitting analysis and screening of both landslide disaster and *Morinda officinalis* distribution data points at a resolution of the environmental variables (30 arc s, ~1 km). This study collected a total of 127 data points on landslide disaster occurrences and 54 points on the distribution of *Morinda officinalis* (Figure 3). Among them, the habitat suitability experiment of *Morinda officinalis* was first conducted nationwide, and then the output results were processed into the study area by an ArcGIS 10.8 software mask.

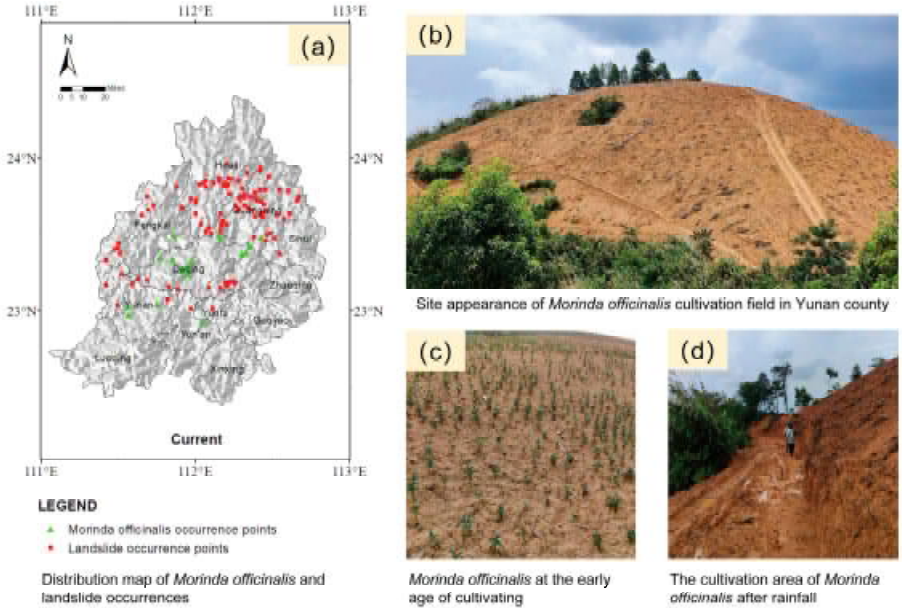


Figure 3. The occurrence points distribution of *Morinda officinalis* and landslide and the appearance of *Morinda officinalis* cultivation field. (**a**) Distribution map of *Morinda officinalis* and landslide occurrences. (**b**) Site appearance of *Morinda officinalis* cultivation field in Yunan county. (**c**) *Morinda officinalis* at the early age of cultivating. (**d**) The cultivation area of *Morinda officinalis* after rainfall.

2.3.2. Selection of Environmental Variables

This study comprises two sets of sub-experiments that differ in the selection of environmental impact variables (Table S1). In the experiment evaluating landslide susceptibility, climate, terrain, geology, and land cover were recognized as the principal variables based on prior studies of landslide occurrences in the Guangdong Province [33,34]. Climate variables were selected based on the prevalence of rainfall-triggered landslides in the area, particularly during the flood season spanning from March to September [35]. The precipitation data spanning from 2020 to 2022 (sourced from the Resources and Environmental Science and Date Center) [36] and future climate predictions covering the period from 2021 to 2060 (obtained from the World Climate Database) [37] were utilized. Topographic variables comprised elevation, slope, and aspect. The elevation data were obtained from the World Climate Database, while slope and aspect data were computed utilizing ArcGIS software. Geological variables, including lithology and distance from faults, were chosen according to regional conditions and previous studies [38–40], utilizing data sourced from the Geocloud Platform of China Geographical Survey (https://geocloud.cgs.gov.cn/, accessed on 23 May 2024). The distance from faults was assessed by importing fault lines into ArcGIS software and computing the Euclidean distance. Land cover involved utilizing vegetation cover data from 2019 [41] and land use data from 2020 [42], sourced from the Resource Environmental Science and Data Center.

At the same time, three primary criteria were established simultaneously to assess the suitability of habitats: climate, soil, and terrain variables. Data regarding climatic and topographic conditions were obtained from the World Climatic Database (http://www.worldclim.org, accessed on 23 May 2024) for both current (1970–2000) as well as future

periods (2021–2040 and 2041–2060). The climatic factor index consisted of 19 bioclimatic variables (bio1-bio19), whereas the topographic factor index replicated the one utilized in a prior landslide susceptibility investigation. Soil data were obtained from the Harmonized World Soil Database (HWSD) by utilizing the Chinese Soil Data Set (v1.1) available at http://vdb3.soil.csdb.cn/ (accessed on 23 May 2024). One soil type was chosen from a selection of 34 options for the purpose of this analysis. Consequently, a comprehensive evaluation of habitat suitability for *Morinda officinalis* involved the consideration of 56 environmental variables, as outlined in Table S2.

Before performing the MaxEnt model simulation, the raster data depicting different environmental variables were standardized in a resolution and geographic coordinate system. For this study, all environmental impact variables were standardized to a uniform resolution of 30 arc seconds and a cohesive geographic coordinate system of WGS1984.

3. Results and Analysis

3.1. Environmental Variables' Screening Results

Upon integrating the distribution points and environmental impact variables of the two experimental groups into the MaxEnt model for simulation, an evaluation of collinearity among the environmental impact variables was conducted following the guidelines detailed in Section 2.2.3 (Figure 2). The selected environmental impact variables for incorporation into the model are delineated in Tables 2 and 3.

Table 2. Environmental variables selected for landslide susceptibility evaluation experiment after collinearity test.

Primary Index	Secondary Index	Code	Percent Contribution	Permutation Importance
Climatic variables	Precipitation in April	prec4	8.1	7.4
	Precipitation in July	prec7	23.1	6.6
	Precipitation in August	prec8	29.2	44.9
Terrain variables	Elevation	elev	22.7	31.1
	Aspect	aspect	1.8	1.2
Geological variables	Lithology	lithology	7.1	6.4
	Distance from fault	dis_fault	8	2.5

Table 3. Environmental variables selected for habitat suitability evaluation experiment of *Morinda officinalis* after collinearity test.

Primary Index	Secondary Index	Code	Percent Contribution	Permutation Importance
Climatic variables	Monthly mean temperature	Bio2	21.4	27.1
	Annual temperature range	Bio7	34.2	39.8
	Wettest monthly precipitation	Bio13	7.8	8.5
Edaphic variables	Subsoil gravel volume percentage	S_gravel	3.5	1.5
	Sediment content in the subsoil	S_sand	2.9	3.4
	Subsoil texture classification	S_usda_tex	5.7	3.3
	Cation exchange capacity of the lower cohesive layer soil	S_cec_clay	0.1	0.2
	Cation exchange capacity of the subsoil	S_cec_soil	8.1	6.3
	The subsoil can exchange sodium salts	S_esp	2.4	2.7
	Cation exchange capacity of upper cohesive layer soils	T_cec_clay	0.2	0.5
Terrain variables	Aspect	Aspect	12.2	4.5
	Slope	Slope	1.5	2.2
	Aspect	Aspect	12.2	4.5
	Slope	Slope	1.5	2.2

3.2. Model Optimization Parameter Results and Accuracy Evaluation

Following the protocol delineated in Section 2.2.2, the optimization and validation of the landslide susceptibility assessment model were conducted. This process involved the utilization of seven environmental variables and 127 instances of landslide occurrences after a screening process. The optimized parameters for the landslide susceptibility assessment

model were determined as RM = 2.2 and FC was set equal to QT. Subsequently, the model underwent refinement and testing using 14 selected environmental variables and 54 data points associated with the distribution of *Morinda officinalis*. The optimized parameters for the habitat suitability assessment model of *Morinda officinalis* were identified as RM = 0.8 and FC was set equal to Q.

The Receiver Operating Characteristic (ROC) curves of the two cohorts, which were subjected to trials for assessing landslide susceptibility and evaluating the suitability of the *Morinda officinalis* habitat, were individually produced utilizing the refined MaxEnt model, as illustrated in Figure 4. In line with the precision assessment methodology outlined in Section 2.2.4, the Area Under the Curve (AUC) metric for the experiments assessing landslide susceptibility and *Morinda officinalis* habitat suitability was calculated to be 0.802. Moreover, the Area Under the Curve (AUC) value for the experiment assessing the habitat suitability of *Morinda officinalis* was determined to be 0.861. These results indicate that the predictive abilities of both experiments have reached a high level of accuracy.

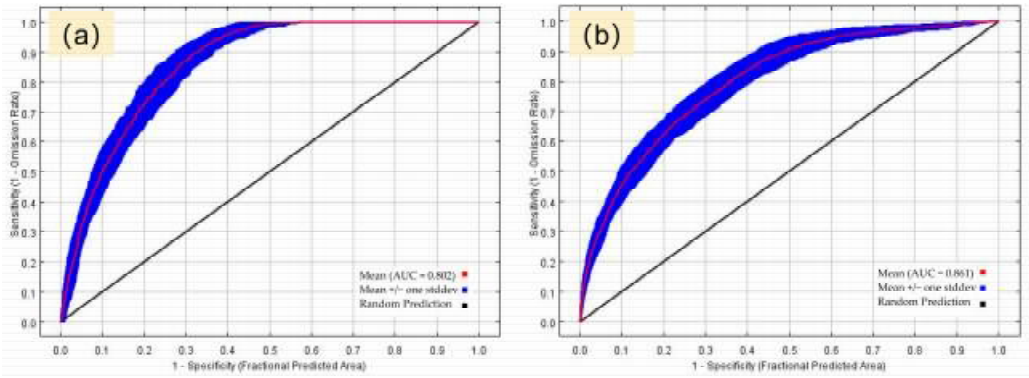


Figure 4. Average AUC of the Landslide susceptibility evaluation model (**a**) and Habitat suitability evaluation model for *Morinda officinalis* (**b**).

3.3. Evaluation of Landslide Susceptibility in Zhaoqing City and Yunfu City of Guangdong Province under Current and Future Climatic Conditions

The natural breakpoint method implemented in the ArcGIS software was employed to segment the outcomes of landslide susceptibility produced by MaxEnt (Figure 5). The landslide susceptibility zones in Zhaoqing City and Yunfu City, located in the Guangdong Province, have been categorized into four levels based on the landslide susceptibility index (P): Non-susceptibility area ($P < 0.14$), low-susceptibility area ($0.15 \leq P \leq 0.32$), medium-susceptibility area ($0.33 \leq P \leq 0.50$), and high-susceptibility area ($P > 0.51$). According to the data provided in Table 4, the current climate conditions suggest that the areas prone to high landslide susceptibility in Zhaoqing City and Yunfu City, located in the Guangdong Province, cover a total area of 4054 km^2. The aforementioned areas are primarily located in the western and north-central regions of the research area, encompassing a substantial portion of the Fengkai County, the southern area of the Huaiji County, the western sector of the Guangning County, the northern vicinity of Sihui City, the northeastern part of the Deqing County, and the northwestern part of Yunfu City. The medium-susceptibility area covers an estimated 5034 km^2, mainly concentrated in the central region of the study area, particularly surrounding the Deqing County, Gaoyao District, Huaiji County, Guangning County, and Fengkai County. Moreover, this geographical area encompasses the northwestern region of the Gaoyao District in Zhaoqing City, the eastern area of the Yunnan County in Yunfu City, the central zone of Luoding City, and the northern sector of the Yuncheng District. The areas of low susceptibility and non-susceptibility, totaling approximately 5306 km^2, are predominantly located in the northern and southern regions of the research area. These areas are particularly concentrated near the Yun'an District, Yuncheng District, Xinxing County, Gaoyao District, Duanzhou District, and Dinghu District of Zhaoqing City. The distribution of landslide susceptibility within the study area shows a spatial pattern

characterized by higher susceptibility in the northern region and lower susceptibility in the southern region. Yunfu City exhibits a lower level of landslide susceptibility in comparison to Zhaoqing.

In the context of climate change, the study area demonstrates diverse trends in landslide susceptibility across regions under distinct climate scenarios (Table 4). This study focuses on investigating the regional variations in areas characterized by low or no susceptibility to landslides. In scenarios SSP1-2.6 and SSP5-8.5, a decrease in the regions with low-to-no susceptibility to landslides is projected from 2021 to 2040 when compared to the current climate conditions. This decrease is especially significant in the northern, southwestern, and southeastern regions of the research area. During the period from 2041 to 2060, there will be an upward trend observed, leading to overall areas that are comparable to the current conditions. Conversely, in the SSP2-4.5 scenario, regions with low-to-no susceptibility to landslides show a consistent decline. Projections suggest a decrease to 3301.02 km^2 by 2041–2060, marking a 38% reduction compared to the present climate conditions. Notably, there has been a rise in the prevalence of areas exhibiting non-susceptibility and low susceptibility within the eastern and central regions of the study area.

Table 4. Statistical unit of landslide-prone zone area in different periods Unit: km^2.

Unit: km^2	Current	2021–2040			2041–2060		
		SSP1-2.6	SSP2-4.5	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP5-8.5
Non-susceptibility area	5015.278	5946.528	3295.139	7519.444	2027.778	7608.333	2478.472
Low-susceptibility area	5806.944	6004.861	4314.583	5435.417	4234.722	6068.055	4597.917
Medium-susceptibility area	5034.028	5095.139	6127.778	5241.668	7215.972	4812.450	7345.833
High-susceptibility area	4054.861	2866.667	6175.694	1716.667	6434.722	1424.306	5490.972

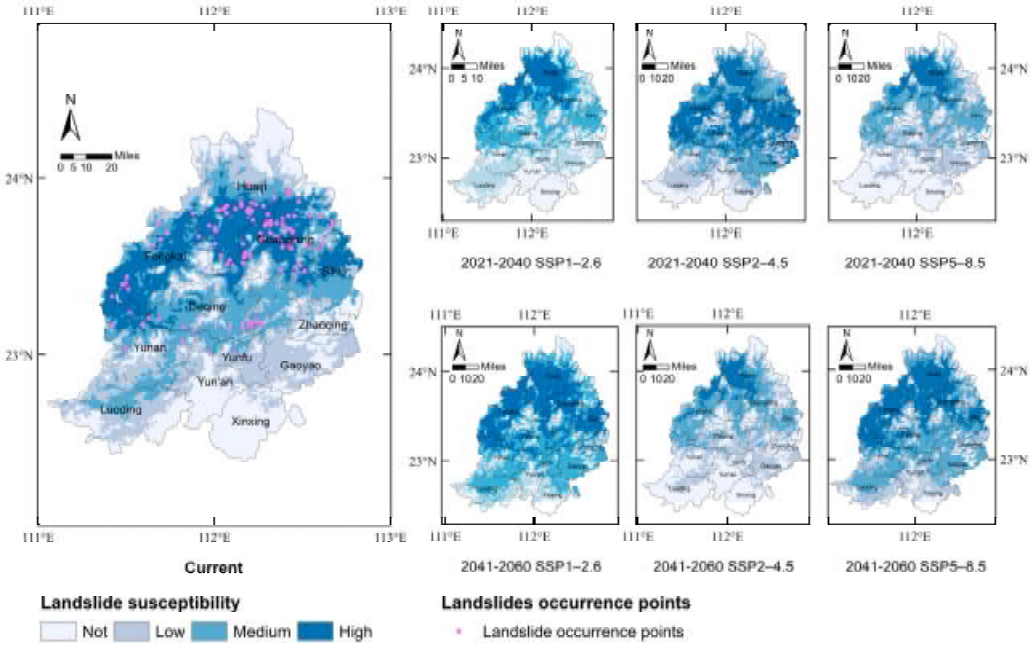


Figure 5. Landslide susceptibility zoning in Zhaoqing City and Yunfu City, Guangdong Province, under current and future climate conditions.

3.4. Habitat Suitability Evaluation of Morinda officinalis in Zhaoqing City and Yunfu City of Guangdong Province under Current and Future Climate Conditions

Similarly, the natural breakpoint method in the ArcGIS software was employed to divide the habitat suitability results of *Morinda officinalis* produced by MaxEnt (see Figure 6). The habitat suitability zoning for *Morinda officinalis* was categorized into four tiers, varying from low to high, according to the habitat suitability index (Q): non-prone area (Q < 0.28),

low-suitability area ($0.29 \leq Q \leq 0.42$), medium-suitability area ($0.43 \leq Q \leq 0.57$), and high-suitability area ($Q > 0.58$). The results revealed that the combined suitable area covered around 15,942 km^2 in Zhaoqing City and Yunfu City, with the majority consisting of the low-suitability area totaling 6695 km^2. The area classified as moderately suitable ranked second, encompassing approximately 37% of the total suitable area. The high-suitability region covers an area of 3336 km^2, primarily located in the western and southern sectors of the study area. The regions characterized by a distinct scale distribution predominantly encompassed the western and southern sectors of the Yunan District in Yunfu City, the eastern segment of the Yunan County, the eastern area of Luoding City, the western part of the Xinxing County, the eastern part of the Huaiji County in Zhaoqing City, the southern part of the Fengkai County, and the central part of the Deqing County, among other locations. The remaining regions were scattered. The high-suitability zones for *Morinda officinalis* in the study area exhibited a relatively dispersed distribution pattern. The suitability pattern was approximately described as being "high in the west and low in the east, high in the south and low in the north".

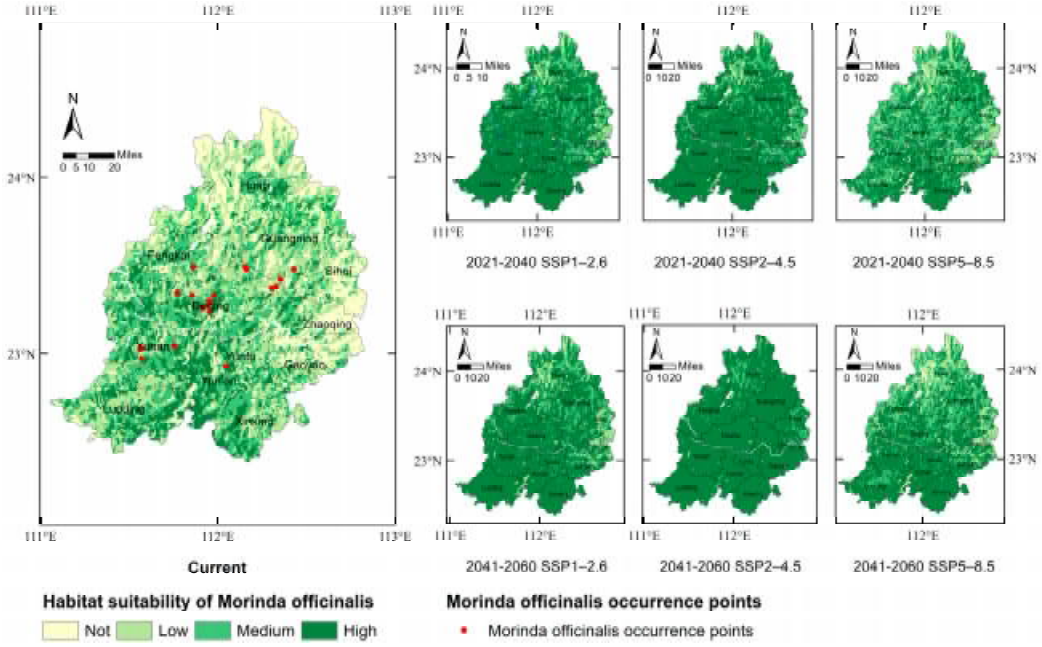


Figure 6. Suitability zoning of *Morinda officinalis* in Zhaoqing City and Yunfu City, Guangdong Province, under current and future climatic conditions.

In the context of climate change, the habitat suitability of *Morinda officinalis* within the research area has experienced substantial changes, as outlined in Table 5. Between the periods of 2021–2040 and 2041–2060, there was a marked increase in the area of highly suitable habitats for *Morinda officinalis*, with a growth pattern that initially showed rapid expansion before slowing down. Projections based on the SSP1-2.6 scenario indicate that the high-suitability habitat area for *Morinda officinalis* is expected to expand to 11,870 km^2 between 2021 and 2040. This represents a 256% increase compared to current climate conditions. This expansion is primarily characterized by a significant increase in the surrounding area with high suitability under the prevailing climate conditions. By the period of 2041–2060, it is anticipated that the area with high suitability will cover 15,336 km^2, indicating a 29% increase compared to the previous period of 2021–2040. Moreover, it is anticipated that the region with high suitability will exhibit increased contiguity. Under the SSP2-4.5 scenario, the high-suitability area of *Morinda officinalis* exhibited a significant increase of 387% from 2021 to 2040, expanding to 16,255 km^2. Subsequently, a more moderate rise was noted from 2041 to 2060, reaching 15,336 km^2. It is noteworthy that only a limited number of isolated regions within the study area were not classified as

high-suitability areas. In contrast, the expansion of the high-suitability area for *Morinda officinalis* was relatively smaller under the SSP5-8.5 scenario compared to the other two climate scenarios. An increase of 201% was observed between 2021 and 2040, leading to a total area of 11,982 km^2 by the period of 2041–2060. The expansion primarily focused on the southwestern and southern sectors.

Table 5. Statistical unit of habitat suitability area of *Morinda officinalis* in different periods. Unit: km^2.

Unit: km^2	Current	2021–2040			2041–2060		
		SSP1-2.6	SSP2-4.5	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP5-8.5
Non-suitable area	3706.944	134.028	33.333	261.111	54.167	4.861	347.222
Low-suitability area	6695.139	2061.806	781.250	2377.778	1188.194	31.250	1981.250
Medium-suitability area	5911.111	5583.333	2579.167	6984.028	3070.139	968.056	5338.194
High-suitability area	3336.111	11,870.139	16,255.555	10,026.389	15,336.805	18,645.139	11,982.639

3.5. Under Current and Future Climate Conditions, the Cultivating Zones of Morinda Officinalis in Zhaoqing City and Yunfu City of Guangdong Province Were Determined

In alignment with the research objectives, the results of the landslide susceptibility and habitat suitability evaluations for Morinda officinaria in Zhaoqing city and Yunfu city, located in the Guangdong Province, were superimposed, yielding a total of 16 combinations. Subsequently, these combinations were stratified into different tiers of cultivating suitability zones for *Morinda officinalis* within the study area, encompassing a total of six levels (Figure 7). The cultivating regions were categorized into different levels of suitability based on a ranking system ranging from the least to most favorable. These categories included extremely unsuitable, unsuitable, low suitability, moderate suitability, high suitability, and optimal suitability. The delineations were visualized using ArcGIS software, and the results are illustrated in Figure 8.

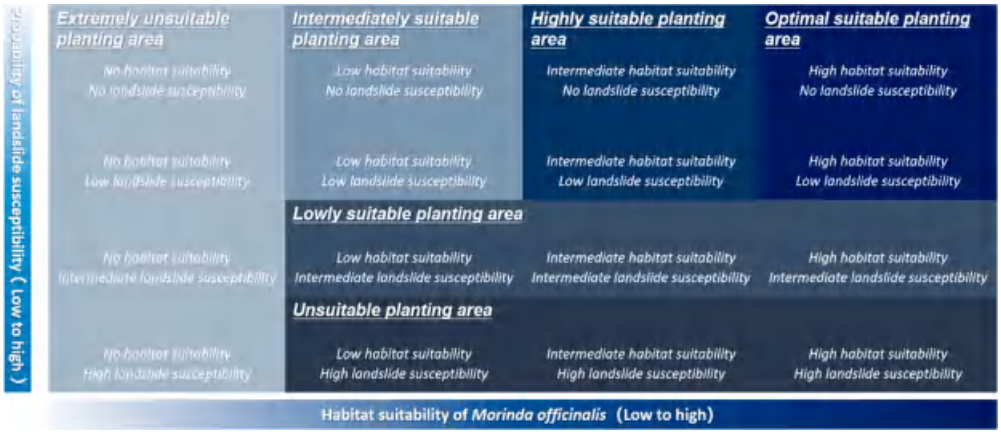


Figure 7. Cultivating zoning of *Morinda officinalis* in Zhaoqing City and Yunfu City, Guangdong Province, China.

The results revealed that under the prevailing climatic conditions, the low-suitability cultivation area for *Morinda officinalis* in the study area accounted for the highest percentage at 22%, covering a landmass of 4239 km^2 (Table 6). Conversely, the cultivation region with the optimal suitability represented only 10% of the total, primarily located in diverse areas such as the Yun'an District of Yunfu City, the southeastern region of Luoding City, and the western and southern parts of the Xinxing County, and sporadically found in the Yuncheng District of Yunfu City, the central and northern Huaiji County of Zhaoqing City, the southwest of the Gaoyao District, and other dispersed sites. The cultivation land area of 2953 km^2 is highly suitable, with a primary concentration in the most favorable cultivation region. The least suitable cultivation area covered 4239 km^2, ranking second in size after

the area with low-suitability cultivation conditions. This area was primarily located in the northern part of the Huaiji County, as well as in the central and eastern areas of Sihui City and Zhaoqing City. The cultivation suitability of *Morinda officinalis* in the study area demonstrated a spatial pattern characterized by higher suitability in the southern regions and lower suitability in the northern areas. This pattern exhibited a negative correlation with the distribution of landslide susceptibility.

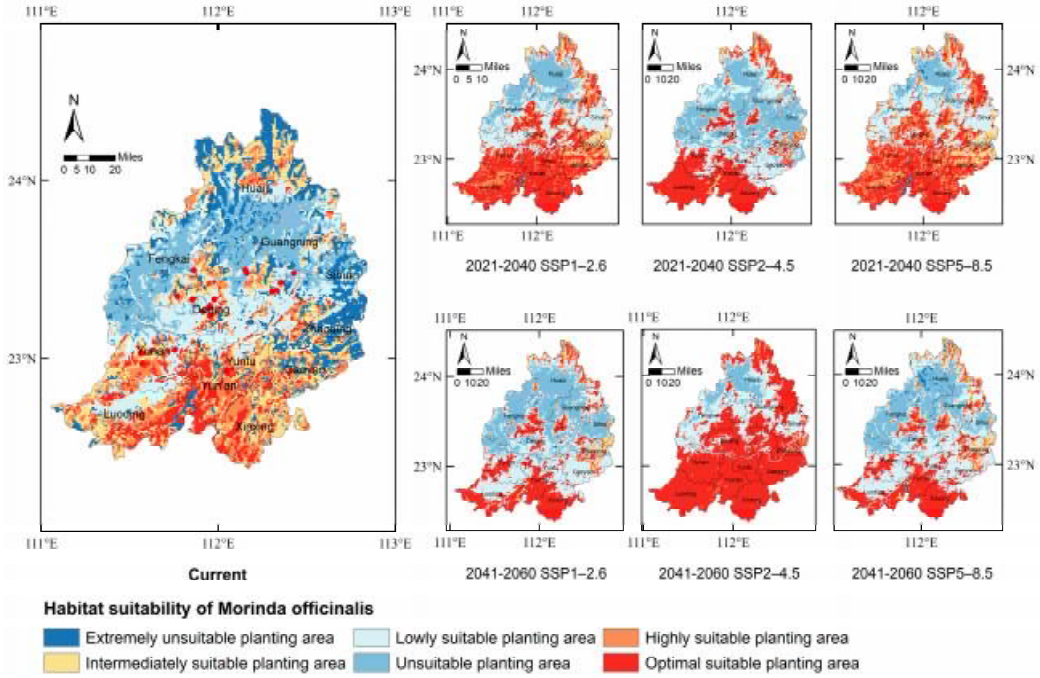


Figure 8. Cultivating suitability zoning of *Morinda officinalis* in Zhaoqing City and Yunfu City of Guangdong Province under current and future climate conditions.

In the context of climate change, the suitability of cultivating areas for *Morinda officinalis* has exhibited variability across various climate scenarios. This study focused on analyzing the changing trends in the highly suitable and optimal cultivating areas for *Morinda officinalis*, as illustrated in Figure 9. Firstly, focusing on the SSP1-2.6 and SSP5-8.5 scenarios, a consistent trend was identified in the alterations to the highly suitable and optimal cultivating areas for *Morinda officinalis*. The projections suggest a notable rise in these regions between 2021 and 2040 in comparison to the prevailing climate conditions. In the SSP1-2.6 scenario, there was an expansion of around 5870 km^2, which equated to a 120% increase. The spatial distribution demonstrated a continuous expansion in urban areas, including Yunfu City, the Yunnan County, Luoding City, the Yun'an District, and the Xinxing County. In the SSP5-8.5 scenario, there was a 133% increase in the area exhibiting a spatial distribution similar to that of the SSP1-2.6 scenario. During the period from 2041 to 2060, the optimal and most favorable cultivating regions for *Morinda officinalis* are anticipated to diminish in comparison to the preceding timeframe (2021–2040). In the SSP1-2.6 scenario, a reduction of approximately 47% is projected, whereas in the SSP5-8.5 scenario, a decrease of around 46% is anticipated, with spatial distributions remaining consistent across both scenarios. Conversely, the SSP2-4.5 scenario exhibited a clear pattern in the alterations of the highly suitable and most suitable cultivating regions for *Morinda officinalis*, demonstrating a consistent upward trend. Between 2021 and 2040, the anticipated expansion of the area is forecasted to grow from around 4868 km^2 under existing climate conditions to approximately 7273 km^2, representing a 49% increase. The anticipated expansion is expected to occur in areas such as Luoding City, the Yun'an District, and the Xinxing County. Moving forward to the period of 2041–2060, the projected expansion of the area is expected to increase by approximately 6218 km^2 in comparison to the preceding

period, reaching an estimated 13,491 km^2. Spatially, this expansion covers the entire area of Yunfu City, along with the Gaoyao District in Zhaoqing City, the Deqing County, and the neighboring regions, creating a vast and interconnected distribution.

Table 6. Statistical unit of cultivating area of *Morinda officinalis* in different periods. Unit: km^2.

Unit: km^2	Current	2021–2040			2041–2060		
		SSP1-2.6	SSP2-4.5	SSP5-8.5	SSP1-2.6	SSP2-4.5	SSP5-8.5
Extremely unsuitable cultivating area	3706.945	134.028	33.335	261.112	54.167	4.862	347.223
Unsuitable cultivating area	3431.945	2812.500	6011.806	1629.167	6298.611	1400.000	5203.472
Low-suitability cultivating area	4239.584	4984.028	6045.833	5082.639	7096.528	4731.945	7176.389
Intermediately suitable cultivating area	3402.084	979.167	285.417	1290.972	472.222	21.528	737.500
Highly suitable cultivating area	2953.472	2745.834	847.222	3968.055	825.694	364.583	1221.528
Optimal suitability cultivating area	1915.278	7993.750	6425.694	7417.361	4902.084	13,126.389	4963.195

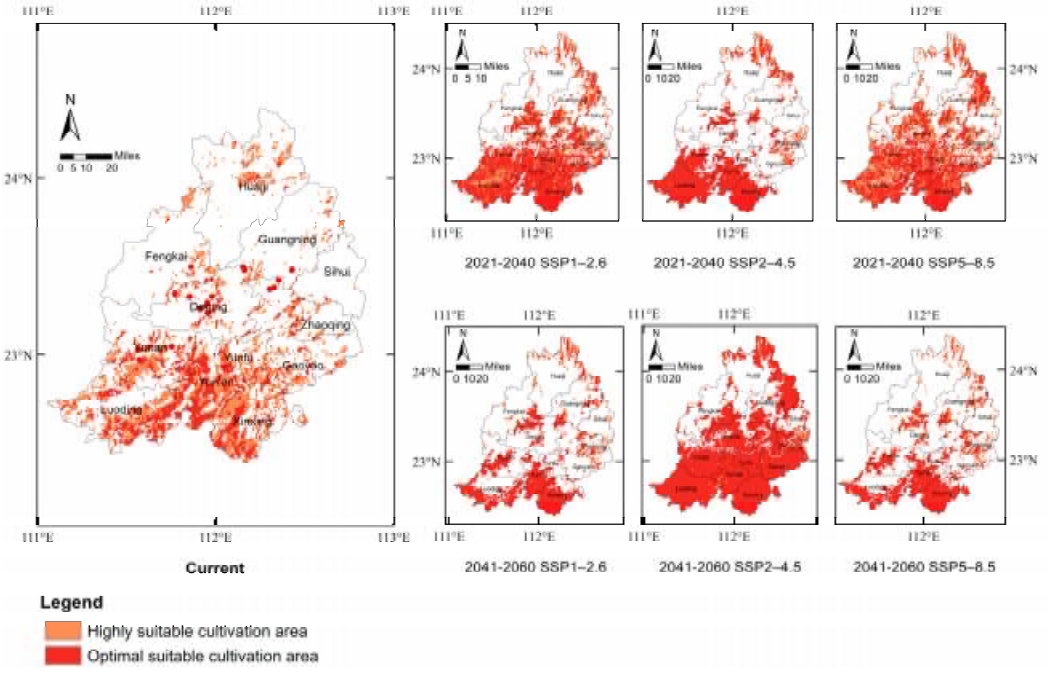


Figure 9. Distribution of the highly and optimally suitable cultivating areas of *Morinda officinalis* in Zhaoqing and Yunfu cities of Guangdong Province under current and future climate conditions.

4. Discussion

4.1. Analysis on the Cause of Relatively Low AUC Value of Two Sub-Experimental Models

In the study area, two sub-experiments were conducted utilizing the MaxEnt model to evaluate landslide susceptibility and assess the habitat suitability of Morbinaria officinalis. The aggregated AUC values for the two experimental models were 0.802 and 0.861, respectively, satisfying the requirements for a "highly accurate" model assessment. However, these values were relatively lower compared to the typical outcomes obtained in conventional assessments of the species' potential distribution utilizing the MaxEnt model [43–48]. Consequently, the following paragraphs will examine the variables contributing to this inconsistency and evaluate the dependability of the research model's output findings from different perspectives.

(1) The difference in sampling distribution points may contribute to the relatively lower observed AUC value in the model. A fundamental principle of Maximum Entropy (MaxEnt) modeling entails the deliberate and/or random selection of distribution points across the study area [49]. A greater quantity of precisely located distribution points for research subjects typically improves the accuracy of the MaxEnt model simulation [50]. Nevertheless, obstacles such as limitations in resources including personnel, equipment,

and expenses impede the achievement of impartial and thorough sampling, rendering the practical execution challenging. The data acquisition methods utilized in the subexperiments of this study closely resemble the common techniques of "field investigation + network data capture" that are prevalent in current relevant studies. The distribution data for *Morinda officinalis* were primarily obtained through a combination of "literature search + specimen data retrieval", supplemented by field sampling. The data on landslide distribution were obtained from geological locations surveyed by the Bureau of Natural Resources in Zhaoqing City and Yunfu City over multiple years. Thus, the experimental data were considered highly reliable and obtained from relatively comprehensive sources. However, limitations such as the research duration, costs, and the inherent uncertainties surrounding landslide occurrences may render it impractical to conduct a comprehensive survey of the study area with absolute precision. This constraint has the potential to result in a slight decrease in the AUC value of the model. Moreover, the choice of a sampling bias correction technique could potentially impact the model's comparatively reduced AUC value. Previous research conducted by Yackulic et al. [51] has brought attention to the significant issue of sampling bias in MaxEnt model studies, emphasizing the need for researchers to address and correct the biased data points sampled. Kong Weiyao et al. [52] delineated 13 distinct correction techniques for addressing sampling bias, which encompass spatial screening. Fourcade et al. [53] conducted a comparative evaluation of different correction methods, determining that spatial screening exhibited slightly superior efficacy compared to other approaches. Currently, there is a lack of standardized protocol for addressing sampling bias. Spatial screening is the primary approach employed to correct bias in the distribution of data points in species distribution studies utilizing the MaxEnt model, a method also utilized in the present study. Notably, this approach involves modifying distribution point data by considering the characteristics of environmental impact variables. This process may lead to the alteration or loss of original data, consequently contributing to a partial decrease in the model's AUC value [53].

(2) Further validation and examination are necessary to assess the suitability of using the MaxEnt model for evaluating landslide susceptibility. The evaluation of landslide susceptibility has been a continuous process since the mid-1970s, with a variety of assessment methods evolving over time. Nonetheless, an optimal model for the effective evaluation of landslide susceptibility is still lacking. In recent years, the MaxEnt model, a machine learning technique that operates analogously to the process of regionalizing landslide susceptibility, has been integrated into studies focusing on landslide susceptibility [54–58]. For example, Felicisimo et al. [20] performed a comparative study of four models, namely MLR, MARS, CART, and MAXENT, to evaluate the susceptibility of landslides in the Deba Valley, Spain. The predictive accuracy of these models was assessed using the Area Under the Curve (AUC) metric, revealing that the MaxEnt model produced the most favorable simulation outcomes. Subsequently, Chen et al. [21] employed three distinct machine learning models, namely MaxEnt, SVM, and ANN, both individually and collectively, to assess the susceptibility of landslides in Wanyuan City, the Sichuan Province, China. The results of the study revealed that the MaxEnt model exhibited the lowest AUC value. Furthermore, Mai Jianfeng et al. [38] evaluated the susceptibility of rain-induced landslides in the Guangdong Province by employing the MaxEnt model. Their analysis yielded an AUC value of 0.820, showing a slight disparity compared to the AUC value documented in our study. The application of the MaxEnt model in the landslide susceptibility assessment appears to be in the experimental stage, indicating a need for further deliberation on its suitability. This factor could potentially be a contributing factor to the comparatively lower AUC values noted in these studies.

In summary, the model's relatively low AUC value can be attributed to various variables. This phenomenon may be attributed to differences in sampling distribution points, corrections for sampling deviations, model optimization, and other relevant variables. The AUC values obtained from the two model experiments in this study were relatively lower in comparison to conventional research on species' potential distribution. However, they

still met the criteria for the "very accurate" category according to the AUC assessment framework. Moreover, the two sub-experiments in this study were optimized by sampling distribution points and performing collinearity evaluations of environmental variables. The optimization of model parameters was conducted utilizing the R programming language package. Consequently, despite the potential decrease in the AUC value of the model [59], it is more reliable in mitigating model overfitting and maintaining model precision, thereby ensuring scientifically sound outcomes [60,61]. Subsequently, the research team intends to conduct a comprehensive and precise field survey in the study area utilizing the landslide susceptibility distribution map and the habitat suitability distribution map of *Morinda officinalis* developed in this study. This will validate this study's findings and lay the groundwork for future research advancements.

4.2. Specific Distribution of the Highest and Most Suitable Cultivating Areas of Morinda Officinalis in the Study Area under Climate Change

Global warming significantly impacts the distribution patterns of plants and the frequency of meteorological disasters. The research indicates that the average surface temperature is projected to increase by 2.6–4.8 °C by the conclusion of the 21st century [62]. The anticipated increase in temperature is projected to modify the habitat suitability and distribution of landslide susceptibility for *Morinda officinalis*. Therefore, climate change should be regarded as a pivotal factor. The ongoing progress of the *Morinda officinalis* cultivation sector in the study region is facing obstacles, highlighting the need for the establishment of a scientifically grounded cultivation zoning map with tangible applications. In consideration of the results outlined in Section 3.5 of this research and given the pressing nature of the issue, the focus is on identifying optimal cultivating locations for the current period and the time span from 2021 to 2040 for further examination. A superposition diagram was generated using ArcGIS software (Figure 10) to depict the spatial distribution of *Morinda officinalis* and identify the optimal cultivating area in the study region under both current climate conditions and projected conditions for the period 2021–2040. In the diagram, the green color block represents the distribution area of *Morinda officinalis* and the optimally suitable cultivating area under the prevailing climate conditions. The red color block delineates the stable distribution area of *Morinda officinalis* at high altitudes and the optimally suitable cultivating area under both current conditions and projected conditions for the period 2021–2040. The yellow color block delineates the newly incorporated region of *Morinda officinalis'* highly and optimally suitable cultivating area under different climate models for the timeframe spanning from 2021 to 2040.

Based on the analysis of satellite remote sensing data, the spatial distribution of *Morinda officinalis*, focusing on areas identified as highly conducive for cultivation and optimal cultivating locations, exhibits a consistent pattern across three different climate models covering the period from 2021 to 2040 in comparison to present climatic conditions. The aforementioned regions demonstrate a continuous geographical spread, encompassing the Yun'an District, Luoding City, and the Xinxing District of Yunfu City. Particularly, notable clusters are identified in Gaocun Town, Shicheng Town, Baishi Town, Nansheng Town, and Fulin Town within the Yun'an District, Yunfu City. The Yuncheng District includes Yaogu Town and Gao Feng Street, among other areas. The Yunan County comprises Dafang Town, Qianguan Town, Li Dong Town, and other regions. Luoding City consists of Luoping Town, Jinyinhe Forest Farm, Longyong Forest Farm, and other areas. The Xinxing County features Bougainzhu Town, Hetou Town, Dajiang Town, and other regions. Additionally, Liantang Town, Live Road Town, the Gaoyao District, and Zhaoqing City are part of this geographical area. Moreover, the analysis reveals a pattern of growth in the areas deemed highly suitable and optimal for cultivating between 2021 and 2040 in contrast to the present climate conditions. This expansion varies in magnitude across the SSP1-2.6, SSP2-4.5, and SSP5-8.5 scenarios. The expansion is notably more pronounced in the SSP1-2.6 and SSP5-8.5 models, while relatively smaller in the SSP2-4.5 model. The results derived from Sections 3.3 and 3.4 of this research indicate a possible association

between the heightened vulnerability to landslides in the research site and the results identified within the SSP2-4.5 model.

The impact of climate change on the habitat's suitability and vulnerability to landslides for *Morinda officinalis* in the study area is a crucial factor that requires careful consideration. This factor significantly influences the trajectory of future research efforts. Subsequently, the upcoming phase of the research will entail analyzing the response curve of environmental variables, specifically concentrating on comprehending the variables influencing changes in habitat suitability and landslide susceptibility of *Morinda officinalis*. Furthermore, the study will integrate more accurate and detailed remote sensing imagery and geographic information, taking into account practical variables such as slope restrictions for growing profitable crops, local agricultural and forestry policies, and on-the-ground conditions. By embracing this methodology, the objective is to augment the scientific and practical significance of defining the study area, consequently boosting its relevance and effectiveness.

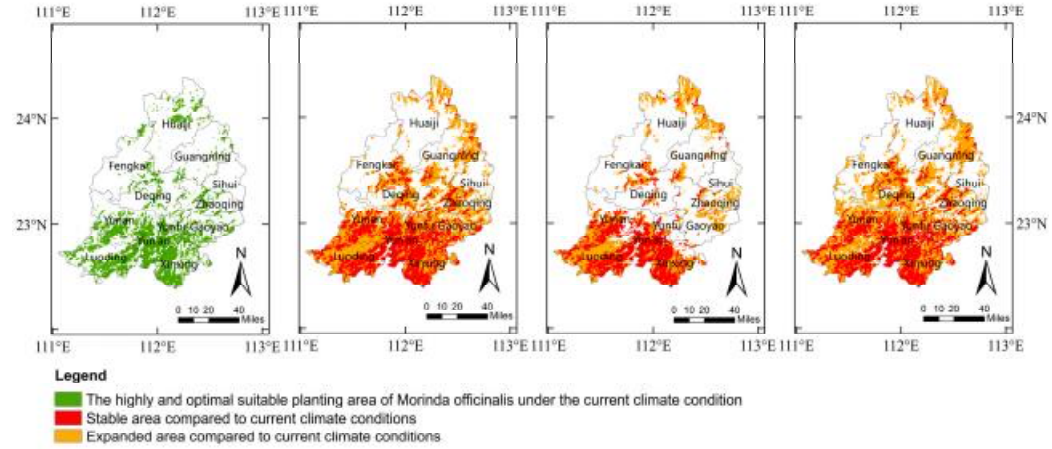


Figure 10. Superimposed spatial distribution map of the highly and optimally suitable cultivating area of *Morinda officinalis* in the study area under current and 2021–2040 climate conditions.

5. Conclusions

This study employed an optimized Maxent model to evaluate the habitat suitability and landslide susceptibility of *Morinda officinalis* in Zhaoqing City and Yunfu City. Through a superposition analysis, the Yun'an District in Luoding City and Xinxing District in Yunfu City have been identified as potential cultivation areas with a low risk of landslides and high suitability for *Morinda officinalis* cultivation. This study also investigated the influence of climate change on the geographical distribution of *Morinda officinalis* across various climate scenarios. The findings reveal a growing pattern in the distribution of *Morinda officinalis* from 2021 to 2040, especially under the SSP5-8.5 scenario, showing a significant rise of 133%. During the period from 2041 to 2060, the suitable cultivating area for *Morinda officinalis* experienced a decline in both high and optimal conditions under the SSP1-2.6 and SSP5-8.5 scenarios. In contrast, there was a notable increase in the cultivating area under the SSP2-4.5 scenario, with the area expanding to around 13,491 km^2. Spatially, the cultivating suitability of *Morinda officinalis* in the study area exhibited a pattern characterized by higher suitability in the southern regions and lower suitability in the northern regions across different climate scenarios and temporal periods. This implies that Yunfu City might be more conducive to the scientific cultivation of *Morinda officinalis* in comparison to Zhaoqing City, taking into account both landslide susceptibility and habitat suitability. The economic ramifications of *Morinda officinalis* and the environmental effects of landslides caused by inappropriate cultivating methods are recognized to influence local industrial advancement. This discovery can be used by *Morinda officinalis* growers and authorities at the local level to improve sustainable cultivation methods. It can help in choosing suitable planting locations and creating strategies to overcome current challenges in the *Morinda officinalis* industry. Additionally, the research methods used in this study can be applied to other studies

on economic crops worldwide, especially those facing challenges in balancing ecological conservation and economic profitability. This can contribute to the sustainable progress of these crops.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14061134/s1, Table S1. Environmental variables affecting the occurrence of landslide disasters. Table S2. Environmental variables affecting the habitat suitability of *Morinda officinalis*.

Author Contributions: J.L.: Investigation, Conceptualization, Data curation, Formal analysis, Methodology, Software, Visualization, Writing-original draft. G.T.: Conceptualization, Data curation, Investigation, Methodology, Software, Validation, Funding acquisition. X.Q.: Data curation, Funding acquisition, Investigation, Supervision, Writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Guangdong Provincial Forestry Bureau Major Forestry Science and Technology Innovation Project (Grant No. 2022KJCX015). The recipient of this project is Xinsheng Qin.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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frontiers | Frontiers in Plant Science

TYPE Systematic Review
PUBLISHED 31 January 2024
DOI 10.3389/fpls.2024.1285050

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OPEN ACCESS

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RECEIVED 29 August 2023
ACCEPTED 15 January 2024
PUBLISHED 31 January 2024

CITATION
Zhou R, Qin X, Hou J and Liu Y (2024) Research progress on Brassicaceae plants: a bibliometrics analysis.
Front. Plant Sci. 15:1285050.
doi: 10.3389/fpls.2024.1285050

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Research progress on Brassicaceae plants: a bibliometrics analysis

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The Brassicaceae is a worldwide family that produces ornamental flowers, edible vegetables, and oilseed plants, with high economic value in agriculture, horticulture, and landscaping. This study used the Web of Science core dataset and the CiteSpace bibliometric tool to quantitatively visualize the number of publications, authors, institutions, and countries of 3139 papers related to Brassicaceae plants from 2002 to 2022. The keywords and references were divided into two phases: Phase 1 (2002-2011) and Phase 2 (2012-2022) for quantitative and qualitative analysis. The results showed: An average annual publication volume of 149 articles, with an overall fluctuating upward trend; the research force was mainly led by Professor Ihsan A. Al-shehbaz from Missouri Botanical Garden; and the United States had the highest number of publications. In the first phase, research focused on the phylogeny of Brassicaceae plants, while the second phase delved into diverse research based on previous studies, research in areas such as polyploidy, molecular technique, physiology, and hyperaccumulator has been extended. Based on this research, we propounded some ideas for future studies on Brassicaceae plants and summarized the research gaps.

KEYWORDS

Brassicaceae, visual analysis atlas, evolution, plants, phylogeny

1 Introduction

The plants of Brassicaceae, characterized by features such as pungent odor (glucosinolates), cruciform corolla, tetradynamous stamens, and siliques, is an important natural family and a globally significant plant family (Zhu et al., 2023). According to the modern angiosperm classification system APG-IV, the Brassicaceae family currently consists of 352 genera and 3350-3660 species (https://duocet.ibiodiversity.net/), and mainly distributed in the northern temperate zone, particularly in the Mediterranean region (Al-Shehbaz, 1984). The Brassicaceae family is highly diverse, comprising two subfamilies: Aethionematoideae and Brassicoideae. In addition, the Brassicoideae are partitioned into five supertribes, including the previously recognized Brassicodae and the

newly established Arabodae, Heliophilodae, Hesperodae, and Camelinodae (German et al., 2023). Under the Brassicodae, the Brassiceae are further subdivided into 13 subtribes. Among them, the Brassiceae has the highest number of genera, with 92. Many of these species have important economic value, with Brassica rapa var. oleifera DC. (rapeseed) being widely cultivated in China as an edible oil crop and ornamental plant. It was worth mentioning that Arabidopsis thaliana L., as a model organism, whose genome is the first higher plant genome to be sequenced and it serves as a key comparison point with other eukaryotic genomes, widely used in research areas such as plant genetics (Polanco and Ruiz, 2002), cell biology (Labuz et al., 2010), and molecular biology (Klepikova et al., 2016). For example, Arabidopsis thaliana, as one of the earliest model organisms worldwide, has been utilized in several comprehensive studies for enhancing genome annotation, profiling organelles, tissues, cells, or subcellular proteomes, as well as investigating developmental processes and responses to biotic and abiotic stresses through differential relative and absolute quantitative strategies (Wienkoop et al., 2010). Apart from the Brassicaceae family being an important area of study, individual tribes within it are also worth mentioning, especially those that hold significant value, such as the Chorisporeae (German et al., 2011). Due to its diverse species, various types of research have been constantly conducted on. Arabis alpina L., a high-altitude plant in the Brassicaceae family, it has become a complementary model to Arabidopsis thaliana for studying evolutionary life history traits such as perenniality and ecological genomics in harsh environments (Wötzel et al., 2021).The glucosinolate-myrosinase system, discovered in the order Brassicales, is one of the best-studied plant chemical defense systems. The defensive function of the glucosinolate-myrosinase system has been confirmed in various studies targeting different insect herbivores. However, many versatile and specialized herbivores utilize glucosinolate-containing plants as hosts, leading to significant agronomical losses in crops such as oil seed rape and other Brassicaceae species. Significant progress has been made in understanding how specialized insect herbivores overcome the glucosinolate-myrosinase system and even utilize it for their own defense purposes (Winde and Wittstock, 2011). Many scholars have conducted comprehensive review studies on various aspects of Brassicaceae plants, including phylogenetics (Al-Shehbaz et al., 2006), genomics (Augustine et al., 2013), resistance breeding (Diederichsen et al., 2009), and self-incompatibility (Hiscock and McInnis, 2003). However, these studies are mostly focused on specific perspectives, and the visual bibliometric analysis is still very rare.

Despite a large body of research literature describing various aspects of Brassicaceae plants, there is a lack of integration of effective discipline-specific information due to variations in authors, institutions, publication dates, and journals. Consequently, it has been challenging to identify the development trends in this field (Wallin, 2005). Given the absence of research on bibliometric analysis specifically focused on Brassicaceae plants, this study was of significant importance as it aimed to provide timely insights into the developmental dynamics and future research trends of this plant family.

As the quantity of published literature has exploded in various fields, bibliometric analysis, as a statistical method for reviewing and describing published articles, can reveal the direction of disciplinary development and the dynamics of research from multiple perspectives, aiding researchers in evaluating academic research in a particular field (Rey-Martí et al., 2016). Qualitative analysis in a single field often struggles to capture research frontiers and hot topics. However, by utilizing scientific knowledge graph tools for bibliometric analysis, researchers can quantitatively and objectively understand the research status and focal points of knowledge structures, promoting cross-disciplinary integration and generating new research ideas (Mokhnacheva and Tsvetkova, 2020). CiteSpace, based on various elements in a large number of publications, allows for operations such as keyword clustering analysis, author co-occurrence analysis, and bursting term analysis. Based on these analyses, it generates visual analysis maps that demonstrate the development process and internal connections of a specific discipline, showcasing research trends and hot topics in that field. This enables scholars to explore essential foundational knowledge and research dynamics in their research areas and provides a scientific reference for predicting future development trends through bibliometric analysis. Currently, CiteSpace software is one of the most popular analysis tools in the field of bibliometric analysis and has been widely employed in both social sciences and natural sciences.

2 Materials and methods

2.1 Data sources

To collect a large amount of data on Brassicaceae plant research topics, we constructed a database of literature on Brassicaceae plant research topics over the past 20 years using the core ensemble of curated literature in the Web of Science (WOS), which is now widely accepted as a database source tool for bibliometric analysis (Chen et al., 2022; Xu et al., 2022). In WOS, we set the subject term as “Brassicaceae” for searching, selected “Science Citation Index Expanded”, and “Social Sciences Citation Index” for the citation index, and selected the type of literature as “Article”. The time of publication was restricted to 2002-2022, and the preliminary search yielded 6273 articles with a search date of July 2023. To exclude disciplines unrelated to Brassicaceae plant research, the WOS categories “Plant Sciences”, “Agriculture”, and “Horticulture” were selected, resulting in a final selection of 3139 papers. These papers were then exported in plain text format in batches for subsequent analysis using CiteSpace software. Finally, a visualization analysis was conducted to generate the corresponding knowledge map. (Relevant data can be found as a zip file in the Supplementary Material).

2.2 Research methodology

CiteSpace is a visualization and analysis software created by Professor Chaomei Chen, a Chinese-American scholar, which is

applied to identify and display new trends and dynamics in the scientific literature (Chen, 2004). The software is free and open source, and the software used in this study was downloaded by the authors from official sources.

The downloaded literature was statistically analyzed by CiteSpace software, and based on the bibliometric statistics, the main research power map and literature co-citation map were constructed; at the same time, the keyword co-occurrence map, hotspot clustering map of keywords, theme evolution map, and keyword mutation map were constructed, so that the hotspots of the research on Brassicaceae and its evolution trend could be analyzed in terms of content.

CiteSpace software parameters were set to the time span for the author, country, and institution was from 2002-2022, while for keyword and reference it was divided into two periods: 2002-2011 and 2012-2022, time slices for Years Per Silce=1. The pruning slice network was selected, with a node threshold of Top N=50, meaning that data extraction was based on the top 50 ranked data for each time slice to generate the final network. The default cosine algorithm was used for the association strength of network nodes, and the k value in the g-index was set to 10. CiteSpace 6.2.R6 basic edition was used for this analysis, and the data results analysis function provided by the WOS was utilized to count the number of publications on Brassicaceae plants. Excel 2016 software was used for chart plotting. Finally, the visualization results were analyzed according to the flowchart steps (Figure 1).

3 Results and analysis

3.1 Analysis of the publication trends

The analysis of publication data can be visually represented in the form of a line graph, which provides an intuitive reflection of the research development speed and publication quantity in the

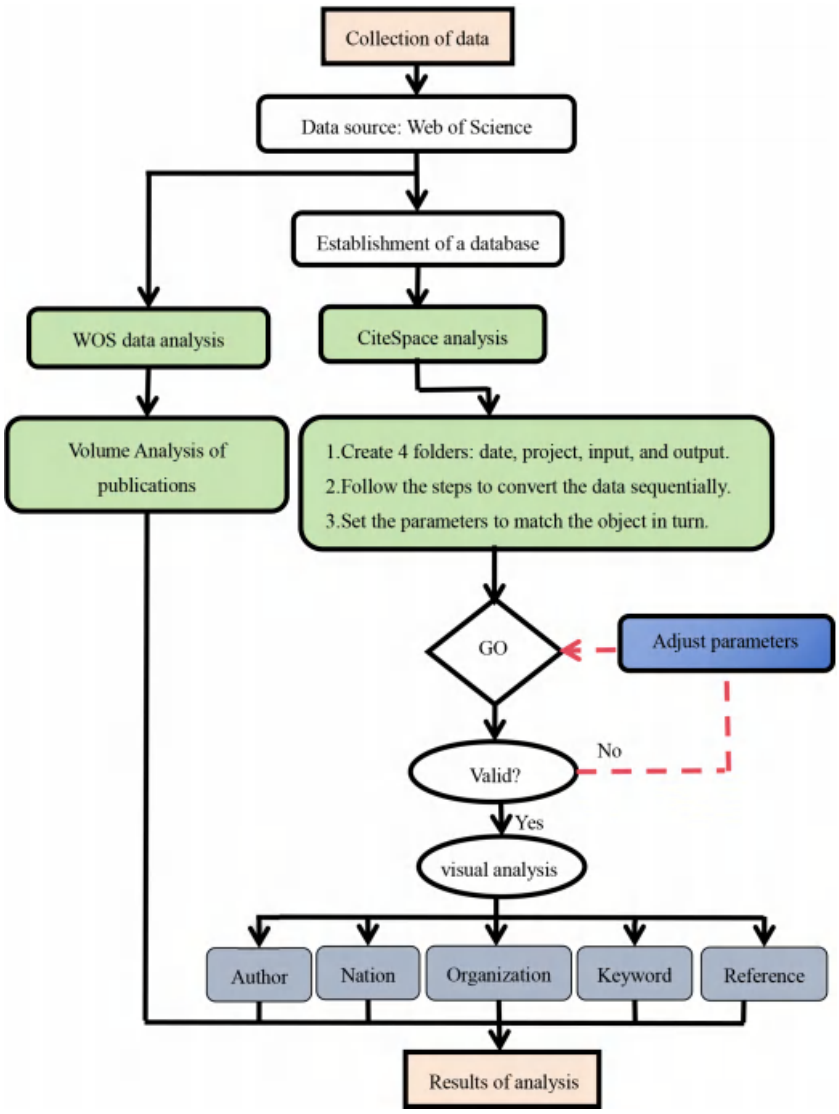


FIGURE 1
Flowchart of CiteSpace bibliometric analysis.

Brassicaceae family. By utilizing the data analysis functionality of the WOS in conjunction with an Excel spreadsheet, a line graph of the publication quantity in the Brassicaceae family (Figure 2) was created. From 2002 to 2022, a total of 3139 published articles related to Brassicaceae plants were identified (Note that the data used in this study was obtained using the filtering method described in section 2.1 and does not represent the entirety of the content in the WOS database). The average annual publication quantity was 149 articles, as a whole, the total publication quantity exhibited a fluctuating upward trend. When examining the data in more detail, it could be roughly divided into three stages: from 2002 to 2010, there was a slow growth phase with an annual growth rate of 2.5% and an average annual publication quantity of 97 articles. There was an upward trend in publication quantity, except for a sudden decline of 31 articles in 2010 compared to the previous year. From 2011 to 2015, there was a rapid growth phase, during which research on Brassicaceae plants flourished. The annual growth rate was 11%, with an average annual publication quantity of 167 articles. 2015 marked the first peak in publication quantity, reaching 224 articles. From 2016 to 2022, there was a steady growth phase, with the highest peak in publication quantity occurring in 2020, reaching 227 articles. By this time, the foundational work had been largely completed, and it was expected that future publication quantity would continue to exhibit a stable growth trend.

3.2 Analysis of major research forces

3.2.1 Analysis of authors

Research on Brassicaceae plants cannot be separated from related scholars and research organizations, and scholars are the direct producers of articles, which determine the depth and breadth of Brassicaceae plant research. Based on the CiteSpace analysis of the WOS literature data for issuing authors, the literature was generated into an author co-occurrence map (Figure 3) as well as the ranking of the amount of issuing articles (Table 1). The author co-occurrence graph generated by CiteSpace analysis revealed that the most prolific author in terms of publication quantity between 2002 and 2022 was Al-shehbaz, Ihsan A., with a remarkable total of 116 papers, accounting for 80% of the average annual publication quantity. This signified the long-standing commitment and substantial contribution of this scholar to the study of Brassicaceae plants. The author co-occurrence graph also indicated that in the early years, Al-shehbaz, I.A. had close collaborative relationships with German, Dmitry A., and Koch, Marcus A. However, the intensity of collaboration with other scholars has decreased in recent years, as evident from the varying colors of the connecting lines. In second place was Lysak, Martin A., with a publication count of 41, significantly lower than the top-ranked author. One possible explanation for this difference was the emergence of young researchers who had focused their efforts on conducting a series of studies on Brassicaceae plants, making it more challenging to explore innovative research topics and elevate the level of publication requirements. Additionally, the author co-occurrence graph revealed that Lysak, Martin A. did not have direct collaborative relationships with the top-ranked author, which indirectly underscored the importance of academic exchanges between different fields. Ranking third was Mummenhoff, Klaus, with a publication count of 39. Mummenhoff, K. had collaborative relationships with both the top-ranked and second-ranked authors, with a greater number of connecting lines, forming a localized core author cluster. Although the number of publications was considerably lower than the top-ranked author, Mummenhoff, K. had the highest betweenness centrality score of 0.04 among all nodes, surpassing even the author with the largest node. This indicated that the stronger the collaboration within the primary group of authors, the higher their centrality and influence. In summary, the core group of authors in the early years was centered around Al-shehbaz, I.A., while in recent years, localized networks of author collaboration have been formed around Mummenhoff, K.

3.2.2 Analysis of most influential institutions

With the development of scientific research, more and more research is accomplished through cooperation among different countries and institutions, which can generate greater impact and scientific value (Cui et al., 2022). CiteSpace was used to visualize and

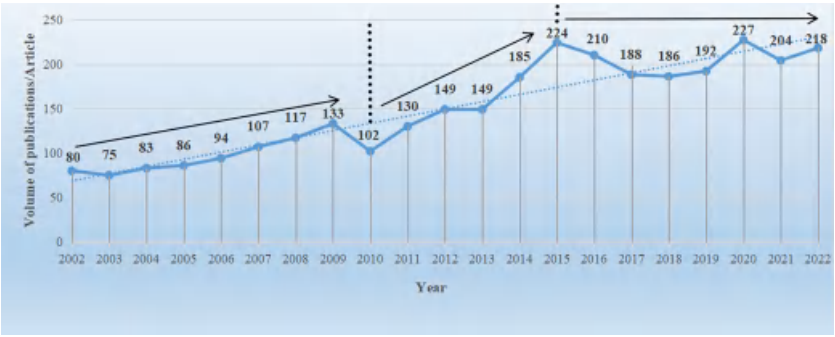


FIGURE 2
Number of literature issuance volumes for Brassicaceae plant research during 2002-2022. The data in the graph were derived from WOS core journal search results, the solid line represents the direction of literature issuance, and the dashed line indicates the auxiliary trend line.

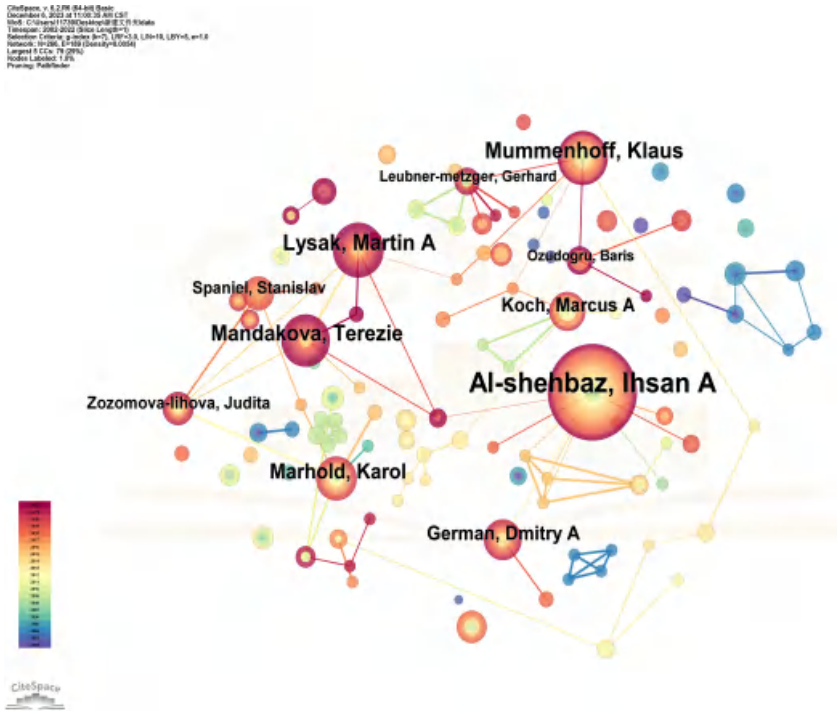


FIGURE 3
Co-presentation of authors for the studies on Brassicaceae between 2002-2022. The node size represents the amount of the number of issued documents, and the larger the node, the more the number of issued documents of the authors. The network structure reflects the cooperative relationship between authors, the thickness and color depth of the lines represent the intensity of cooperation between authors, and the different colors of the connecting lines represent the different publication times, the brighter the color means that they were published in the last few years, while the darker the color indicates that they were published for a long time.

TABLE 1 Authors with more than 10 articles for the studies on Brassicaceae between 2002-2022.

Year	Author	Post quantity/Article	Betweenness centrality
2006	Al-shehbaz, Ihsan A.	116	0.03
2013	Lysak, Martin A.	41	0.01
2009	Mummenhoff, Klaus	39	0.04
2013	Mandakova, Terezie	36	0.01
2006	Marhold, Karol	31	0.01
2012	German, Dmitry A.	23	0
2009	Koch, Marcus A.	21	0.03
2012	Zozomova-lihova, Judita	15	0
2016	Spaniel, Stanislav	15	0
2009	Mueller, Caroline	13	0
2009	Leubner-metzger, Gerhard	11	0.01
2018	Ozudogru, Baris	10	0.01

Betweenness centrality is an indicator that evaluates the importance of a node in the whole network, the higher the centrality, the greater its influence in the network.

analyze the documents screened to generate a knowledge graph of the co-occurrence of Brassicaceae plant research institutions (Figure 4) and a ranking table of the top 20 issuing institutions (Supplementary Table 1), with a total of 208 nodes, 392 line segments, and a network density of 0.0182. Individual institutions were connected in the graph to show their collaborative relationships. The map showed that the lines were dense and concentrated, and there was frequent communication between the major research institutions. The top 20 institutions had a total of 1247 publications, accounting for 40% of the total active literature. The institution with the largest node in the graph was Missouri Botanical Gardens, which was ranked first with 158 publications, accounting for 13% of the total number of publications in the top 20. The second largest node was the Max Planck Society with 85 publications. The purple ring on the outermost layer of the node indicated that the node had a high degree of intermediary centrality, and the larger the node, the higher the centrality and thus the greater the influence. The graph showed that Max Planck Society had a purple ring on the outer ring of the node and the node was larger, with a mediated centrality of 0.23, while Missouri Botanical Gardens, which had the largest number of publications, did not have a purple ring on the outer ring of the node, with a mediated centrality value of only 0.09. This suggested that close communication and cooperation between research organizations could better promote the development of the discipline and more effectively promote the innovative development of the whole Brassicaceae plant research system.

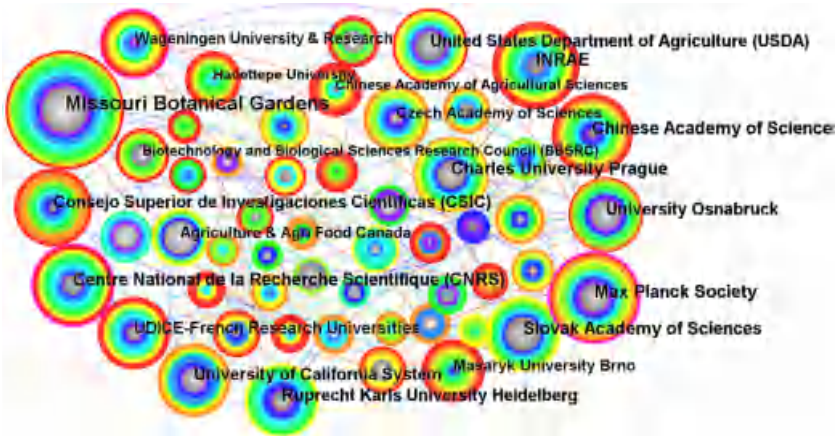


FIGURE 4
Co-current relationships of institutional cooperation network for the studies on Brassicaceae during 2002-2022.

3.2.3 Analysis of countries

The number of papers indexed by the Science Citation Index (SCI) to some extent reflects a country's research strength and influence in a particular research field. Based on CiteSpace analysis of the publications on Brassicaceae plants in the WOS from 2002 to 2022, a network graph was created (Figure 5) and a bar chart was used to visually represent the publication counts of different countries (Supplementary Figure 1). The network graph and bar chart revealed that the main publishing countries were distributed in Asia, Europe, North America, and Oceania. Among them, the United States had the highest number of publications, with a total of 830 papers, accounting for 27% of the total valid publications. The country with the highest betweenness centrality score was also the United States, with a value of 0.25. Germany and China ranked second and third with 484 and 335 papers respectively. Canada, Japan, Spain, and France followed closely behind with publication counts surpassing 100 papers. The connections in the network graph represented collaborative relationships with other countries, and the more connections there were, the closer collaboration. Additionally, countries with larger nodes and a purple outer ring had a higher betweenness centrality, indicating that the United States and Germany held important positions in the research field of Brassicaceae plants. Since Brassicaceae plants gained significant attention in the scientific community in 2002, the United States has embarked on early research in this area, resulting in the highest number of publications and notable achievements. Canada, Australia, Germany, Italy, the United Kingdom, France, and Japan had also begun research and achieved certain results at an early stage. With the opening-up policy and response to global collaboration, China gradually deepened its research on

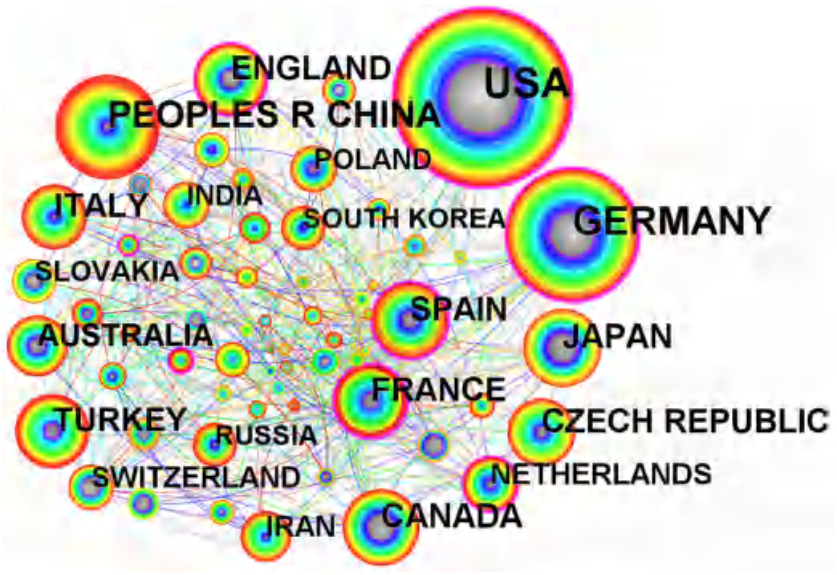


FIGURE 5
Countries of origin and partnerships on Brassicaceae during 2002-2022.

Brassicaceae plants and actively collaborated with foreign scholars and institutions.

3.3 Keyword analysis

Keywords are the essence and focus of each article. They provide a concise summary of the entire article and possess strong generality. The frequency of keywords reflects the frontier hotspots of research topics during a certain period and the core strength of the keywords in the network (Ding and Yang, 2020). Betweenness centrality is a measure of the centrality of a node in a network. The higher the centrality, the greater the influence of the node in the network. When the betweenness centrality of a node is ≥0.1, it is considered a key node. From the perspective of scientometrics, literature with high betweenness centrality values usually plays a significant role in the information transmission process (Qian, 2014). This study focuses on exploring the recent research trends and future directions of Brassicaceae plants by comparing the visualized results of keywords from the periods 2002-2011 and 2012-2022.

3.3.1 Analysis of co-occurrence

Using CiteSpace, we exported data from the years 2002-2011 and 2012-2022. The node type selected was "Keyword", and the time slice was set to 1 year. Through pruning the slice network, keyword frequency and betweenness centrality analyses were conducted. Upon running the analysis, we obtained a co-occurrence network graph of keywords (Figure 6) and keyword information (Table 2). Based on the analysis of the chart, it can be observed that there are only 3 keywords with a frequency of over 100 in phase 1 (2002-2011). However, in phase 2 (2012-2022), there are 9 keywords, which is three times more than the former. The main keywords (phase 1) are Arabidopsis thaliana, Brassicaceae, and Evolution. In phase 2, in addition to these three keywords, there are also Arabidopsis (DC.) Heynh., Expression, Plants, Identification, Growth, and Diversity. With the progress of science and the development of the era, more profound and novel topics are constantly emerging. CiteSpace can be used to find the most frequently cited literature related to a specific node, For example, the articles (Figure 6A) related to the keyword "Arabidopsis thaliana" was Brown et al. (2003) analyzed the glucosinolate content of various organs of the model plant Arabidopsis thaliana, Columbia (Col-0) ecotype at different stages during its life cycle. They thought that dormant and germinating seeds had the highest concentration, followed by inflorescences, siliques (fruits), leaves, and roots. Rather, during seed germination and leaf senescence, there were significant declines in glucosinolate concentration. This article mainly discusses the physiological and ecological significance of the aforementioned findings, providing valuable insights for future research on plant physiology and biochemistry. Furthermore, the keyword (Figure 6B) was also "Arabidopsis thaliana", the most highly cited article was related to the topic of transgenerational increased resistance in plants, Rasmann et al. (2012) designed a series of experiments to investigate the role of jasmonates and siRNA in transgenerational induced resistance to herbivory in two well-studied model species, Arabidopsis and tomato (Solanum lycopersicum). Their results showed that both Arabidopsis and tomato plants were subjected to herbivory are more resistant to subsequent attacks in the next generation. In summary, Arabidopsis thaliana serves as a "treasure trove" for researchers in the scientific community, particularly in the field of plant physiology. In addition, the presence of five keywords in phase 2 that are not present in phase 1, such as Expression and Identification, indicates that research on Brassicaceae plants began in 2012. Specifically, there has been a gradual involvement of Arabidopsis thaliana research at the genetic and hereditary level.

3.3.2 Analysis of clustering

In this study, the clustering labels were extracted using the clustering function and default LLR algorithm in CiteSpace. The software calculated the modularity value (Q) and average silhouette value (S) based on the network structure and clustering clarity, which were used to assess the visualization effect. Generally, a Q value between 0.4-0.8 indicates a reliable network structure. The Silhouette index, which measures the similarity within clusters, typically ranges from 0-1, with higher values indicating higher similarity (Zhu et al., 2018). In the first stage, the Q value reached 0.528, and the Mean Silhouette value was calculated as 0.7735, indicating a highly reliable network structure and similarity between clusters. In the second phase, the Q value reached 0.7766, and the Mean Silhouette value reached 0.9254, It was proven that the clustering at this stage was highly plausible and suggested that the study on Brassicaceae plants was extensive and characterized by a rich and well-defined range of topics. The different colors of the blocks and cluster labels correspond to different periods. The more vibrant the color, the earlier the research topic, indicating that it is continuously evolving and developing, rather than being from previous years. In Figure 7A, the largest cluster label is "multivariate morphometrics", which contains 34 subclusters. In Figure 7B, the largest cluster label is "local adaptation", with 42 subclusters.

Table 3 listed the cluster members for each period, highlighting the differences between the two periods. The bolded entries were those that appear in both stages, with "Arabidopsis thaliana" appearing four times consecutively, indicating its widespread use as a model organism across various fields. Additionally, the term "taxonomy" in the first stage changes to "phylogeny" in the second stage, demonstrating that research related to Brassicaceae plants had evolved from basic classification work to species evolution and racial development.

3.4 Reference analysis

The definition of co-citation is when two published articles are cited together by another publication. The citation frequency of a literature can quantify its academic influence. Generally, co-cited articles share similar topics and research backgrounds, and the number of citations can serve as an indicator of their impact level. It is also a way to measure the relationships between different papers



FIGURE 6
Co-occurrence of keywords for the studies on Brassicaceae during 2002-2011 (A) and 2012-2022 (B). The size of nodes represented the frequency of keyword occurrence, with larger nodes indicating higher frequency and representing the research hotspots of the article.

and identify core papers that play a key role in the field (Chen, 2012). Consistent with the keyword analysis approach, the entire period is divided into two phases to discuss the clustering of cited literature and the burst of emergent literature.

3.4.1 Cluster analysis of cited literature

To gain a clearer understanding of the research trends in Brassicaceae plants, we further extracted the co-citation network using CiteSpace. By selecting “Reference” as the node type in the CiteSpace interface, we obtained a cluster map of the cited literature as shown in Figure 8. In Figure 8A, the Q value was 0.8781, and the Mean Silhouette value reached 0.9654, which was close to 1. This indicated that the cited literature within this cluster had a high degree of similarity and close connections to each other. The largest cluster label was “chloroplast DNA sequence data”, consisting of 26 sub-members. The most highly cited article in this cluster was a review by Al-Shehbaz on the systematic and phylogenetic studies of Brassicaceae published in the cluster #7 “phylogenetic relationships” (Al-Shehbaz et al., 2006). They conducted a critical review of the traits used in Brassicaceae plant systematics and discussed the origin, classification, and delineation of genera within this family. In Figure 8B, the co-citation cluster had a Q value of 0.8396 and a Mean Silhouette value of 0.9473, indicating that the generated cluster structure was reliable and convincing. The most highly cited literature in this cluster, with 122 citations, belonged to cluster #5 “multiple hybridization events”. It referred to an R project supported by the R Core Team, which was widely popular, especially in the field of statistics. Research on Brassicaceae plants often involved physiological, biochemical, molecular genetic, and genetic aspects, requiring extensive database analysis.

TABLE 2 Information on keywords with a posting frequency of more than 100 times in two phases.

Rank	Years			
	2002-2011		2012-2022	
	keyword	times	keyword	times
1	Arabidopsis thaliana	144	Arabidopsis thaliana	317
2	Brassicaceae	140	Evolution	262
3	Evolution	123	Brassicaceae	247
4	/	/	Arabidopsis	203
5	/	/	Expression	176
6	/	/	Plants	159
7	/	/	Identification	143
8	/	/	Growth	118
9	/	/	Diversity	105

Frequency refers to the number of times keywords appear in the retrieved papers, and keywords with higher frequency can to some extent reflect the research hotspots in the field.

Therefore, using the R language can effectively assist in data computation and analysis.

3.4.2 Analysis of citation burst

The detection of key term bursts can be used to identify rapidly growing specialized vocabulary in a short period. There are two ways to rank burst literature based on the existing features of CiteSpace (Shi and Liu, 2019): one is by burst start time, and the other is by burst strength. This study adopts the former method for ranking. Based on the temporal distribution and dynamic changes of burst terms, this reflects the research hotspots or new development trends during that period (Chen et al., 2012). An increase in citation bursts indicates that the scientific community is or has been particularly interested in these articles (Su and Lee, 2010). This paper employed CiteSpace to perform a visual analysis and successfully identified highly cited references. The Burstmess function in WOS was used, setting the ɡ value at 0.8, to reveal 25 burst references (Figure 9). The burst intensity analysis no longer compares two stages but rather highlights the popularity of individual publications or a set of publications and predicts future research trends. As shown in the graph, it can be seen that the top two papers in terms of emergence intensity were both authored by Al-Shehbaz. The first one, published in 2012, was titled “A generic and tribal synopsis of the Brassicaceae (Cruciferae)”; the second one, published in 2006, has been analyzed in section 3.4.1. It was evident that Professor Al-Shehbaz was not only an important botanist in the field of Brassicaceae but also his publications were closely related to the taxonomy of Brassicaceae and provided a valuable reference for other scholars. Additionally, based on the duration of burst intensity, the publication by Chinese scholar Huang et al. (2015) remained a burst term for six years, indicating that the articles published by this research group were among the hot topics in the field. They primarily utilized nuclear genes to resolve the phylogeny of the Brassicaceae family, revealing a nested radiation and providing support for convergent morphological evolution.

4 Discussion

The family Brassicaceae is a highly diverse and globally distributed group of plants that plays a significant role in the plant kingdom, and their evolutionary history is intricate and fascinating. No studies have been found so far (not retrieved in WOS) regarding bibliometric analysis of Brassicaceae plants. Despite many areas that need improvement, the study has also achieved remarkable results.

4.1 Global contribution to Brassicaceae research

The trend in the publication volume of literature to some extent reflects the research intensity in a particular field during a certain period. The research on Brassicaceae plants has been through three stages in terms of publication volume: a slow development stage (2002-2010), a rapid growth stage (2011-2015), and a steady development stage (2016-2022). Overall, there was an upward trend in the publication volume of literature (Figure 2), indicating that the research content related to Brassicaceae plants was constantly expanding. Early on, a group of distinguished scientists emerged, including prominent authors such as Al-shehbaz, Koch, and Mummenhoff (Table 1). Their collaborative review article published in the Annals of the Missouri Botanical Garden effectively summarized the research achievements in the systematic taxonomy, population genetics, and evolutionary biology of Brassicaceae plants prior to the 20th century. They critically discussed the traditional and molecular-based phylogenies, new generic alignments were proposed, and groups in need of molecular studies were identified(Koch et al., 2003). The final advice given was the future directions of research should move beyond assessing generic relationships or limits, and should address character development and evolution, the molecular basis of various homoplastic characters, the nature of the genome, and many other

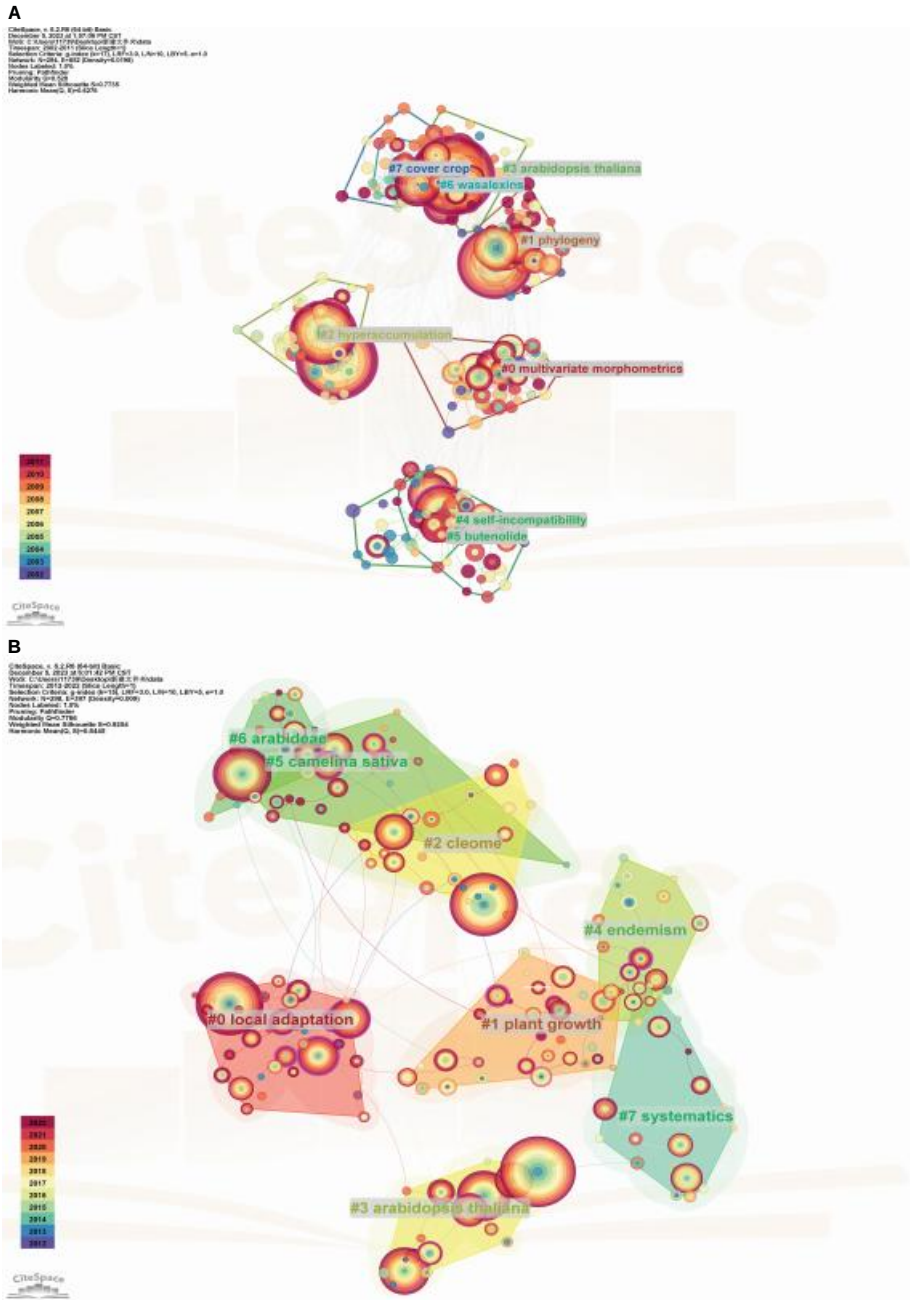


FIGURE 7
Clustering analysis of keywords for the studies on Brassicaceae during 2002-2011 (A) and 2012-2022 (B).

new challenges that are emerging from detailed molecular studies of Arabidopsis thaliana. This finding further confirms the position of the third-ranked article in the burst analysis of cited literature, which had a sustained burst duration of four years. Subsequently, an increasing number of research institutions and countries began to actively engage in Brassicaceae plant research.

Missouri Botanical Gardens is the oldest botanical garden in the United States and is now one of the world's leading botanical research institutions, with core research on conserving plant diversity. After conducting a literature citation metrics visualization analysis using CiteSpace, we obtained results in the form of network graphs and rankings based on publication frequency. Missouri Botanical Gardens is the most influential and highly-contributing institution. Importantly, the articles published by this institution have provided valuable theoretical guidance and conceptual frameworks for future research on Brassicaceae plants. The institution primarily focuses on research related to the phylogenetics and population relationships of Brassicaceae plants. For example, institutional scholars were based on oil analyses of the ITS (internal transcribed spacer) regions of the nuclear ribosomal DNA and the chloroplast trnL-intron and spacer sequences from 72 American Draba taxa and 6 European Draba species to conduct a systematic analysis. Their analysis discovered that the existing tribal classifications of the Brassicaceae were mostly artificial and that the segregation of Draba and Arabis into separate

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TABLE 3 Comparison of keyword clustering information between the two stages.

Cluster-ID	Years					
	2002-2011			2012-2022		
	Sise	Silhouette	LLR	Sise	Silhouette	LLR
#0	34	0.933	Local adaptation; biological invasions; flowering time; Phenotypic plasticity; aflp	42	0.764	Multivariate morphometrics; chromosome numbers; flow cytometry; phenotypic plasticity; polyploidy
#1	33	0.943	plant growth; biofumigation; Cover crops; sinapis alba; brassica juncea	41	0.742	Phylogeny; its; arabidopsis thaliana; arabis; ndhf
#2	23	0.918	Cleome; taxonomy;annotation; turkey; new species	40	0.741	Hyperaccumulation; zinc (zn); phytoremediation; nickel; arabidopsis halleri
#3	20	0.938	Arabidopsis thaliana; protein; identification; brassica rapa; expression	38	0.734	Arabidopsis thaliana; brassica napus; camalexin; brassica oleracea; expression
#4	20	0.875	Endemism;nickel; arabidopsis helleri; flowers	28	0.796	Self-incompatibility; inflammation; tapetum; resistance; host-pathogen interaction
#5	19	0.94	Camelina sativa; raphanus sativus; resistance; brassica rapa; brassica napus	27	0.836	Butanolide; pollen competition; seed germination; seed dormancy; soil seed bank
#6	19	0.957	Arabideae; arabidopsis thaliana; Miocene; mustards; symbiosis	21	0.836	Wasalexins; Cruciferae; condensing enzyme; abiotic stress; methionine
#7	19	0.955	Systematics;Cruciferae;vascular flora; pollen; turkey	21	0.727	Cover crop; Alliaria petiolata; Biofumigation; integrated weed management; widely targeted metabolomics

tribes or subtribes did not accurately reflect their phylogenetic relationship (Koch and Al-Shehbaz, 2002). Based on the above analysis, it is evident that a scholar's popularity, as reflected in the citation of their publications, can elevate not only their affiliated institution but even their country to a leading position in a particular field or discipline, placing them at the forefront of their time. In terms of national publication volume analysis, the United States holds the top position, followed by Germany and China. This was closely related to the rankings of research institutions and authors based on publication volume, with authors from institutions that published more articles also producing a higher number of publications. This indicated a higher level of emphasis or priority given to the topic by their respective countries (Supplementary Table 1, Table 1). It was also strongly influenced by the primary distribution areas of Brassicaceae plants (Al-Shehbaz, 1984). The scientific research strength of the United States is widely recognized, and its influence is undeniable.

4.2 Advance in Brassicaceae research

The above analysis mainly indicated the quantitative analysis of Brassicaceae, and in the keyword analysis of literature metrology, clustering functions could be used to aggregate related literature or topics together, giving each cluster a specific clustering label. Combining the characteristics and progress of Brassicaceae research, five aspects will be discussed.

4.2.1 Phylogeny of the Brassicaceae

The Brassicaceae family is a plant family of significant economic value and scientific importance, particularly in the fields of agriculture and scientific research. It encompassed several model species and was becoming a model for evolutionary studies at the family level. However, resolving the phylogenetic relationships within the family has been challenging, and there was still a lack of large-scale molecular systematic studies with comprehensive sampling and gene coverage (Couvreur et al., 2009). To our knowledge, several scholars have conducted numerous review studies in this area, including a highly cited review by Al-Shehbaz et al. (2006) on the systematics and phylogeny of the Brassicaceae family. Schranz et al. (2006) summarized advances in their understanding of phylogenetics, polyploidization, and comparative genomics in the family Brassicaceae. At that time, their findings paved the way for a unified comparative genomic framework.

In the first phase of the citation clustering analysis (2002-2011) as shown in Figure 8A, it was noteworthy that there were studies focusing on phylogenetic relationships using nuclear ribosomal DNA ITS sequences and chloroplast DNA trnL-F sequences, which also served as cluster label names. As early as 2002, researchers conducted phylogenetic studies on the Alliaria genus within the Brassicaceae family. Sisymbrium exemplifies a lack of clear generic boundaries and unique synapomorphies (Al-Shehbaz, 1988). Warwick et al. (2002) Used sequence data from the internal transcribed spacers of nuclear ribosomal DNA and the 5.8S rRNA gene (collectively, ITS region), examined the evolutionary relationships of Old and New World Sisymbrium species with its segregate genera and the validity of O.E. Schulz's classical sectional treatment of Sisymbrium. For a long time, the Brassicaceae and Capparaceae families have been considered closely related, with the monophyly of the Capparaceae family being called into question. Hall et al. (2002) analyzed sequence variation for a large sampling,

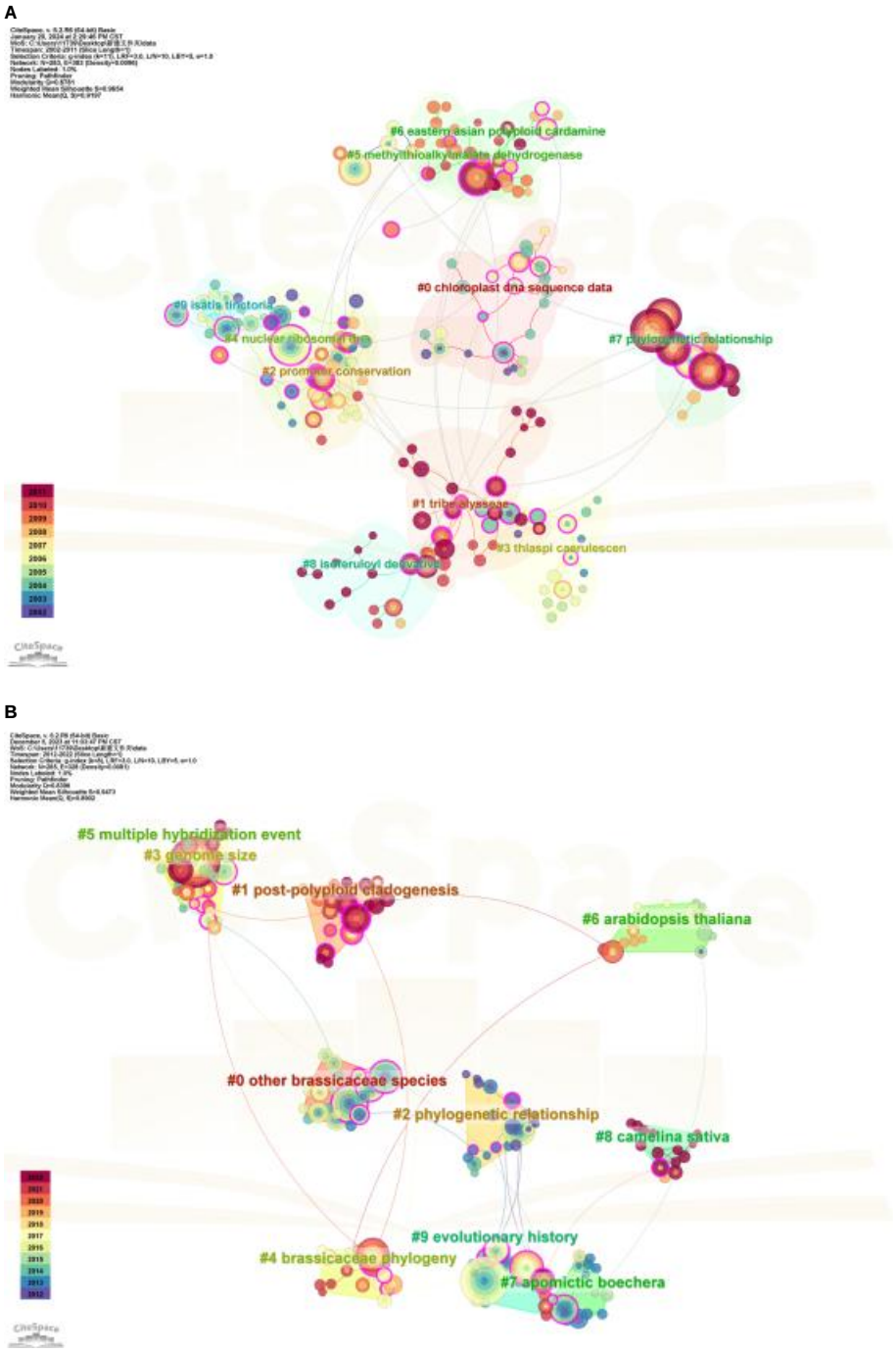


FIGURE 8
Clustering analysis of cited references for the studies on Brassicaceae during 2002-2011 (A) and 2012-2022 (B).

especially of Capparaceae, of these two families, using two chloroplast regions, trnL-trnF and ndhF. Their results elucidate the relationship between Brassicaceae and Capparaceae as well as address infrafamilial relationships within Capparaceae.

The Brassicaceae family has long been known to present significant challenges in the classification and delineation of its genera and tribes. Fortunately, substantial progress has been made in recent years in understanding the phylogenetic relationships and establishing tribal classifications. In the clustering of cited references at the second stage, the labeled theme was presented as “other Brassicaceae species, Phylogenetic relationship, and Brassicaceae phylogeny” (Figure 8B), indicating that research on the phylogenetics of the Brassicaceae family had reached a new level. It is well-known that among families with a large number of members, the Brassicaceae family is one of the best-studied in terms of phylogenetics (Warwick et al., 2010; Al-Shehbaz, 2012; Koch et al., 2012). To provide nuclear gene sequence resources for evolutionary research in the Brassicaceae family, Huang et al. (2015)

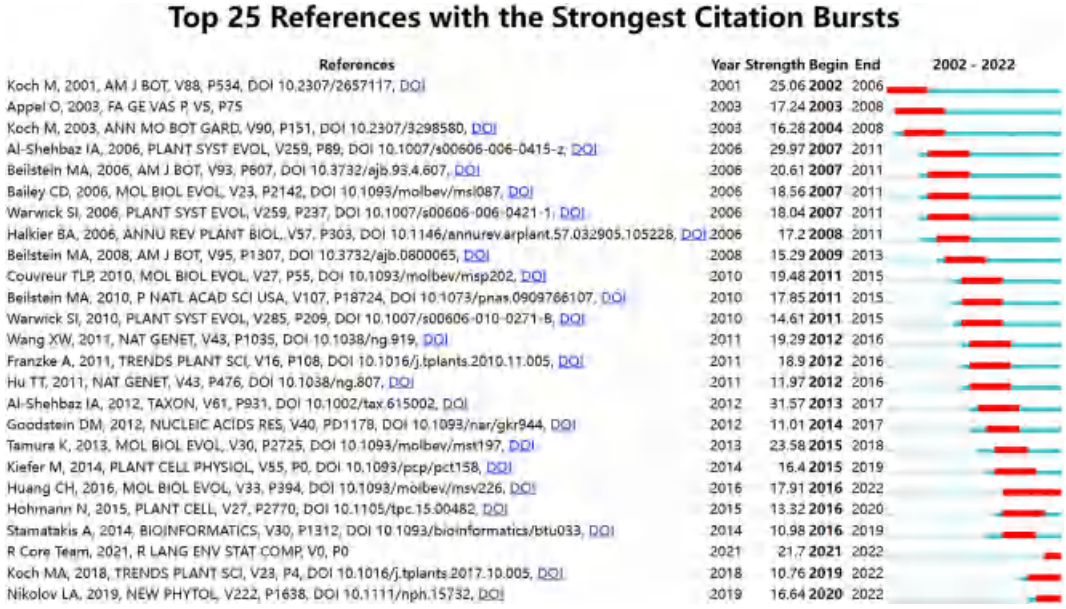


FIGURE 9
The strength and period of the emergence of 25 subject terms during 2002-2022. The red parts indicate that the references are prominent during this period, while the blue parts are not prominent.

utilized a large dataset consisting of 55 Brassicaceae species to screen a set of marker genes for phylogenetic reconstruction. This approach led to the development of a robust phylogeny, resulting in the first highly resolved framework referred to as Branches A-F, which encompasses six major clades. These results form a foundation for future evolutionary analyses of structures and functions across Brassicaceae. Koch and Grosser (2017) investigated the phylogenetic relationships and evolutionary history of East Asian Arabis spp. (Brassicaceae) using plastid trnL-F and nuclear internal transcribed spacer 1 and 2 sequences (ITS). Their study demonstrated that the widespread occurrence of Arabis hirsute L. in East Asia, particularly in China, was not supported by their findings. A recent study built upon previous work in the field of Brassicaceae phylogenetics presented the most complete Brassicaceae genus-level family phylogenies to date (Brassicaceae Tree of Life or BrassiToL) based on nuclear and plastome data (Hendriks et al., 2023). Their results strongly supported a recently published new family classification (Classifications mentioned in the Introduction). With a worldwide community of thousands of researchers working on Brassicaceae and its diverse members, this new genus-level family phylogeny will be an indispensable tool for studies on biodiversity and plant biology.

4.2.2 The prominent position of Arabidopsis thaliana

Arabidopsis thaliana is characterized by its small chromosome number, compact plant size, short life cycle, and abundant seed production. Additionally, it was the first plant to have its genome fully sequenced. The Arabidopsis Genome Initiative (AGI), a collaborative effort involving researchers from Europe, Japan, and the United States, took 7 years and cost 70 million USD to complete (Initiative, 2000). From the keywords with a node citation frequency greater than 100 times (Table 2), Previous studies focused on the yield of phylogeny; In recent years, the focus of research has expanded to include a broader range of fields, such as gene expression, identification, and genetic diversity at the molecular level. Willing et al. (2015) conducted a de novo assembly for the 375 Mb genome of the perennial model plant, Arabis alpina L. They emphasized that compared to Arabidopsis thaliana, the significant reduction in symmetric CG and CHG methylation indicates a weakened maintenance of DNA methylation in Arabis alpina. Whole-genome sequences of members of the Brassicaceae family (including the plant model Arabidopsis thaliana) are greatly expanding the scope for comparative genomics among closely related plant species (Wang et al., 2011). Nguyen et al. (2013) built a transcriptome reference from 2047 Sanger ESTs and more than 2 million 454-derived sequence reads, representing genes expressed in developing camelina seeds. These transcriptomic data will be useful for the breeding and engineering of additional camelina seed traits. Fornalé et al. (2014) have characterized Arabidopsis thaliana AtMYB7, the closest homolog of AtMYB4 and AtMYB32, described as inhibitors of different branches of phenylpropane metabolism. The results showed that AtMYB7 acts as an inhibitor of flavonol biosynthesis, which led us to propose AtMYB4 and AtMYB7 as part of the regulatory mechanism controlling the balance of major UV-sunscreens in Arabidopsis thaliana. A study conducted by Willige et al. (2021) revealed another epigenetic mechanism, indicating that shading effects from neighboring plants can promote increased plant height. The study found that Arabidopsis mutants lacking PIFs transcription factors exhibited elongation and rapid growth cessation in simulated shading experiments. More and more scientists were placing greater emphasis on the relationship

between plants and the environment, especially in terms of climate (Méndez-Vigo et al., 2019; Pierce et al., 2020). Therefore, in the future, Arabidopsis thaliana research at the micro level holds the promise of providing a basis for improving the global environment.

4.2.3 Progress in polyploidy research

The Brassicaceae are well known for taxonomic difficulties mostly caused by the extensive, difficult to interpret, convergent evolution in morphological and anatomical characters and by the limited number of diagnostic characters (Koch et al., 2010). Polyploidization can provide abundant genetic variation for adaptive evolution and species formation. Hohmann et al. (2015) presented a comprehensive time-calibrated framework with important divergence time estimates based on whole-chloroplast sequence data for 29 Brassicaceae species. Their results highlighted polyploidization as an important source for generating new evolutionary lineages adapted to changing environments. The Brassicaceae family, owing to its remarkable species, genetic, and physiological diversity as well as its significant economic potential, has become a model for polyploidy and evolutionary studies. Repetitive polyploidization has played a crucial role in the evolution of the Brassicaceae family (Lysak and Koch, 2011), with nearly half of the Brassicaceae taxa hypothesized to have experienced recent polyploid origins (Franzke et al., 2011). Kagale et al. (2014) by revealing the origins of approximately half of the new/mid-polyploids in the Brassicaceae taxa and identifying coincidences between the diversification of Brassicaceae and significant geological events during Earth's history in the Neogene period, insights into the evolution of the Brassicaceae have been provided. The origin of certain species in the Brassicaceae family is known to be complex and challenging, such as Cardamine *fl*exuosa With. Mandáková et al. (2013) presented a whole-genome cytomolecular map of an allopolyploid plant for the first time, by combining comparative chromosome painting and genomic in situ hybridization (CCP/GISH), they elucidate the origin and evolution of the Cardamine *fl*exuosa chromosome complement. In conclusion, there is still a long way to go in the research of polyploidy in Brassicaceae plants.

4.2.4 Physiological research

Over the past few decades, there has been a particular focus on edible plants, especially those rich in secondary metabolites. Brassicaceae vegetables are a great source of natural antioxidants, as they have high levels of carotenoids, tocopherols, and ascorbic acid. Strong epidemiological evidence suggests that these compounds may help protect the human body from damage caused by reactive oxygen species (Cartea et al., 2010). In recent years, phenolic compounds have been extensively studied due to their potential health-promoting effects (Vallejo et al., 2002). It was reported that the nutritional interest of Brassica L.crops was partly related to their phenolic compound contents. They have been reported to possess many useful properties for human health, the most important action of phenolics was their antioxidant activity (Cushnie and Lamb, 2005). In a study on Brassica oleracea L., Podsędek et al. (2006) found that the antioxidant activity between red cabbage and Brussels sprouts was equivalent, being 5 to 2.2 times higher than that of white cabbage and savoy cabbage. Broccoli, as a crop, possesses high antioxidant potential associated with high levels of phenolic compounds (Moreno et al., 2006). In addition to Brassica oleracea mentioned above, numerous other Brassicaceae species are rich in phenolic compounds. For example, Bennett et al. (2006) studied the phenolic compound composition in several cruciferous species such as Diplotaxis erucoides L., and Diplotaxis tenuifolia L.

Plants employ complex defense systems to protect against pests and pathogens, including the production of low molecular weight secondary metabolites with antimicrobial activity. These secondary metabolites are synthesized de novo after stress and are collectively referred to as phytoalexins. So far, a total of 44 plant phytoalexins have been isolated from cultivated and Brassicaceae vegetables. The majority of these phytoalexins are sulfur-containing alkaloids synthesized through the biosynthesis of amino acid (S)-tryptophan (Ahuja et al., 2012). Detailed studies related to this have been reported (Pedras et al., 2011). Glucosinolates are classic examples of plant compounds that influence insect-plant interactions. They are mainly found in Brassicaceae, which includes several important crops. There are significant quantitative and qualitative differences between plant genotypes, tissues, and developmental stages, which pose specific challenges to herbivorous insects. Although glucosinolates serve as constitutive defenses, their levels are influenced by both abiotic and biotic factors, including insect herbivory (Hopkins et al., 2009). In order to characterize the long-term persistence of plant immunity, a study conducted by Rasmann et al. (2012) examined the plant resistance of Arabidopsis thaliana and Solanum lycopersicum L. by challenging them with caterpillar herbivory, application of methyl jasmonate, or mechanical damage during the nutritional growth process. The resistance of the offspring was evaluated to assess plant resistance. The observed genetic resistance in Brassicaceae and Solanaceae suggested that this trait may be more widely distributed in plants. Therefore, the phenotypic plasticity mechanism of herbivore-induced epigenetic resistance represented a means to enhance defensive capabilities across generations.

4.2.5 Hyperaccumulator research

In the visualization graph of keyword cluster analysis, the term "Hyperaccumulator" appeared in the second phase(2012-2022), and the cluster encompassed a substantial number of subsets.This suggested that studies related to hyperaccumulators were gradually gaining attention from researchers (Table 3). The hazards of heavy metal-contaminated soils to human and animal health are increasingly severe. Efforts to use plants for phytoremediation, the process of removing specific metals from soil through plant uptake, have emerged in the past two decades. Metal-accumulating species can be utilized for either phytoextraction or phytomining (Amabogha et al., 2023; Prasad and De Oliveira Freitas, 2003). Hyperaccumulating plants refer to functional plant groups capable of rapidly and heavily accumulating one or multiple heavy metal elements while maintaining normal growth, reproduction, and resistance to toxicity (Rascio and Navari-Izzo, 2011). Among them, Thlaspi arvense L. in the Brassicaceae family

can accumulate large amounts of heavy metals such as zinc and cadmium in its aboveground tissues. It is widely recognized as a hyperaccumulator plant. However, due to its small biomass, it is unsuitable for direct use in phytoremediation of heavy metal-contaminated soils. Instead, it is commonly used as a model plant for studying the mechanisms of metal accumulation (Liu et al., 2010). Among the known zinc hyperaccumulating plants, the majority belong to the Brassicaceae family, representing at least three independent evolutionary events of zinc hyperaccumulation (Broadley et al., 2007). Brassica juncea (L.) Czern. was an important vegetable-use and oil-use crop worldwide and exhibited the potential to tolerate and accumulate Cd, and it could be considered as a Cd hyperaccumulator plant (Li et al., 2023).Identifying which metal hyperaccumulating plants were safe to consume was crucial to avoid potential health risks. As the Brassicaceae family includes various common crops, it was important to understand the reasons behind significant differences in leaf metal concentrations observed in the field and within populations to better comprehend the phenomenon of metal hyperaccumulation. In the future, further exploration of plants with hyperaccumulation abilities, combined with synergistic interactions of organic defense compounds, can enhance the plants' inherent defense mechanisms, thereby reducing the use of chemical pesticides.

4.3 Tendency in Brassicaceae research

After understanding the past and current situation of research on Brassicaceae plants, it is necessary to explore future research trends, especially for those species threatened or endemic (Perrino and Wagensommer, 2022). The citing literature is the frontier of the research and the cited literature is the theoretical basis of the research. Combining the citation clustering and burst intensity of the cited literature (Figures 8, 9), each stage has its emphasis on research directions, with the second stage being particularly pronounced. In the first stage, the top 10 clusters were analyzed, and the red cluster (the largest cluster) was mainly related to DNA sequences, especially the research on plant phylogeny using nuclear ribosomal DNA ITS sequences and chloroplast DNA trnL-F sequences. The largest cluster in the second stage was related to whole-genome duplications (WGDs; or polyploidization). In addition to Brassicaceae systematics research, other researchers have also investigated plant biogeography and floristic analysis, such as Koch et al. (2010) using cpDNA, found five North American lineages of Arabis with distinct distribution patterns, of which only the purple/red-flowered lineage consists of proven diploids that evolved directly from East Asian progenitors. They also provided the first evidence for the systematic circumscription of East Asian Arabis taxa, which together with the North American taxa, form one clade distantly related to European and Eurasian Arabis hirsute.

In summary, the early research trends and frontiers primarily focused on the phylogenetics of Brassicaceae plants, while in later stages, molecular and genetic approaches were gradually integrated into the systematic foundation to explore the origins and explain the diversity of the extensive Brassicaceae family. In the cluster analysis of cited literature in the second stage, researchers showed interest in the model organism Arabidopsis thaliana. The Brassicaceae include several major crop plants and numerous important model species in comparative evolutionary research such as Arabidopsis, Brassica, Boechera, Thellungiella, and Arabis species. Hohmann et al. (2015) proposed a comprehensive time-calibrated framework based on complete chloroplast sequence data from 29 Brassicaceae species, which provided important estimates of divergence times. Whole-genome duplication (WGD) is a ubiquitous genetic mechanism throughout the history of angiosperms (Soltis et al., 2009). Huang et al. (2020) established a time-calibrated chronogram based on whole plastid genomes comprising representative Brassicaceae taxa and published data spanning the entire Rosidae clade. They also utilized BAMM to investigate the diversity patterns of these tribal-level chronograms and compared them with genome size variation and species richness data from the entire family. Finally, they thought the combined effect of tribal crown group age and net diversification rate (speciation minus extinction) was likely to explain sufficiently species richness across Brassicaceae tribes. In the previous section (3.4.1), it had been analyzed that a popular research focus in recent years is the R language technology supported by the R Core Team. Additionally, there are other relatively novel and long-standing topics concerning oilseed crops. Camelina sativa is an annual oilseed crop within the Brassicaceae family, as a climate-resilient oilseed, seed meal, and biofuel (biodiesel and renewable or green diesel) crop received increased attention. Neupane et al. (2022) focused on the study of Camelina sativa and summarized the major biotic constraints limiting its production. Additionally, they provided an overview of strategies to enhance this important and versatile crop in the face of rapidly changing climates, including molecular breeding, rhizosphere microbial communities, genetic engineering, and genome editing methods, aiming to increase its global yield. Brassicaceae plants are predominantly crops, and an important future research direction is how to effectively improve crop yield prediction. Of course, the research on Brassicaceae plants goes far beyond what has been described above. However, the information provided earlier is based on the citation literature generated by the analysis tool of the software used. Due to space limitations, it is not possible to cover all aspects in detail. The specific data analysis of clustered cited literature will be presented in the Supplementary Materials (Supplementary Table 2).

5 Conclusion

Citation analysis using CiteSpace software generated a network graph that visualizes the research landscape. This graph illustrates the citation relationships, co-authorship relationships, and other relevant indicators among different publications, helping us understand the structure and development trends of the research field. This study focused on analyzing the relevant literature from the WOS core dataset, covering the years 2002-2022. CitesSpace software was used to quantitatively visualize the publication count, authors, countries, and research institutions. In terms of qualitative analysis, the study examined the keywords, co-citation analysis, clustering analysis, and burst analysis of the relevant literature from

two time periods: 2002-2011 and 2012-2022. These analyses were conducted to map the research topics related to the family Brassicaceae and generate network diagrams.

Overall, the number of articles related to Brassicaceae plants published in WOS has shown an increasing trend. However, as more emerging disciplines and specialties emerge, there will be fewer individuals focusing on Brassicaceae plant research. Currently, the main sources of articles are the Missouri Botanical Garden in the United States, the Max Planck Society in Germany, and the Chinese Academy of Sciences, which are the most active publishing institutions in this field. Comparing keywords and co-cited literature from two periods, the research focus in the first stage was relatively concentrated, with a majority of studies focused on phylogenetics. This was likely because, during the initial stages, researchers primarily laid the groundwork by establishing the fundamental theoretical framework, such as the popular application of the model organism Arabidopsis thaliana, understanding the racial relationships, classification methods, and principles of family lineage construction within Brassicaceae. In the later stage, building upon the previous work and theoretical foundations, researchers were able to reach higher levels of analysis by utilizing nucleotide sequences through molecular marker technologies to explain the origin of Brassicaceae biodiversity and establish a universally recognized genomic database for Brassicaceae plants, thereby enhancing the efficiency of future research in molecular directions.

6 Strengths and limitations

This study had certain limitations. Compared to review articles, bibliometric analysis can handle thousands or even tens of thousands of publications, and there was no specific and detailed review. However, since the analysis methods are based on publications and their references, they are inevitably influenced by various biases, such as publication bias and citation bias (Urlings et al., 2021; Wu et al., 2023). In addition, there were some limitations of the CiteSpace software when analyzing networks. Due to the large amount of data, not every node will be computed, and only representative and prominent nodes will be presented. Nevertheless, WOS has been widely accepted by researchers and is considered a common tool for retrieval and bibliometric analysis due to its high-quality and comprehensive data (Ding and Yang, 2020). The study served as a summary of the past twenty years of research on Brassicaceae plants. Its purpose was to assist researchers interested in the field of Brassicaceae plants in quickly understanding the current research landscape and hot topics, providing a general direction for future investigations, and identifying areas that require further exploration or updating. In fact, there was a wealth of research content related to Brassicaceae plants, and using “Brassicaceae” as a subject terms had certain limitations. For instance, the purpose of this study was to understand various types of research related to Brassicaceae plants, encompassing both macro aspects such as Arabidopsis thaliana and Brassica species, as well as micro aspects including phylogenetics, evolutionary biology, molecular breeding, and genomics. The function of CiteSpace software was to extract the desired information from a large amount of tedious and repetitive data. The conclusions drawn from this study covered numerous aspects in both the micro and macro domains. However, it was inevitable that important literature could be missed due to the lack of precision and specificity of the subject terms. This is an area where improvements can be made in similar studies and should be considered for future research endeavors. Through the analysis process, it became apparent that “Arabidopsis thaliana” had a very high frequency of occurrence, and there was abundant content related to this species. In the future, researchers can conduct searches using the keyword “Arabidopsis thaliana” and combine it with other bibliometric software, such as VOSviewer, to achieve better results. Overall, this study provided a systematic exploration of the development, trends, and prospects of Brassicaceae plant research, deepening our understanding of Brassicaceae phylogenetics and providing a basic understanding of current research dynamics.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Author contributions

RZ: Data curation, Writing – original draft, Writing – review & editing. XQ: Funding acquisition, Writing – review & editing. JH: Data curation, Writing – review & editing. YL: Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This research was funded by the Forestry Science and Technology Innovation Project of the Guangdong Forestry Bureau (GDZZDC20228703), and thanks to the support of SCAU Wushan Campus Teaching&Research Base.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpls.2024.1285050/full#supplementary-material

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Phytotaxa 676 (2): 169–180
https://www.mapress.com/pt/
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Article

ISSN 1179-3155 (print edition)
PHYTOTAXA
ISSN 1179-3163 (online edition)

https://doi.org/10.11646/phytotaxa.676.2.5

Ophioglossum hongii (Ophioglossaceae), a new species from Xizang, China

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Abstract

Ophioglossum hongii (Ophioglossaceae) is described as a new species from the plateau area of Xizang, China. It was recorded as the species *O. nudicaule* previously, but obviously differs in its shorter sporophores and the conspicuous persistent petiole bases at the top of rhizome. *O. hongii* is similar to *O. polyphyllum* in morphology, but it can be distinguished from the latter by plant size, trophophyll shape, fertile stalk and exospore ornamentation. *O. hongii* is the sister to the clade (*O. polyphyllum*, *O. engelmannii*) according to molecular phylogenetic analysis of seven plastid fragments (*atpB*, *matK*, *psbA-trnH*, *rbcL*, *rps4*, *rps4-trnS*, and *trnL-F*). Detailed taxonomic description, distribution, ecology, conservation status and chloroplast genome resources are provided.

Key words: chloroplast genome, Himalayas, phylogeny, pteridophytes, taxonomy

Introduction

Ophioglossum Linnaeus (1753: 1062) is a diverse fern genus with about 41 species (PPGI 2016). This genus has extremely simple morphological characters, with the entire aerial part often reduced to a single frond divided into sterile (trophophore) and fertile (sporophore) segments (Clausen 1938). It is one of the most primitive and ancient members of the living eusporangiate ferns (PPGI 2016) and possesses the highest chromosome number among all known organisms (Verma 1957, Wang 1986), with some species having up to 1440 chromosomes (Ghatak 1977). *Ophioglossum* is so distinctive that it has attracted widespread attention from botanists, cytologists, and evolutionary biologists (Field *et al.* 2015, Goswami 2013, Goswami & Patel 2020, Grewe *et al.* 2013, Khandelwal 1990). Most species in this genus were thought to have cosmopolitan distribution (Clausen 1938, Wagner 1990). Since the species were difficult to distinguish due to their similar morphology, Zhang *et al.* (2022) suspected that there might be cryptic species within *Ophioglossum*. In recent years, new taxa have been continuously discovered through the combination of morphological, palynological, and phylogenetic evidence (Goswami *et al.* 2020, Patel *et al.* 2018, Patil *et al.* 2018, Patel & Narsimha Reddy 2018, 2019, Petchsri *et al.* 2022, Yadav *et al.* 2021), indicating that the cryptic species diversity of the genus still requires further investigation.

During a field survey in Xizang of China, one of the co-authors, F. S. Yang, discovered an interesting species of *Ophioglossum* featuring small-sized and subfleshy sterile lamina. The species is similar to *Ophioglossum nudicaule* L. f. (1781: 443) in plant size and trophophyll shape. However, a thorough review of the literature and comparison of plant

Accepted by Marcus Lehnert: 14 Nov. 2024; published: 10 Dec. 2024

specimens showed these samples did not belong to any *Ophioglossum* species. Our palynological and phylogenetic analyses also indicated that Yang's collections represent a new species, which was most closely related to *Ophioglossum polyphyllum* A.Braun ex Seub. (1844: 17) and *Ophioglossum engelmannii* Prantl (1883: 351). We named it here as *Ophioglossum hongii* and provided a detailed morphological description and diagnosis, information on distribution and ecology, preliminary conservation assessment, as well as the chloroplast genome.

Material and methods

Morphological study

Plant materials were collected during 2021 and 2024 from Xizang, China. Voucher specimens were deposited in NOCC (voucher no.: YYH22612) and PE (voucher no.: 2021412). Morphological measurements were made from dried herbarium specimens. To ensure the identity of the new species, the collections were compared with specimens deposited at BISH, BM, BNRH, E, FI, GH, HAL, IBSC, KUN, LINN, MEXU, MO, NAS, NCU, NU, P, PE, S, TEX, UBT, US, W, and XZ. Further comparisons were also made among literatures of the genus *Ophioglossum* of various regions including Asia (Balakrishnan *et al.* 1960, Kachhiyapatel *et al.* 2018, Tagawa & Iwatsuki 1979, Zhang *et al.* 2013), North America (Wagner *et al.* 1993), Central America (Davidse *et al.* 1995), South America (Meza-Torres 2016, Perestrello & Sylvestre 2020), Europe (Stafford & Paul 2009), and Southern Africa (Crouch *et al.* 2011, Roux 2001). Given that the micro-morphology of spores is a necessary to delineate species within the genus *Ophioglossum*, mature spores were collected from the sporangia dissected from mature spikes for scanning electron microscopy (SEM) observation, with both distal and proximal surfaces being analyzed.

Molecular phylogeny

DNA extraction, sequencing, and plastome assembly

The fresh leaves of *Ophioglossum hongii* were collected and dried with silica. Silica-dried material was then sent to Beijing Novogene Co., Ltd. (Beijing, China) for DNA extraction and sequencing, which was performed on an Illumina Novaseq platform (Illumina, SanDiego, CA). The plastid genome was assembled using GetOrganelle v1.7.7.0 (Jin *et al.* 2020) with default parameters. The results were viewed and edited using Bandage v0.8.1 (Wick *et al.* 2015). The assembled chloroplast genome was annotated by Geneious Prime 2023.2.1 (https://www.geneious. com) (Kearse *et al.* 2012), with *O. thermale* (NC_088530) serving as a reference at 90.27% similarity. Two sequences of *O. hongii* (GenBank accession: PQ140141 & PQ140142) collected from the Xizang were generated for this study.

Data matrices and phylogenetic analyses

51 sequences of seven chloroplast regions (*atpB*, *matK*, *psbA-trnH*, *rbcL, rps4, rps4-trnS*, and *trnL-F*) from 12 samples (Table S1), and 15 plastomes were obtained from GenBank (Table S2). The seven chloroplast regions were extracted from these 15 plastomes and two newly sequenced plastomes of *Ophioglossum hongii*. A combined sequence matrix of 29 samples was used to reconstruct the phylogenetic relationship of the genus. *Botrychium lunaria* Swartz (1801: 110) and *Helminthostachys zeylanica* Hooker (1840: 47) were used as outgroups referring to Patil *et al.* (2018). The sequences were aligned using MAFFT v7.505 (Nakamura *et al.* 2018) and all positions containing gaps and missing data were excluded using trimAl v1.2 (Capella-Gutiérrez *et al.* 2009). The trimmed matrices were concatenated into a supermatrix for phylogenetic analysis. The best-fitting model (GTR+F+G4) was selected by ModelFinder (Kalyaanamoorthy *et al.* 2017), and phylogenetic analysis based on Maximum likelihood method was performed using IQ-TREE v. 2.1.4 (Minh *et al.* 2020) with 10,000 bootstrap replicates. FigTree v1.4.4 (Schneider *et al.* 2000) was used to view and edit constructed phylogenetic tree.

Prediction of potential suitable distribution

A total of 10 distribution points of the holotype and paratypes of *Ophioglossum hongii* were recorded, and the distribution points were arranged in the order of species name, longitude, and latitude to generate a CSV file. We initially screened 21 environmental factors with a 2.5-arcminute resolution, including 19 bioclimatic factors, one soil factor, and one elevation factor (Table S3). The climatic data were sourced from the WorldClim database (www.worldclim.org), while the soil and elevation data were obtained from the China Soil Science Database (https://www.vdb3.soil.csdb.cn/). Strong correlation among the environmental variables can reduce model accuracy. Therefore, Pearson correlation coefficients (r) were calculated between variable pairs using SPSS software (https://www.ibm.com/spss). Variables with absolute correlation coefficients greater than 0.8 were removed to avoid multicollinearity impacts. Finally, 10 variables were selected as the environmental variables (Table S3). The species distribution model was constructed based on 10 environmental factors and 10 distribution points of *O. hongii* by using MaxEnt v3.4.4 (Phillips *et al.* 2023). The specific parameters of the MaxEnt model were set as follows: a random selection of 80% of the species distribution points was used as training samples, while the remaining 20% were designated as test samples. Chose the Replicated run type as Bootstrap and set the number of the Replicates to 100 times.The output format was set to 'Cloglog' and the output type was set to 'ASC'. Other parameters are set to their default values. After completing the MaxEnt model simulations, the species distribution map was visualized in ASCII format using ArcGIS 10.2 and then converted to raster format. Using the "Natural Breaks" method in the Reclassify tool, the suitability thresholds for *O. hongii* are classified into four classes: nonsuitable (0–0.1), slightly suitable (0.1–0.3), moderately suitable (0.3–0.6), and highly suitable (0.6–1).

Taxonomic treatment

Ophioglossum hongii M. Y. Li, F. S. Yang & J. P. Shu *sp. nov.* (Figs 1–2)

Type:—CHINA. Xizang Autonomous Region, Shannan City, Gongga County, 29°17′12.79″N, 90°59′30.14″E, ca. 3568 m, 13 Aug 2021, *F. S. Yang* YYH22612 (holotype: NOCC!; isotype: PE!).

Diagnosis:—*Ophioglossum hongii* resembles *O. polyphyllum*, but differs in its smaller size, ovate-elliptic or elongate-elliptic trophophyll (vs narrowly elliptic to oblong lanceolate), 1.2–2 cm long fertile stalk (vs 3–6 cm) and spores with granular tubercles forming a densely reticulate ridge on the distal face (vs zigzag plates often mixed up forming smaller gaps among ridges and furrows on the distal face)

Plants less than 10 cm, terrestrial; *rhizome* subterranean, cylindrical, yellow-brown, bearing numerous fleshy roots; *common stalk* 2.5–4.5 cm long, terranean-subterranean, white when subterranean, green when terranean, glabrous, covered with persistent brown petiole at base; *trophophylls* born close to the ground, concave from above, 1.5–3.5 cm long, 0.8–1.2 cm broad, 1–2(–3) per rhizome, ovate-elliptic or elongate-elliptic, mucro at apex, cuneate at base, margins entire, dark green, glabrous, texture subfleshy; *venation* reticulate, indistinct; *fertile segment* 2–3.5 cm long, round-flat, arising from base of trophophyll lamina; *strobili* 0.8–2 cm long, thick, apex apicalute, green when young, yellow when mature; *sporangia* 10–20 on either side; *spores* triradiate, globose, equatorial diameter 40–45 μm, granular tubercles forming a densely reticulate ridge on distal face, irregular tubercles with scattered micro perforation on proximal face.

Etymology:—The specific epithet is chosen to honour Professor De-Yuan Hong for his outstanding contribution to the compilation of *Flora of Pan Himalaya*.

Phenology:—*Ophioglossum hongii* was observed at fertile phase between July and October.

Distribution & Ecology:—*Ophioglossum hongii* was found growing on soil in sparse shrubland at elevation ca.3000–4000 m in the plateau region of southwestern China.

Conservation status:—*Ophioglossum hongii* is currently recorded from three locations: Xizang Autonomous Region, Sichuan, and Yunnan provinces in China. Based on predictions of the potential suitable distribution areas of *O. hongii* under current climatic conditions, the main environmental factors influencing species distribution are Elevation and Isothermality, with a combined contribution of up to 63.3%. The highly suitable areas cover 100,380 km^2, mainly concentrated in the plateau regions of three provinces (Fig. 3), which roughly correspond to the natural distribution areas. According to the International Union for Conservation of Nature categories and criteria (IUCN 2024), *O. hongii* is widespread with stable populations and minimal human interference, thereby qualifying it for the Least Concern (LC) classification.

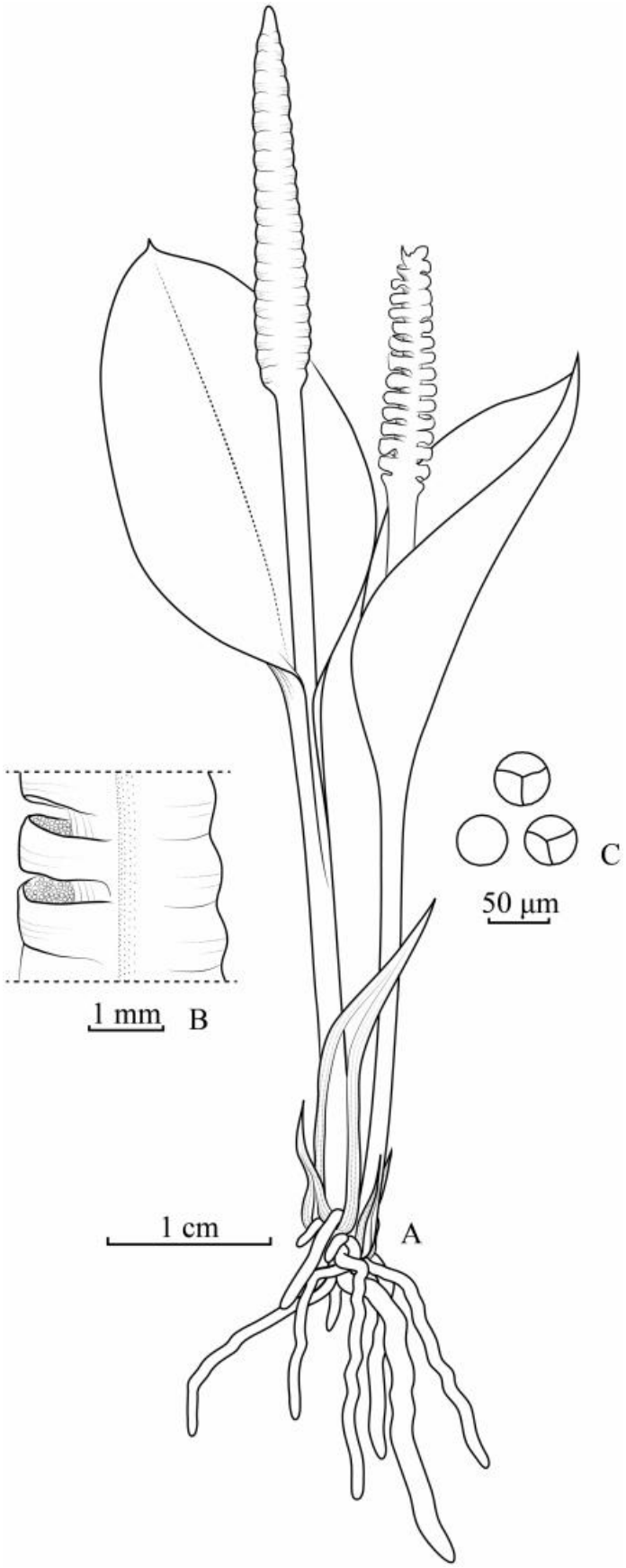


FIGURE 1. *Ophioglossum hongii* M. Y. Li, F. S. Yang & J. P. Shu *sp. nov.* (A) habit, (B) detail of spike, (C) spores.

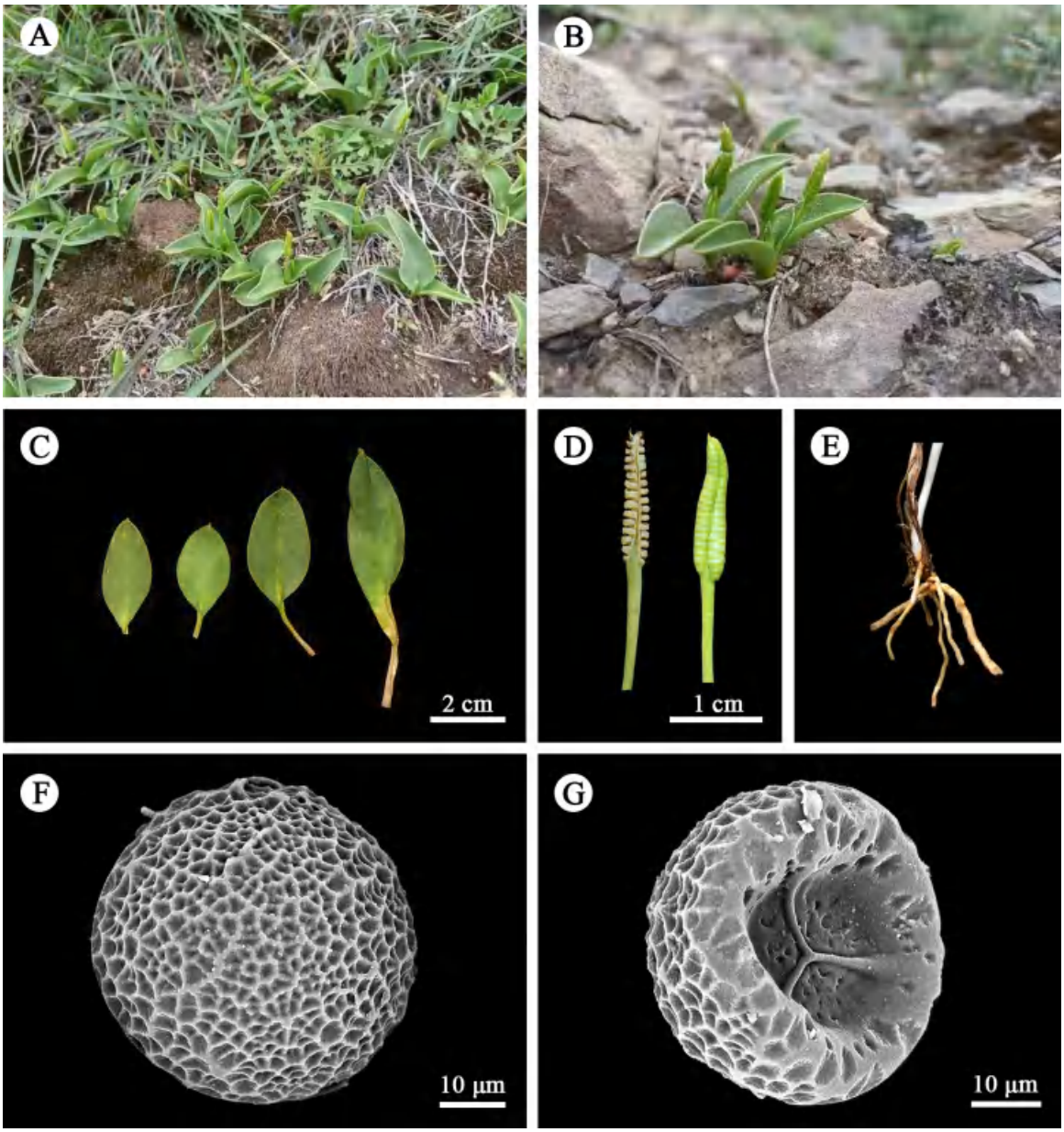


FIGURE 2. *Ophioglossum hongii sp. nov.* (Ophioglossaceae) from Xizang Autonomous Region, China. (A–B) Habitat, (C) Trophophylls, (D) Sporophore, (E) Rhizome and Roots, (F) SEM photomicrographs of spore distal view, (G) SEM photomicrographs of spore proximal view. Photo by Xin-Xin Zhu (C–E) & Jiao He (F–G).

Taxonomic notes:—Some specimens of *Ophioglossum hongii* have been misidentified as *O. nudicaule* due to their similar plant size and trophophyll morphology. But the conspicuous persistent petiole bases at the top of rhizome, shorter sporophores and molecular results indicated the distinctness of the new species from *O. nudicaule* (Fig. 4). It may also be confused with *O. polyphyllum* because they are similar in having the conspicuous persistent petiole bases, but it can be distinguished by the trophophyll shape, which is ovate-elliptic or elongate-elliptic in *O. hongii* and narrowly elliptic to oblong lanceolate in *O. polyphyllum*. In addition, *O. hongii* has 1.2–2 cm long fertile stalk versus 3–6 cm in *O. polyphyllum.* The spore ornamentation with granular tubercles forming a densely reticulate ridge on distal face in *O. hongii* versus zigzag plates often mixed up forming smaller gaps among ridges and furrows on distal face in *O. polyphyllum* (Patel & Narsimha Reddy 2019). A detailed morphological comparison is provided in Table 1.

Additional specimen examined (paratype):—CHINA, Xizang Autonomous Region: Shannan, Gongga, 13 Aug 2021, *F. S. Yang PE-YANGFS2021-412* (PE); Changdu, Gongjue, 22 Aug 1976, *Qinghai-Tibet Team Vegetation Group 9717* (PE); Rikaze, Angren, 13 Aug 1961, *Zhang J.W. 2703* (PE); Shannan, Jiacha, 29°3′56″N, 92°42′51″W, 8 Oct 2010, *Xu B.Q. & Tong Y.H. XiaNh-07zx-0657* (IBSC); Linzhi, Chayu, Sacred mt. Kar-war kar-boo, Tsa-wa rung, Sept 1935, *Wang Q.W. 66236* (NAS); Lasa, Chengguan District, Lhalu Wetland Reserve, 29°41′21.3″N, 91°6′37.6″W, 15 Aug

2020, *Zhu X.X. et al. ZXX201765* (KUN). Sichuan Province: Ganzi Tibetan Autonomous Prefecture, Daofu, 16 Aug 1960, *Sichuan Pharmaceutical Source Census Team 15532* (NAS); Aba Tibetan and Qiang Autonomous Prefecture, Maerkang, 18 July 1960, *Sichuan Pharmaceutical Source Census Team 22092* (NAS); Ganzi Tibetan Autonomous Prefecture, Xiangcheng, 31 July 1981, *Qinghai-Tibet Team 3115* (PE). Yunnan Province: Diqing Tibetan Autonomous Prefecture, Deqin, Feilai Monastery, 8 Aug 2018, *Hu J. et al. SC-a-074-B26* (NAS).

TABLE 1. Main characters distinguishing *Ophioglossum hongii* from the three most similar species.

Characters	***O. hongii***	***O. polyphyllum***	***O. engelmannii***	***O. nudicaule***
Plant size	3–10 cm	5–15 cm	5–25 cm	4–13 cm
Rhizome	Cylindrical	Cylindrical	Cylindrical	Cylindrical or occasionally nearly spherical
Persistent petiole bases at top of rhizome	Present	Present	Absent	Absent
Common stalk length	2.5–4.5 cm	3–8 cm	2.5–9 cm	0.5–2.5 cm
Trophophyll no.	1–2(–3)	1–2	1–2	1–2(rarely 3)
Length	1.5–3.5 cm	2–6 cm	3–6 cm	0.5–2.5 cm
Width	0.8–1.2 cm	0.5–1 cm	1.5–2.5 cm	0.5–1.5 cm
Shape	Ovate-elliptic or elongate-elliptic	Narrowly elliptic to oblong lanceolate	Ovate-elliptic or elongate-elliptic	Ovate to lanceous
Texture	Subfleshy	Rather fleshy	Herbaceous	Herbaceous
Venation	Reticulate	Reticulate	Complex-reticulate, veinlets forming numerous, very tiny, secondary areoles within the major areoles	Reticulate, areoles with included veinlets
Fertile stalk	1.2–2 cm	3–6 cm	4–10 cm	3.5–10 cm
Spike length	0.8–2 cm	1–2.5 cm	2–4 cm	0.5–2 cm
Sporangium no.	10–20 on each side	12–30 on each side	20–30 on each side	10–20 on each side
spores	40–45 μm dia., trilete, with granular tubercles forming a densely reticulate ridge ornamentation	32.5–47.5 μm dia., trilete, with zig-zag wide plates and small gaps ornamentation	38–42 μm dia., trilete, with dense reticulum and punctate ornamentation	30–40 μm dia., trilete, with reticulate ornamentation

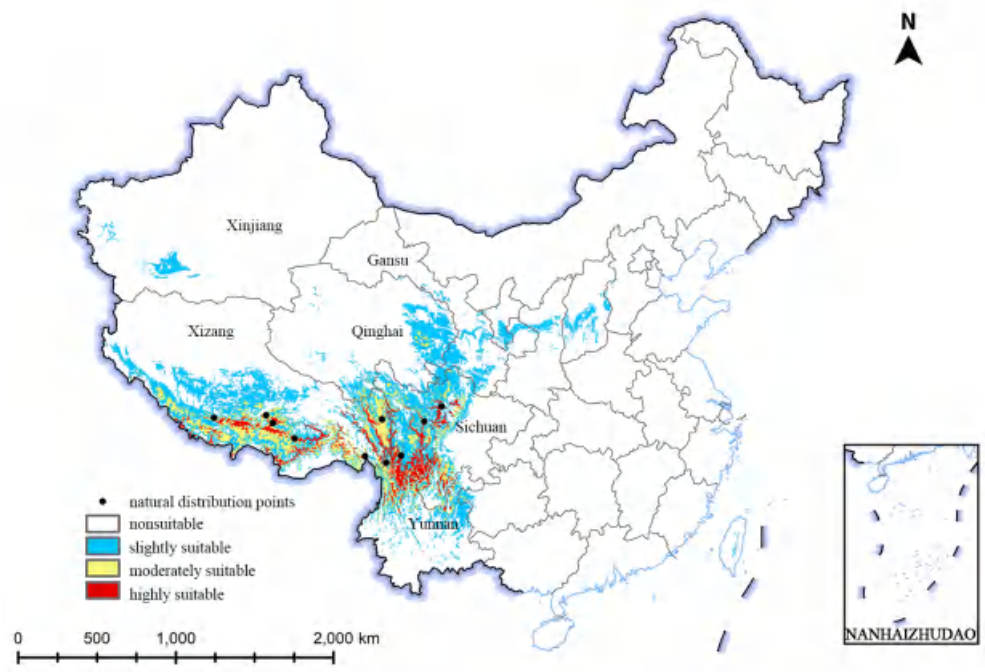


FIGURE 3. Distribution map and prediction of potential suitable distribution for *O. hongii* in China.

Phylogenetic analysis:—In the phylogenetic tree of seven chloroplast DNA sequences (*atpB*, *matK*, *psbA-trnH*, *rbcL*, *rps4*, *rps4-trnS*, and *trnL-F*), *O. hongii* is clustered with *O. polyphyllum* and *O. engelmannii* in a monophyletic clade. Additionally, two samples of *O. hongii* are recovered as a separate lineage, sister to the clade composed of *O. polyphyllum* and *O. engelmannii* with 100% support (Fig. 4).

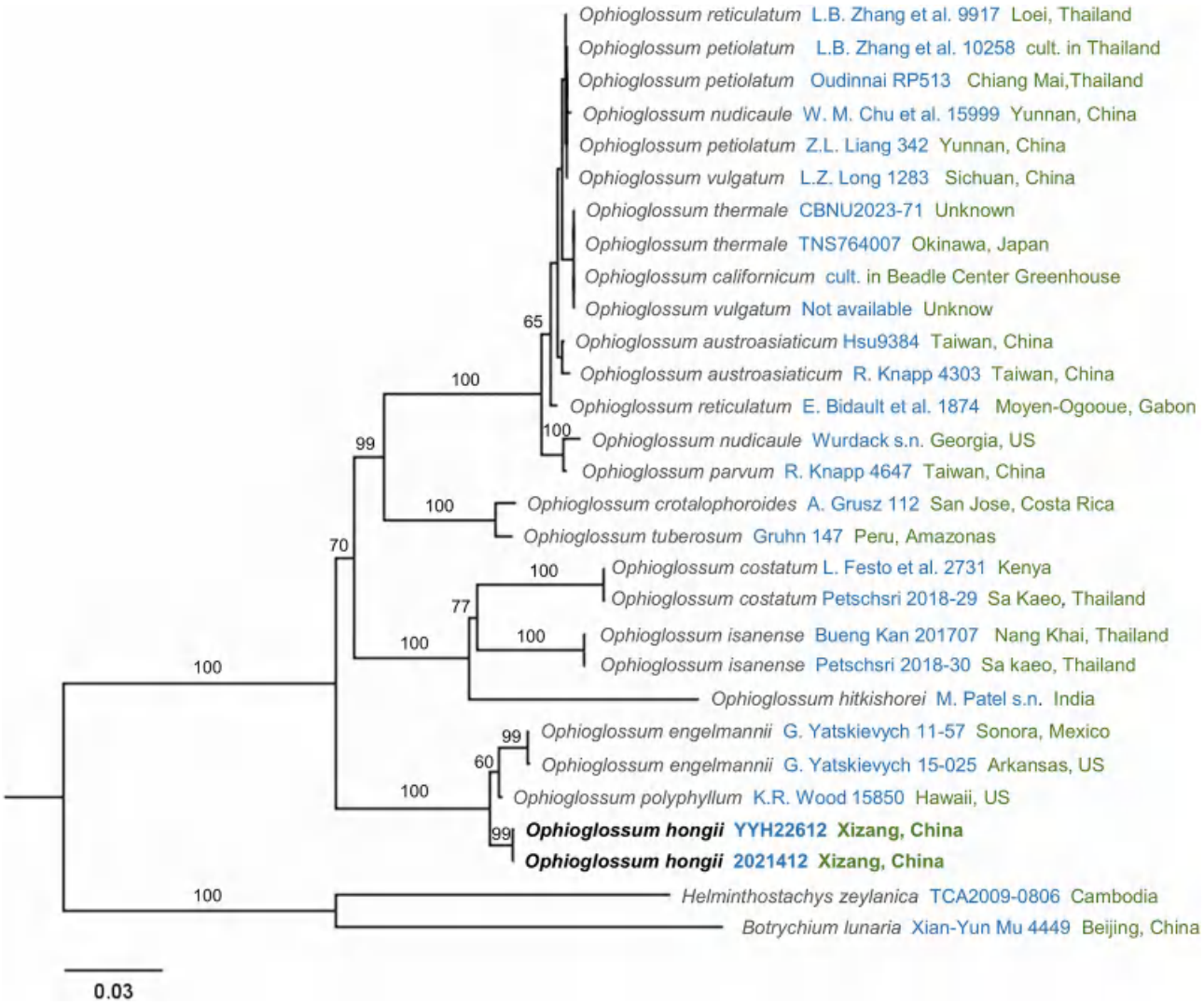


FIGURE 4. Maximum-likelihood phylogenetic tree of Ophioglossaceae based on seven plastid regions. The number on each node indicates the bootstrap support (BS) values (>50%). The new sequences are shown in thick font. Voucher information is indicated in blue. Geographical provenances are indicated in green.

Chloroplast genome:—The complete chloroplast genome sequence of *Ophioglossum hongii* was 135,126 bp in length with a GC content of 41.4%, and showed a typical quadripartite structure (Fig. 5), comprising a pair of inverted repeats (IR) regions of 19,928 bp each, a large single-copy (LSC) region of 95,906 bp, and a small single-copy (SSC) region of 19,292 bp. A total of 129 genes were annotated, including 84 protein-coding genes, 37 transfer RNA (tRNA) genes, and eight ribosomal RNA (rRNA) genes. Additionally, 10 cis-splicing genes including *ndhB*, *atpF*, *rpoC1*, *ycf3*, *clpP*, *petB*, *petD*, *rpl16*, *rpl2*, and *ndhA* were detected.

Discussion

The genus *Ophioglossum* has a nearly cosmopolitan distribution (Patil & Dongare 2014) and exhibits a simple morphology, making it readily recognizable as a genus but difficult to distinguish between species; many cryptic species are expected (Zhang & Zhang 2022).

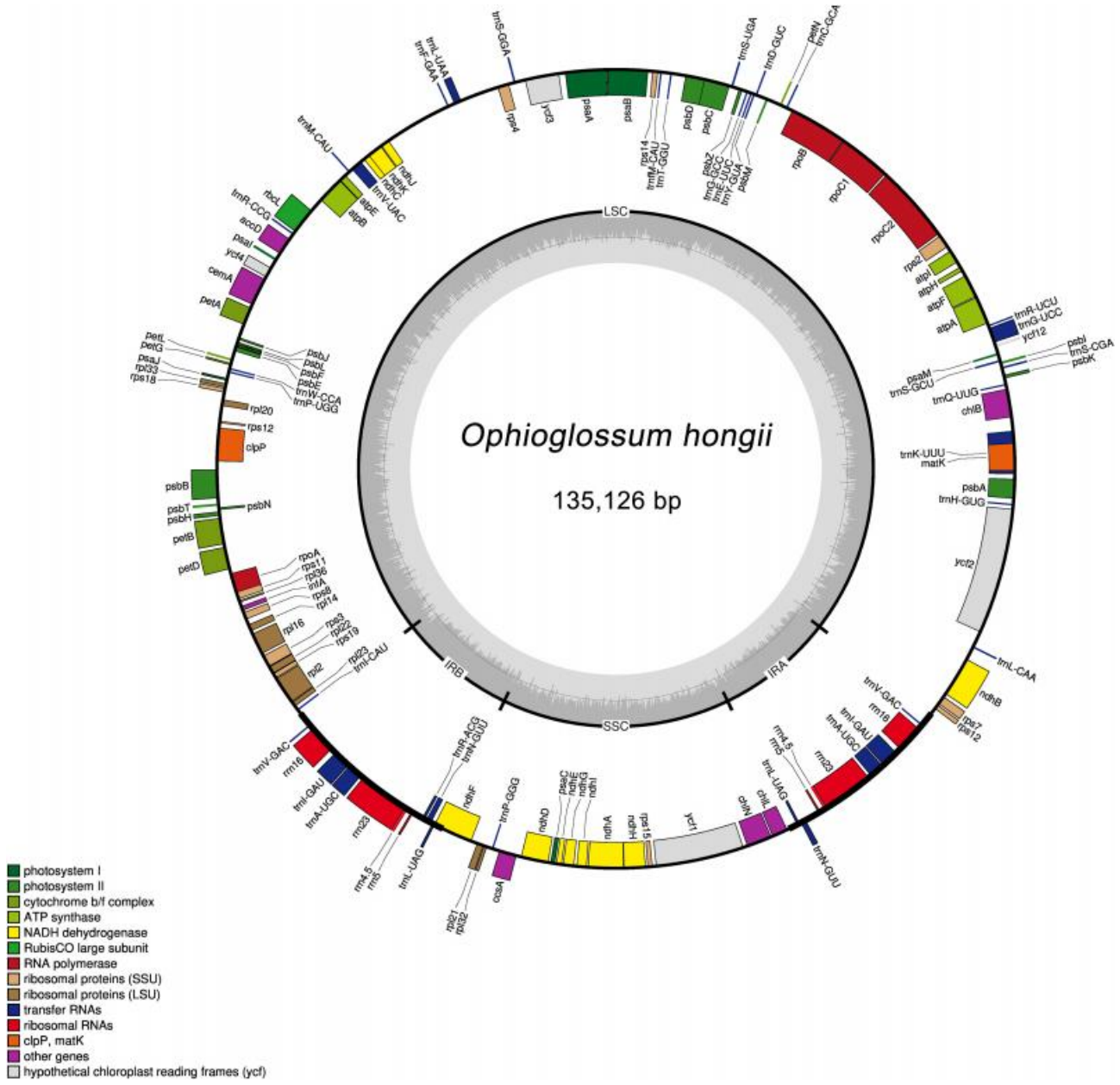


FIGURE 5. Chloroplast genome map of *Ophioglossum hongii*. Genes on the inner side of the circle undergo transcription in a clockwise direction, while those on the outer side are transcribed in a counterclockwise direction. The inner circle, represented in dark gray, corresponds to the GC content, whereas the light gray denotes the content. Diverse colors symbolize different functional genes. The pronounced line on the large circle delineates the boundaries of the inverted repeat regions (IRA and IRB), segregating the genome into small single-copy (SSC) and large single-copy (LSC) regions.

The *Ophioglossum* specimens here described from Xizang are characterized by their small size and slightly fleshy sterile lamina, and in that regard similar to *O. nudicaule*, which matches also in trophophyll shape. However, *O. nudicaule* has longer sporophores and lacks the persistent petiole bases at the top of rhizome. *Ophioglossum nudicaule* exhibits a pantropical distribution, with its type specimen originating from Cape Province, South Africa. It has been recorded in the West Indies, the Americas, Asia, Africa, and the Pacific Islands (Balakrishnan *et al.* 1960, Davidse *et al.* 1995, Faseena & Thoppil 2007, Kachhiyapatel *et al.* 2018, Ortiz-Díaz *et al.* 2020, Wagner *et al.* 1993, Zhang *et al.* 2013). By comparing the original published texts with regional flora, we have discovered morphological variations among specimens of *O. nudicaule* collected from different regions. This observation has aroused our suspicion of the existence of cryptic species within *O. nudicaule.* Phylogenetic analyses (Zhang & Zhang 2022; this study) have resolved this species as polyphyletic (Fig. 4), but always in unsupported clades without resolution. Consequently, more thorough investigation is required.

Species delimitation of *Ophioglossum* based solely on morphology is challenging due to the high likelihood of homoplasy (Patel & Narsimha Reddy 2019). The new species *Ophioglossum isanense* Petchsri *et al.* (2022) from Thailand was initially labeled as *O. cf. nudicaule* because of its smaller plant size (Petchsri *et al.* 2022). However, molecular results confirmed that these two species are different from each other. We made a combination of morphological, spore microstructural, and molecular evidence to demonstrate the distinctiveness of *O. hongii*. It closely resembles *O. polyphyllum* due to the presence of persistent petiole bases and cylindrical rhizome. However, *O. polyphyllum* can reach up to 15 cm tall, with fertile stalks 3–6 cm long and trophophyll lamina narrowly elliptic to oblong lanceolate. In contrast, *O. hongii* is often less than 10 cm tall, with fertile stalks 1.2–2 cm long and trophophyll lamina ovate-elliptic or elongate-elliptic (Table 1). When it comes to spore microstructure, there are notable differences between the two species. In *O. polyphyllum*, the distal face is often characterized by zigzag plates mixed together, forming smaller gaps between ridges and furrows (Patel & Narsimha Reddy 2019). Whereas in *O. hongii*, the spore ornamentation consists of granular tubercles forming a densely reticulate ridge on the distal face (Fig. 2F–G). Moreover, molecular phylogenetic results supported the species status of *O. hongii* and as a sister to the clade consisting of *O. polyphyllum* and *O. engelmannii*, with a bootstrap value of 100% (Fig. 4).

Notably, a recent taxonomic treatment of the Ophioglossaceae (Zhang & Zhang 2022) recognized a new genus *Whittieria* with only one species, *Ophioglossum engelmannii*. In our analysis, *O. engelmannii* and the similar *O. polyphyllum* (Zech *et al.* 1998) form one clade with *O. hongii* (Fig. 4). Morphologically, *O. hongii* is similar to *O.* (*Whittieria*) *engelmannii*, but there are significant differences in sporangial stalk length and sporangium number between *O. hongii* and *O. engelmannii*. In addition, the genus *Whitteria* has only few supporting morphological characters, and none are salient (Zhang & Zhang 2022). A large-scale plastid phylogenomic analysis by Kuo *et al.* (2024) resolved the phylogenetic positions of the genera within Ophioglossoideae varyingly and differently from Zhang and Zhang (2022) and our result (Fig. 4). Thus, we are unsure if this recognition of additional genera within *Ophioglossum s.l.* has a practical advantage and prefer to describe our new species under *Ophioglossum* rather than *Whittieria*.

Consequently, it is hereby reported as a new species, *Ophioglossum hongii*. Our results provide important genetic information for further phylogenetic studies of the genus *Ophioglossum*.

Acknowledgments

This work was supported by Shenzhen Fundamental Research Program (JCYJ20220818103212025), National Science and Technology Basic Resources Survey Program and Survey of Wildlife Resources in Key Areas of Xizang (ZL202203601, ZL202303601). The authors are grateful to Xin-Xin Zhu for providing the pictures of the paratype and Jiao He for helping with spores scanning electron microscopy.

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https://doi.org/10.1016/j.ympev.2022.107512

Supplementary Materials. The following supporting information can be downloaded at the DOI landing page of this paper:

TABLE S1. The voucher information and GenBank accession numbers of plastid regions used in this study.

TABLE S2. The voucher information and GenBank accession numbers of complete plastid genome used in this study.

TABLE S3. List of 21 environmental variables considered at the initial stage of model development. Ten variables with the code shown in bold font were chosen for the MaxEnt modeling study.

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安徽农学通报

Anhui Nongxue Tongbao

1995年创刊　半月刊

第30卷　第15期　2024年

Anhui Agricultural Science Bulletin

Started in 1995, Semimonthly

Volume 30, Issue 15, 2024

主管单位 安徽省科学技术协会	**Administrated by** Anhui Association of Science and Technology
主办单位 安徽省农学会	**Sponsored by** Anhui Association of Agricultural Science Societies
编辑出版 安徽农学通报	**Edited and published by** Anhui Agricultural Science Bulletin
主　　编 卢仕仁	**Editor-in-chief** LU Shiren
地　　址 合肥市滨湖新区洞庭湖路3355号	**Address** 3355 Dongtinghu Road, Binhu New District, Hefei
电　　话 0551-62675980、0551-62652596	**Tel** 0551-62675980, 0551-62652596
电子邮箱 anhuinxtb1995@163.com	**E-mail** anhuinxtb1995@163.com
网　　址 http: //www.ahnxtb.cn	**Web Site** http: //www.ahnxtb.cn
邮　　编 230091	**Postal code** 230091
印刷单位 合肥华苑印刷包装有限公司	**Printed by** Hefei Huayuan Printing and Packaging Co., Ltd.
发行单位 中国邮政集团有限公司安徽省邮政报刊发行局	**Distributed by** Anhui Postal Newspaper and Publication Distribution Bureau of China Post Group Co., Ltd.

本期执行编辑　李　媛

法 律 顾 问　夏跃东律师（上海建纬（合肥）律师事务所　13637059816）

中国标准连续出版物号： ISSN 1007-7731 / CN 34-1148/S　　**邮发代号** 26-146

2024年8月15日出版　　**定　价** 20.00元

封面图片源自安徽应时农业设计院有限公司

中国期刊全文数据库全文收录期刊

中国学术期刊（光盘版）全文收录期刊

中国学术期刊综合评价数据库统计源期刊

中国核心期刊（遴选）数据库全文收录期刊

ISSN 1007-7731

CN 34-1148/S

安徽农学通报

安徽农学通报

ANHUI NONGXUE TONGBAO



第三十卷　第十五期

二〇二四年八月

15

2024　8月

安徽农学通报（半月刊）

郑之宽　题字

1995年创刊

2024年第15期

总第30卷479期

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期刊基本参数：CN34—1148/S*1995*s*A4*144*zh*P*￥20.00*1000*34*2024-08

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Anhui Agricultural Science Bulletin
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基于CiteSpace文献计量分析的红豆属植物研究进展

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摘要　鉴于红豆属植物在生态保护、生态服务以及资源开发利用等方面的重要性，本研究梳理并分析有关红豆属植物的研究文献，揭示红豆属植物研究进展、趋势以及关键学科间的交叉融合现状。收集CNKI数据库中有关红豆属植物的文献，借助CiteSpace、Excel等软件进行计量分析、可视化处理以及关键词聚类。研究结果表明，2005—2021年，年度发文量波动式增长，2021年发文数量最高，呈现突破式增长；韦小丽发文量较多（29篇），存在多个较大的作者群，已经形成中大型合作网络的基本骨架，但作者群间的合作还有进一步深化的空间；形成了高校、研究院并重的研究格局，贵州大学林学院和中国林业科学研究院亚热带林业研究所在该领域发表的研究成果具有较高的水平和影响力；研究机构已经形成群簇现象，该领域机构、机构群之间的合作交流还有提升空间；相关研究集中在红豆属物种的育苗和造林等方面，关键词聚类主要包括人工林探析、野生群落特征探析及保护、植物资源利用探析；当前，学者对红豆属植物的木材利用以及野外种群复壮较为关注，红豆属下多物种的濒危保护、生态恢复及其环境适应性研究成为新的研究焦点。基于研究现状与趋势，建议加强基础研究与跨学科融合，促进学术交流与资源共享，强化种质资源保护利用。

关键词　文献计量；红豆属；CiteSpace；前沿分析；可视化分析

中图分类号　F326.2　　**文献标识码**　A　　**文章编号**　1007-7731（2024）15-0059-05

DOI号　10.16377/j.cnki.issn1007-7731.2024.15.014

Advances in the study of *Ormosia* based on CiteSpace bibliometric analysis

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Abstract　In view of the importance of *Ormosia* in ecological protection, ecological services, and resource development and utilisation, the research literature on *Ormosia* has been sorted and analyzed in order to reveal the progress of research on *Ormosia* and its trends as well as the current status of cross-fertilisation among the key disciplines. Literature on the *Ormosia* from CNKI databases was collected, and metrological analyzed, visualisation and keyword clustering were carried out with the help of CiteSpace, Excel and other software.From 2005 to 2021, the annual publication volume fluctuated and increased, with the highest number of publications in 2021, showing a breakthrough growth. Wei Xiaoli had published a large number of articles（29）and had several large author groups, forming the basic framework of a medium to large collaborative network. However, there was still room for further deepening of cooperation among author groups. A research pattern that emphasized both universities and research institutes had been formed, and the research results published by the School of Forestry at Guizhou University and the Institute of Subtropical Forestry at the Chinese Academy of Forestry in this field had a high level of influence. Research institutions had formed a cluster phenomenon, and there was still room for improvement in cooperation and communication between institutions and groups in this field. Related research focused on the seedling cultivation and afforestation of species in the *Ormosia* genus, with keyword mainly including exploration of artificial forests, analysis and protection of wild community characteristics, and exploration of plant resource utilization. Scholars were paying more attention to the wood utilization and wild population rejuvenation of plants in *Ormosia*. The endangered protection, ecological restoration, and environmental adaptability of multiple species in *Ormosia* had became

基金项目　广东省林业局林业科技创新项目（2022KJCX015）；广东省林木种质资源普查项目（GDZZDC20228703）。

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收稿日期　2024-02-05

中国知网　https://www.cnki.net

new research focuses. Based on the current research status and trends, it was recommended to strengthen basic research and interdisciplinary integration, promote academic exchanges and resource sharing, and strengthen the conservation and utilisation of germplasm resources.

Keywords　bibliometric; *Ormosia*; CiteSpace; hotspot prediction; visual analysis

红豆属植物(*Ormosia*)隶属于豆科(Fabaceae),为自然类群,乔木居多,约有130种[1-3]。该属植物起源于亚洲大陆,经长距离的跨洋传播扩散到新大陆,而后又经过多次海洋扩散形成了如今的分布格局[2,4]。中国产红豆属植物有44种(含变种、变型),以广东、广西、海南及云南等地为主分布区。红豆属植物具有良好的经济效益及开发利用价值,少数种类的种子是制作项链、耳饰和戒指等装饰品的原材料;部分种类的根、枝、叶和种子可作药用;还有部分种类因具有良好的材用性质,常作为高级家具和雕刻用材[5-7]。受人类活动的影响,红豆属植物种群数量有所下降,对其种群的保护力度有待进一步加大[8]。赵文茵等[9]研究认为,文献计量法是运用统计学算法等,对文献数据进行分析和可视化表达的方法。余开船等[10]、周超峰[11]研究认为,CiteSpace是目前文献计量较为常用的分析软件,聚类视图的可视化呈现是该软件的特点之一,能将海量文字信息转化为知识图谱,有助于分析相关学者在某领域的研究兴趣和热点。为及时了解红豆属植物的研究动态,为红豆属植物的种质资源调查、野外种群保护、育种和造林等工作提供支撑,本研究利用Execl和CiteSpace软件,通过汇总和信息可视化功能,结合科学图谱对中国知网(CNKI)数据库有关红豆属的文献进行了梳理及分析。

1　材料与方法

研究数据来源于CNKI数据库,以主题词“红豆属”“红豆树”“花榈木”等红豆属下137个种名检索学术期刊库和硕博论文库。检索时间为1980年1月1日至2023年1月1日,对检索结果去重并剔除无关条目后,最终获得中文文献294篇。运用信息可视化软件CiteSpace,以Execl软件进行辅助,对检索结果进行分析,通过数据可视化呈现,分析文献发表情况、作者及作者合作情况、研究机构及机构合作情况以及研究热点情况。

2　结果与分析

2.1　年度发文量及趋势分析

该主题的年度发文量情况如图1所示。1980—2005年,相关发文较少,较早发表的3篇文献,是张若蕙对红豆属及属下等级分类的系统性整理,该阶段是红豆属植物相关研究的初步探索阶段;2005—2021年,年度发文量波动式增长,2021年发文数量最高,呈现突破式增长。

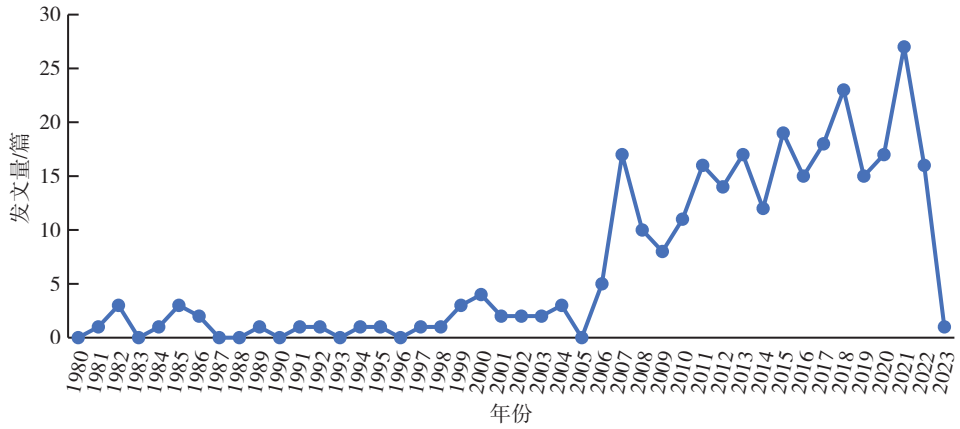


图1　1980—2023年红豆属植物研究文献年度发文趋势

2.2　主要发文作者及合作分析

红豆属植物不同作者的合作网络共现图谱如图2所示,每个节点代表一位作者,节点越大则发文量越大,作者间合作用连线代表,节点颜色代表发文时间,颜色越深代表发文时间越早。由图2可知,共有4个较大节点,分别代表作者韦小丽、郑天汉、周春

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志和倪林。其中,韦小丽发文量较多(29篇),主要关注花榈木种子萌发、幼苗和容器苗生长的影响因素[12-14]。图2存在数个较大的作者群,已经形成中大型合作网络的基本骨架,但作者群间的合作还有进一步深化的空间。



图2 红豆属植物研究作者合作网络共现图谱

2.3 研究机构及合作分析

2.3.1 研究机构分析 贵州大学林学院发文数量较高,达37篇,占总检索文献的12.59%,研究多涉及花榈木和红豆树育苗实验;浙江省龙泉市林业科学研究所发文量为15篇,占比5.10%,研究集中于红豆树生态学及栽培学问题;中国林业科学研究院亚热带林业研究所、贵州大学和福建农林大学植物保护学院发文量均为10篇,占比3.40%。浙江省龙泉市林业局发文量为8篇,贵州省生物研究所和福建省林业厅发文量为7篇。中国林业科学研究院亚热带林业研究所中心性最高,表明其与较多的机构开展合作研究,是机构群中的连接中心点之一。因此,红豆属植物科研领域形成了高校、研究院并重的研究格局,贵州大学林学院和中国林业科学研究院亚热带林业研究所在该领域发表的研究成果具有较高水平和影响力。

2.3.2 研究机构合作关系分析 不同机构的合作网络共现图谱如图3所示。由图3可知,有关红豆属植物的研究形成以贵州大学林学院、福建农林大学和中国林业科学研究院亚热带林业研究所等机构为中心的机构群,机构群节点间的连线数量和不同机构之间的连线数量有待增加,说明研究机构已经形成群簇现象,而未来该领域研究机构、机构群之间的合作交流还有提升空间。

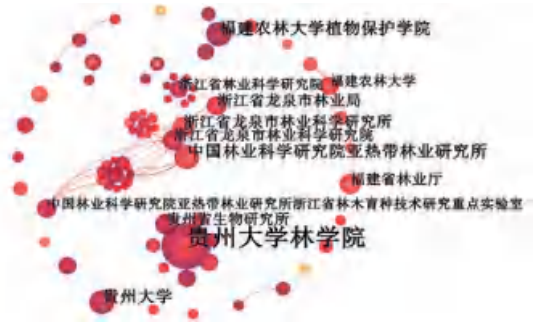


图3 红豆属植物研究机构合作网络共现图谱

2.4 研究热点分析

2.4.1 高频关键词分析 红豆属植物研究领域高频关键词频次及中心性如表1所示,红豆属植物研究关键词网络共现图谱如图4所示。由表1可知,CNKI数据库中红豆属植物研究领域,引用频次前六的关键词分别为“红豆树”(114次)、“花榈木”(58次)、“人工林”(11次)、“容器苗”(10次)、“海南红豆”(10次)和“红豆属”(9次),表明相关研究集中在红豆属物种的育苗和造林等方面。

表1 红豆属植物研究领域高频关键词频次及中心性

关键词	中心性	频次	占比/%
红豆树	1.12	114	28.64
花榈木	0.44	58	14.57
人工林	0.10	11	2.76
容器苗	0.35	10	2.51
海南红豆	0.12	10	2.51
红豆属	0.16	9	2.26
杉木	0.12	8	2.01
生长	0.21	8	2.01
岩生红豆	0.20	7	1.75
混交林	0.07	7	1.75

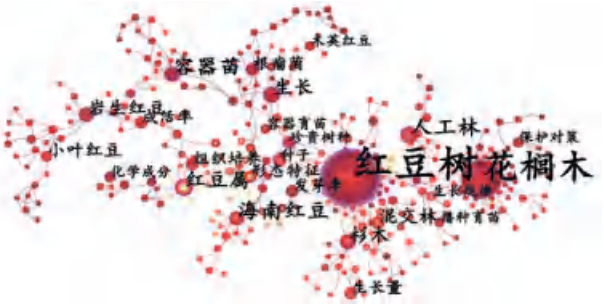


图4 红豆属植物研究关键词网络共现图谱

2.4.2 关键词聚类分析 关键词聚类分析结果如图5所示。共得到11个聚类、398个节点和617条节点间连线的网络图谱。在该网络中,最大联结模块拥有350个节点,占该网络节点总数的87%。该网络Q值为0.845 3(Q值大于0.3表明网络结构合理),这说明在红豆属植物研究领域,关键词聚类符合要求。

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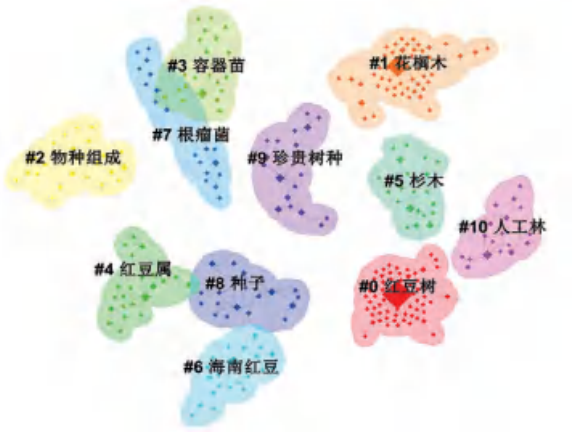


图5　红豆属植物研究关键词聚类

将得到的聚类分析结果进一步分析，得到如下聚类分析结果。(1)人工林探析。人工林探析包括苗木繁殖及培育和人工林实地研究。苗木繁殖及培育主要特征词有红豆树、花榈木和培育技术等。该小类研究主要集中在红豆树及花榈木的育苗实验。红豆树和花榈木具有极高的开发利用价值和前景，野生种群易受干扰，对其进行育苗研究意义重大[15-16]。张发游等[17]、王帮顺等[18]和陆孝建[19]研究认为，进行红豆树有性繁殖时，对种子采用沙藏催芽、高温浸种和机械破皮等技术或者使用破皮加冷水浸泡技术，均有利于种子萌发；在无性繁殖时，将插穗浸入适宜浓度的生根粉溶液，并使用新鲜细黄心土混入细砂作为基质，可提高插穗成活率。

(2)野生群落特征探析及保护。野生群落特征探析及保护的主要特征词有资源分布、物种组成和濒危原因等。学者对大中尺度范围内特定物种的群落特征进行了实地调研，目的是了解特定物种的野生资源特征并做好保护工作。李晓芳等[20]对贵州岩生红豆野生资源进行了考察，针对性地提出以就地保护为主，迁地保护、种苗繁育和回归引种为辅的综合保护措施。刘鹏等[16]研究了花榈木复壮的科学方法，提出应加强对花榈木种子败育和休眠等问题的研究，做好病虫害防治工作。

(3)植物资源利用探析。植物资源利用探析的特征词有海南红豆、种子萌发和抗寒性等，研究主要聚焦于海南红豆。植物观赏利用方面，海南红豆具有树形优美、适应性较好、生长迅速、繁殖系数高、抗风且嫩叶鲜艳等特性，是园林绿化的优良树种[21-24]。弓明钦等[25]对海南红豆行道树红锈病的病毒症状、原物及病害发生规律进行了报道，为该树种病害防治提供了参考。植物抗性方面，张柔等[26]研究认为，海南红豆具有一定的抗涝性；郭淑红等[27]、杨振意等[28]研究认为，海南红豆的抗寒性较南五味子强，为选择适合的海南红豆栽培生境提供了参考。

2.4.3　研究前沿趋势分析　　对红豆属植物研究前沿时区视图(图6)进行分析可知，20世纪80年代，相关研究大多属于基础性学科研究，如红豆属植物分类；20世纪90年代，针对特定种类的育苗试验兴起，主要聚类有红豆树(关键词分别为“红豆树”“花榈木”“培育技术”“正交试验”“试验”)、花榈木(关键词分别为“花榈木”“人工繁殖”“研究进展”“资源分布”“播种育苗”)；21世纪前后，混交林研究成为热点，根据聚类杉木、人工林的关键词可知，该时期研究聚焦红豆属植物与杉木混交林效益以及混交林树种的选择；21世纪10年代至今，主要聚类有容器苗、珍贵树种和成活率，关键词包括“供水量”“废菌棒”“空气切根”等，因此，目前学者对红豆属植物的木材利用以及野外种群复壮较为关注。

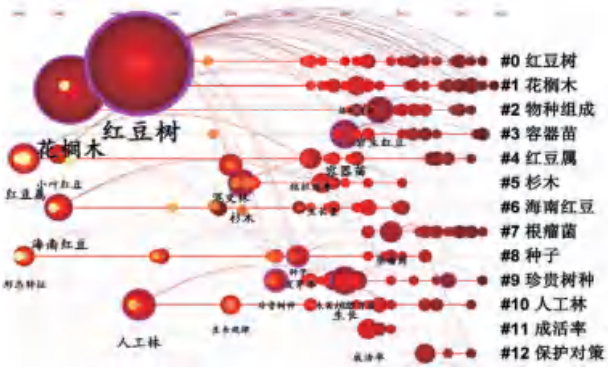


图6　红豆属植物研究前沿时区视图

对红豆属植物研究突现关键词分析可知(图7)，共有15个重点突现关键词。1985—2002年，海南红豆为研究热点，研究集中在海南红豆的园林应用、种子萌发培育以及育苗技术改善上。21世纪初，“混交林”“生长规律”“育苗技术”等关键词成为阶段内的热点。近年来，随着相关保护政策持续陆续出台及自然保护意识逐渐增强，“种源”等关键词成为新兴焦点。

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图7　CNKI数据库红豆属植物研究突现关键词

3　结论与讨论

运用文献计量学方法，对CNKI数据库中涉及红豆属植物的文献进行分析，结果表明，2005—2021年，年度发文量呈波动式增长，2021年发文数量最高，呈突破式增长；韦小丽发文量较多（29篇），存在数个较大的作者群，已经形成中大型合作网络的基本骨架，但作者群间的合作还有进一步深化的空间；形成了高校、研究院并重的研究格局，贵州大学林学院和中国林业科学研究院亚热带林业研究所在该领域发表的研究成果具有较高的水平和影响力；研究机构已经形成群簇现象，该领域机构、机构群之间的合作交流还有提升空间；相关研究集中在红豆属物种的育苗和造林等方面，关键词聚类主要包括人工林探析、野生群落特征探析及保护和植物资源利用探析；当前，学者对红豆属植物的木材利用以及野外种群复壮较为关注，红豆属下多物种的濒危保护、生态恢复及其环境适应性成为新的研究焦点。

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第43卷 第8期
Vol.43 No.8

中国野生植物资源

Chinese Wild Plant Resources

8
2024

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2024年08期目次

赋能“土特产” 助力乡村振兴

响应面法优化流苏香竹叶黄酮提取工艺及其抗糖尿病潜力分析
李振霖;闫武;赵一鹤;
目的：优化复合酶辅助提取流苏香竹叶黄酮工艺条件，评价流苏香竹叶黄酮体外抗糖尿病潜力。方法：采用响应面法优化流苏香竹叶黄酮超声协同复合酶提取工艺，以提取物及其萃取组分的总黄酮得率为评价指标，研究其对α-葡萄糖苷酶和蔗糖还原酶的抑制活性。结果：流苏香竹叶黄酮提取的最佳工艺条件为料液比1∶24 g/mL，复合酶比例（果胶酶∶纤维素酶）为1∶3，酶解温度51℃，pH值为6.0，此条件下黄酮得率为8.95%。流苏香竹叶粗提物水相萃取组分的总黄酮含量为1.175 mg/mL。生物活性研究表明，与阿卡波糖相比，乙酸乙酯和二氯甲烷相萃取组分的α-葡萄糖苷酶抑制活性更高，分别为阿卡波糖的4.14和9.70倍。同时，二氯甲烷相萃取组分有最强的蔗糖还原酶抑制活性（IC_(50)=0.167 mg/mL），表明该溶剂能更好的从流苏香竹叶中富集这两种酶活性抑制的有效成分。皮尔森相关性分析表明，黄酮类化合物是流苏香竹叶中主要的活性成分，与α-葡萄糖苷酶和蔗糖还原酶抑制活性呈中高度相关。结论：流苏香竹叶黄酮在抗糖尿病药物或保健产品等领域的开发潜力较大。
2024年08期 v.43;No.246 1-9页 [查看摘要][在线阅读][下载 2634K]
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独一味不同入药部位止血止痛独有成分分析
张丽;陈海娟;张国燕;闫军;
目的：基于独一味地上部分和根成分的差异性，探究独一味不同入药部位止血止痛的作用。方法：利用UHPLC-Q-Exactive-Orbitrap-MS快速表征和识别两种不同入药部位的化学成分。利用网络药理学挖掘不同入药部位独有成分及其与止血止痛功能相关的靶点，探究独一味地上部分和根独有成分止血止痛的药效物质基础并分析主要活性成分。结果：独一味地上部分鉴定出193个化合物，根中鉴定出191个化合物，其中地上部分和根部独有成分分别为13和11个。网络药理学结果表明发挥止血止痛作用的5个核心成分（吉草次酸、熊果酸、左旋千金藤啶碱、α-香附酮、多疏草甲素）均来自地上部分，这些成分通过作用于177个交集基因并调控多条信号通路达到止血止痛的目的。结论：该研究表明独一味不同部位止血止痛的药效物质基础存在差异，独一味地上部分更适合作为止血止痛的入药部位，此结果可为独一味不同部位的开发利用及资源保护提供依据。
2024年08期 v.43;No.246 10-20+28页 [查看摘要][在线阅读][下载 5070K]
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超声辅助低共熔溶剂法优化提取珊瑚菌多糖及其抗氧化活性研究
祝晓慧;宋建强;董伟;王克昊;胡林奎;
目的：采用超声辅助低共熔溶剂法提取珊瑚菌中的多糖。方法：以Box-Behnken体系为基础，采用单因素结合响应面的方法进行四因素三水平试验设计优化珊瑚菌多糖的最佳提取工艺条件。结果：各因素对珊瑚菌多糖提取率的影响大小排序为：孵化时间>液料比>提取温度>提取时间。以摩尔比1∶2的氯化胆碱—乙二醇体系作为提取剂，在提取温度60℃、液料比20∶1、超声时间40 min、孵化时间24 h时的多糖提取率最高为31.76%。结论：采用超声辅助低共熔溶剂法提取珊瑚菌多糖比传统方法效果显著，可为珊瑚菌资源的开发利用提供理论参考。
2024年08期 v.43;No.246 21-28页 [查看摘要][在线阅读][下载 2292K]
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研究报告

糙叶败酱中獐牙菜苷的高速逆流色谱分离及其抗肿瘤活性研究
王梦凡;李怡;辛安琪;马超环;石晓峰;
目的：采用高速逆流色谱法（HSCCC）对糙叶败酱中的环烯醚萜类化合物獐牙菜苷进行分离纯化，并对其体外抗肿瘤活性进行初步评价。方法：HSCCC的溶剂体系为正丁醇-乙酸乙酯-水（5∶2∶5），上相为固定相，下相为流动相，正进正转，分离温度25℃、转速850 r/min、流动相流速2.0 mL/min、进样浓度10 mg/mL、进样量15 mL、检测波长240 nm，并采用细胞计数试剂盒-8(CCK-8)法检测糙叶败酱对8种不同肿瘤细胞的增殖抑制作用。结果：从糙叶败酱中分离得到了纯度大于92%的獐牙菜苷。獐牙菜苷对人源肝癌细胞HepG2、结肠癌细胞ST480、肺癌细胞A549、人慢性髓原白血病细胞K562和宫颈癌Hela细胞这5种肿瘤细胞的增殖均有较强的抑制作用，且呈现明显的剂量依赖关系和时间依赖关系。结论：本研究为应用HSCCC高效分离纯化糙叶败酱中獐牙菜苷提供了技术支持，也为其抗肿瘤活性研究提供了思路。
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广东省封开县野生林木种质资源调查研究
涂利月;赵幼祥;蒋新生;
基于广东省林木种质资源项目，采用样线、样方的实地调查方式，确定封开县野生林木资源情况。进而对其物种组成、地理区系特点、资源利用方式等进行研究。结果表明：封开县有野生林木种质资源83科209属380种，其中蕨类植物1科1属1种，裸子植物1科1属2种，被子植物81科207属377种；根据封开县野生林木科属种的地理区系分析结果，其林木种质资源区系以热带成分占绝对优势地位，呈现出明显的热带-亚热带属性；此外，根据植物资源用途将封开县野生林木种质资源分为药用、观赏、材用、食用等13种类型，其中药用植物资源最丰富。封开县林木种质资源丰富，资源利用类型多样，建议当地结合生产实际，合理开发利用林木种质资源，深度挖掘林木种质资源的药用、材用、观赏等价值，促进封开县野生林木种质资源的可持续发展。
2024年08期 v.43;No.246 112-119页 [查看摘要][在线阅读][下载 1379K]
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doi:10.3969/j.issn.1006-9690.2024.08.017

广东省封开县野生林木种质资源调查研究

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摘 要 基于广东省林木种质资源项目,采用样线、样方的实地调查方式,确定封开县野生林木资源情况,进而对其物种组成、地理区系特点、资源利用方式等进行研究。结果表明:封开县有野生林木种质资源83科209属380种,其中蕨类植物1科1属1种,裸子植物1科1属2种,被子植物81科207属377种;根据封开县野生林木科属种的地理区系分析结果,其林木种质资源区系以热带成分占据优势地位,呈现出明显的热带-亚热带属性;此外,根据植物资源用途将封开县野生林木种质资源分为药用、观赏、材用、食用等15种类型,其中药用植物资源最丰富。封开县林木种质资源丰富,资源利用类型多样,建议当地结合生产实际,合理开发利用林木种质资源,深度挖掘林木种质资源的药用、材用、观赏等价值,促进封开县野生林木种质资源的可持续发展。

关键词 野生林木资源;植物区系;利用类型

中图分类号:Q948.2 **文献标识码**:A **文章编号**:1006-9690(2024)08-0112-08

Research on Wild Forest Germplasm Resources in Fengkai County, Guangdong Province

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Abstract Based on the Guangdong Forest Tree Germplasm Resources Project, field surveys of sample lines and sample plots were conducted to determine the status of wild forest tree resources in Fengkai County. This involved investigating species composition, flora characteristics and resource utilizations, supported by a review of existing literature. The results showed that there were 83 families, 209 genera, and 380 species of wild forest germplasm resources in Fengkai County, including 1 family, 1 genera, and 1 species of ferns, 1 family, 1 genera, and 2 species of gymnosperms, 81 families, 207 genera, and 377 species of angiosperms. Upon geographic zonation analysis of the plants in Fengkai County, it was found that the wild forest germplasm resources in this area were dominant by the tropical composition, exhibiting distinct tropical-subtropical properties. Futhermore, according to the use of plant resources, the wild forest germplasm resources in Fengkai County were divided into 15 types, including medicinal, ornamental, material, and edible, with medicinal plants being the most abundant. Fengkai County was rich in forest germplasm resources and offered a variety of resource utilization types. It was suggested that the local government rationally develop and utilize these resources, while also exploring the medicinal, material and ornamental values of forest germplasm resources to promote the sustainable development in Fengkai County.

Key words Wild forest resources; Flora; Utilization type

收稿日期:2024-04-26,录用日期:2024-07-08
基金项目:广东省林业局林业科技创新项目(GDZZDC20228703)。
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林木种质资源是国家的重要战略资源，是遗传多样性和物种多样性的基础，关系到国家生态安全和经济社会的可持续发展，同时也是国家科技体系建设及科技创新的一项重要保障[1-2]。我国林木资源丰富，但在资源搜集管理、资源保护利用上与世界先进水平仍有较大差距。广东省植物资源丰富，木本植物类型多样，但植物本底相对不清，导致植物资源开发利用受限。本研究基于广东省林木种质资源调查项目，以封开县野生林木种质资源为调查对象，通过实地调查与文献查阅，对封开县的野生林木种质资源的资源组成、植物区系、植物利用类型等进行分析，意在摸清封开县野生林木种质资源情况，归纳总结其利用价值，为保护与合理开发当地野生林木种质资源提供参考。

1　研究区概况

封开县隶属广东省肇庆市，地处西江、贺江两江和广东、广西两省交汇处，与广西梧州市、贺州市均有接壤，古时为中原与岭南的水陆交通要隘，商业贸易繁荣[3-4]。介于北纬 23° 13' ~ 23° 59'，东经 111° 21' ~ 112° 02'之间，总面积 2 723.93 km^2，海拔 800 ~ 1 000 m，年平均气温 20℃左右，年平均降雨量 1 500 ~ 1 700 mm，属亚热带季风湿润气候[5-6]。受季候风影响，气候温暖，冬短夏长，无霜期长。封开县森林资源丰富，主要植被类型有常绿阔叶林、针阔混交林、针叶林等。

2　研究方法

基于广东省林木种质资源调查项目，在 2023 年 8 月对封开县野生林木进行样线和样方调查。其中样线调查为记录沿线两侧 10 m 范围内的木本植物种类，样方调查为记录大小为 20 m × 20 m 区域内的木本植物种类，样线、样方多选择人类活动影响小、植物种类丰富的区域进行调查，共调查了 28 条样线和 6 个样方。利用《广东植物图鉴》[7]、《广东植物志》[8]等植物学著作以及中国植物智网站（https://www.iplant.cn/frps）对调查所得数据进行核对和鉴定，整理出封开县野生林木资源名录。其中蕨类植物按秦仁昌系统（1978）分类，裸子植物按照郑万钧系统（1978）分类，被子植物按照哈钦松系统（1926 ~ 1934）分类。

3　结果与分析

3.1　野生林木种质资源组成

调查数据显示，封开县野生林木种质资源共记录有 83 科 209 属 380 种。如表 1 所示，其中裸子植物 1 科 1 属 2 种，分别占封开县林木种质资源科、属、种的 1.20%、0.48% 和 0.53%；被子植物共计 81 科 207 属 377 种，分别占封开县林木种质资源科、属、种的 97.60%、99.04% 和 99.21%。根据《世界自然保护联盟濒危物种红色名录》（IUCN 红色名录）[9]，其中极危物种（CR）有短序楠（*Phoebe brachythyrsa* H. W. Li）1 种；濒危物种（EN）有润楠［*Machilus nanmu*（Oliv.）Hemsl.］、白桂木（*Artocarpus hypargyreus* Hance）2 种；近危物种（NT）有浙江润楠（*Machilus chekiangensis* S. K. Lee）、翻白叶树（*Pterospermum heterophyllum* Hance）、桫椤［*Alsophila spinulosa*（Wall. ex Hook.）R. M. Tryon］3 种；易危物种（VU）有土沉香［*Aquilaria sinensis*（Lour.）Spreng.］、吊皮锥（*Castanopsis kawakamii* Hayata）、黑老虎［*Kadsura coccinea*（Lem.）A. C. Sm.］、蝴蝶果［*Cleidiocarpon cavaleriei*（H. Lév.）Airy Shaw］、壳菜果（*Mytilaria laosensis* Lecomte）、紫荆木［*Madhuca pasquieri*（Dubard）H. J. Lam］、花榈木（*Ormosia henryi* Hemsl. & E. H. Wilson）、茸荚红豆（*Ormosia pachycarpa* Champ. ex Benth.）8 种，分别占总种数的 0.26%、0.52%、0.79%、2.11%。参考《国家重点保护野生植物名录》[10]，确定封开县木本植物中共有国家二级保护物种 8 种，分别是桫椤、润楠、土沉香、紫荆木、花榈木、海南红豆［*Ormosia pinnata*（Lour.）Merr.］、茸荚红豆、软荚红豆（*Ormosia semicastrata* auct. non Hance：Y. Chen）。

表 1　封开县野生林木种质资源植物类型表

Tab. 1　Plant types of wild forest germplasm resources in Fengkai County

植物类型	科数	科占比（%）	属数	属占比（%）	种数	种占比（%）
蕨类植物	1	1.20	1	0.48	1	0.26
裸子植物	1	1.20	1	0.48	2	0.53
被子植物	81	97.60	207	99.04	377	99.21
合计	83	100.00	209	100.00	380	100.00

根据科中所含种数，可将本次调查的 83 科植物划分为 4 个等级（表 2），其中单种科包含 1 个种、寡种科包含 2 ~ 10 种、中等科包含 11 ~ 20 种、多种科

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种数大于20[11]。单种科有金丝桃科(Hypericaceae)、红树科(Rhizophoraceae)等26科26属26种,占总科数的31.32%;寡种科有桃金娘科(Myrtaceae)、鼠李科(Rhamnaceae)等47科113属176种,占总科数的56.63%;中等科有桑科(Moraceae,4属19种)、蝶形花科(Papilionaceae,8属18种)、壳斗科(Fagaceae,4属17种)、茜草科(Rubiaceae,12属16种)、马鞭草科(Verbenaceae,4属16种)、蔷薇科(Rosaceae,6属14种)、山茶科(Theaceae,6属12种)、紫金牛科(Myrsinaceae,4属11种),共8科48属123种,占总科数的9.64%;多种科有大戟科(Euphorbiaceae,14属29种)、樟科(Lauraceae,8属26种),共2科22属55种,占总科数的2.41%。其中寡种科占总科数比例最大且包含种数量最多,说明寡种科是封开县野生林木资源科级的主要组成部分;而单种科和寡种科所含种类共202种,占总种数的53.16%,具有明显的数量优势,说明封开县种质资源种类丰富且分化程度较高。

表2 封开县野生林木种质资源植物科、属、种组成

Tab. 2 Family, genera and species composition of wild forest tree germplasm resources in Fengkai County

科类别(所含种数)	科数	科占比(%)	属数	属占比(%)	种数	种占比(%)
单种科(1种)	26	31.32	26	12.44	26	6.84
寡种科(2~10种)	47	56.63	113	54.07	176	46.32
中等科(11~20种)	8	9.64	48	22.96	123	32.37
多种科(>20种)	2	2.41	22	10.53	55	14.47
合计	83	100.00	209	100.00	380	100.00

3.2 生活型组成

生活型的形成是不同植物对相同环境条件产生趋同适应的结果,可以反映植物分布的生态环境特征[12]。根据实地调查结果,封开县野生林木种质资源生活型可分为乔木、灌木、木质藤本、木本竹类[13]、木本蕨类(表3)。其中乔木种数最多,有189种,占总种数的49.74%;灌木次之,有141种,占总种数的37.10%;木质藤本44种,占总种数的11.58%;木本竹类1科4属5种,占总种数的1.32%;木本蕨类仅有桫椤1种,占总种数的0.26%。

表3 封开县野生林木种质资源植物生活型构成

Tab. 3 Plant life type composition of wild forest germplasm resources in Fengkai County

生活型	种数	占比(%)
乔木	189	49.74
灌木	141	37.10
木质藤本	44	11.58
木本竹类	5	1.32
木本蕨类	1	0.26
合计	380	100.00

3.3 植物区系成分分析

3.3.1 科的区系成分分析

按照吴征镒等[14]对中国种子植物科分布区类型的划分,可将封开县83科植物划分为10个分布区类型(表4)。热带分布区类型(2~7型)共54科,占非世界广布类型科总数的81.82%,温带分布区类型(8~14型)有壳斗科、金缕梅科(Hamamelidaceae)等12科,占非世界广布类型科总数的18.18%。热带性成分与温带性成分的比值(Tropical/Temperate,R/T)为4.5。其中,热带广布类型最多,共38科,如山茶科、樟科、大戟科等,占非世界广布类型科总数的57.58%,具有优势地位,表明封开县野生林木种质资源的热带、亚热带性质较为明显,伴有向温带过渡的类型。

3.3.2 属的区系成分分析

按照吴征镒[15]对中国种子植物属分布区类型的划分,可将封开县209属植物划分为12个分布区类型(表4)。封开县野生林木种质资源中世界广布属有悬钩子属(*Rubus* L.)、卫矛属(*Euonymus* L.)、茄属(*Solanum* L.)3属。热带分布区类型(2~7型)共163属,占非世界广布类型属总数的79.13%,其优势属有樟属(*Camphora* Fabr.)、榕属(*Ficus* L.)、蒲桃属(*Syzygium* Gaertn.)等。温带分布区类型(8~14型)共42属,占非世界广布类型属总数的20.39%,优势属有枫香树属(*Liquidambar* L.)、锥属(*Castanopsis* Spach)、栎属(*Quercus* L.)等。属的R/T值为3.88,略低于科的R/T值。说明封开县野生林木种质资源属级区系以热带成分为主,与热带植物区系具有更强的联系。

3.3.3 种的区系成分分析

种是植物区系地理分析的最基本单元[16],作为

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表 4　封开县野生林木种质资源科属分布区类型

Tab. 4　Types of family and genus distribution areas of wild forest germplasm resources in Fengkai County

分布区类型	科数	科占比(%)	属数	属占比(%)	种数	种占比(%)
1. 世界广布	17	–	3	–	6	–
2. 热带广布	38	57.58	58	28.16	76	20.32
3. 东亚(热带、亚热带)及热带南美间断	10	15.15	12	5.83	13	3.48
4. 旧世界热带	2	3.03	23	11.17	33	8.82
5. 热带亚洲至热带大洋洲	2	3.03	25	12.14	33	8.82
6. 热带亚洲至热带非洲	1	1.52	13	6.31	16	4.28
7. 热带亚洲	1	1.52	32	15.53	157	41.98
热带分布小计(2 ~ 7)	54	81.82	163	79.13	328	87.70
8. 北温带	8	12.12	10	4.85	1	0.27
9. 东亚及北美间断	2	3.03	19	9.22	18	4.81
10. 旧世界温带	–	–	3	1.46	–	–
14. 东亚	2	3.03	10	4.85	12	3.21
温带分布小计(8 ~ 14)	12	18.18	42	20.39	31	8.29
15. 中国特有	–	–	1	0.48	15	4.01

注：世界广布类型不计算比例。

区系存在的实体，种的区系类型分析能进一步反映一个地区的植被类型演化状态[17]。本研究参照上述关于中国种子植物属的分布区类型划分，通过中国植物志(英文版)逐个查询种的地理分布信息，结合《中国自然地理：植物地理》(上册)[18]中的内容，依据吴悦宏等[19]提出的删繁就简原则，取消亚型的划分，将封开县 380 种木本植物划分为 11 个分布区类型。

热带分布区类型(2 ~ 7 型)共 328 种，占非世界广布类型种总数的 87.70%，占绝对优势，热带分布树种有铁冬青(*Ilex rotunda* Thunb.)、厚壳桂[*Cryptocarya chinensis* (Hance) Hemsl.]、阴香[*Cinnamomum burmanni* (Nees & T. Nees) Blume]等。其中，热带亚洲分布种数最多，有 157 种，占非世界广布类型种总数的 41.98%。温带分布区类型(8 ~ 14 型)共 31 种，占非世界广布类型种总数的 8.29%，包括枳椇(*Hovenia acerba* Lindl.)、楤木[*Aralia elata* (Miq.) Seem.]、栗(*Castanea mollissima* Blume)等。

中国特有分布型(15 型)共 15 种，占非世界广布类型种总数的 4.01%，包括鼎湖钓樟(*Lindera chunii* Merr.)、广东冬青(*Ilex kwangtungensis* Merr.)、广东山龙眼(*Helicia kwangtungensis* W. T. Wang)、广东紫珠(*Callicarpa kwangtungensis* Chun)等。

3.4　资源利用类型

封开县地处粤西北，是广东省肇庆市管辖的山区县，北回归线穿境而过，气候湿润、光照充足、无霜期长、水资源丰富，有着突出的地理优势和丰富的植被资源。根据应用价值，封开县林木种质资源可以划分为 15 个应用类型(表 5)。

3.4.1　药用植物

药用植物是指根、茎、叶、花、果实等含有特殊成分而可供人类使用，具备治疗疾病、强身保健等相关医疗作用的植物[20]。封开县野生林木种质资源具有药用价值的植物有 69 科 161 属 248 种，是该地区资源植物最主要的组成部分，占总种数的 65.26%，如常用的粗叶榕(*Ficus hirta* Vahl)、朱砂根(*Ardisia crenata* Sims)、猪肚木(*Canthium horridum* Blume)等。

3.4.2　观赏植物

植物的茎、叶、花、果或其个体、群体有较高观赏价值的都可称为观赏植物[21]，而野生观赏植物是观赏植物的重要组成部分，是原生地天然生长处于半野生或野生状态，尚未广泛应用，具有种类丰富、观赏类型多样的植物群体[22]。封开县野生林木种质资源中观赏植物共 52 科 96 属 174 种，占总种数的 45.79%。如山鸡椒[*Litsea cubeba* (Lour.) Pers.]、桃金娘[*Rhodomyrtus tomentosa* (Aiton) Hassk.]、豆梨(*Pyrus calleryana* Decne.)等。野生观赏植物往往在花期或嫩叶期具有色彩鲜艳或形态舒展奔放的特点，具有较大的园林应用潜力。如山鸡椒是先花后叶，在花期抽出很多新的枝条，花苞长满枝条，从抽花枝到开花时间相对短暂，花期在 2 ~ 3 月，黄白色的小花极具观赏价值；桃金娘的花则是桃红色，观赏价值高，且已在园林上得到应用。

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3.4.3　材用植物

材用植物是指其木材结构、性质优良，材质上乘，适用于建筑、船舶、家具、军工器材、胶合板、工艺品等方面的植物，是经济建设中的重要资源之一[23]。封开县林木种质资源中材用植物共45科73属110种，占总种数的28.95%。其中乔木有94种，占材用植物种类的85.45%，是材用树种的主要生活型，主要有樟（*Camphora officinarum* Nees）、阴香、浙江润楠、红锥（*Castanopsis hystrix* Hook. f. & Thomson ex A. DC.）、青冈（*Quercus glauca* Thunb.）等。

3.4.4　食用植物

食用植物概念多引自野生食用植物，其范畴较大，可以概括为一切可供人们直接或间接食用，同时对正常人的身体健康不造成威胁的植物[24-25]。封开县林木种质资源中食用植物共33科50属78种，占总种数的20.53%，如常见的余甘子（*Phyllanthus emblica* L.）、杨梅（*Morella rubra* Lour.）、岭南山竹子（*Garcinia oblongifolia* Champ. ex Benth.）等。

表5　封开县野生林木种质资源植物利用类型

Tab. 5　Plant utilization types of wild forest germplasm resources in Fengkai County

资源类型	科	科占比（%）	属	属占比（%）	种	种占比（%）
药用植物	69	83.13	161	77.03	248	65.26
观赏植物	52	62.65	96	45.93	174	45.79
材用植物	45	54.22	73	34.93	110	28.95
食用植物	33	39.76	50	23.92	78	20.53
纤维植物	21	25.30	33	15.79	44	11.58
油料植物	23	27.71	29	13.88	36	9.47
鞣料植物	20	24.10	29	13.88	35	9.21
淀粉植物	7	8.43	10	4.78	22	5.79
芳香植物	8	9.64	14	6.70	20	5.26
有毒植物	12	14.46	13	6.22	14	3.68
香料植物	7	8.43	8	3.83	10	2.63
染料植物	6	7.23	7	3.35	8	2.11
防火植物	5	6.02	5	2.39	6	1.58
蜜源植物	4	4.82	5	2.39	6	1.58
饲料植物	4	4.82	4	1.91	4	1.05
合计	361	–	537	–	814	–

注：部分植物有多种用途，故本表科、属、种总数超过实际数量。

3.4.5　纤维植物

纤维植物，依照《中国资源植物》一书是指可为人类提供纤维的植物，指植物体某一部分的纤维细胞特别发达，能够产生植物纤维并作为主要用途而被利用的植物，广泛地用做编织、造纸、纺织等行业的原材料[26-27]。封开县林木种质资源中纤维植物共21科33属44种，占总种数的11.58%，常见的有毛桐［*Mallotus barbatus*（Wall. ex Baill.）Müll. Arg.］、紫麻［*Oreocnide frutescens*（Thunb.）Miq.］、粉单竹（*Bambusa chungii* McClure）、构［*Broussonetia papyrifera*（L.）L'Hér. ex Vent.］等。

3.4.6　油料植物

油料植物包括草本油料植物和木本油料植物，是利用果实、种籽、根茎等部位中含有的大量蛋白质和脂肪，提取油脂供食用植物油或为化工行业、医药行业等提供原料的特殊植物种类[28]。封开县林木种质资源中油料植物共23科29属36种，占总种数的9.47%，如常见的乌榄（*Canarium pimela* K. D. Koenig）、南山茶（*Camellia semiserrata* C. W. Chi）、余甘子等。

3.4.7　鞣料植物

鞣料植物资源是指能制栲胶的富含单宁的植物资源。天然单宁，是一种具有鞣性的植物提取液，主要存在于植物的皮、木、叶、果中，是一种含量丰富的绿色可再生资源。我国鞣料资源丰富，栲胶含量高，达20%～40%，具有巨大的工业开发价值[29-30]。封开县林木种质资源中鞣料植物共20科29属35种，占总种数的9.21%，如常见的岭南山竹子、乌桕［*Triadica sebifera*（L.）Small］、野漆［*Toxicodendron succedaneum*（L.）Kuntze］、豺皮樟［*Litsea rotundifolia* var. *oblongifolia*（Nees）C. K. Allen］等。

3.4.8　淀粉植物

淀粉对植物生长发育极其重要，是人类赖以生存发展的主要食物来源之一，也是重要的工业原料。不同的淀粉植物含淀粉的主要部位及用途不尽相同。贵州野生淀粉植物含淀粉的部位主要集中在种子、果实、茎及根[31-32]。封开县林木种质资源中淀粉植物共7科10属22种，占总种数的5.79%。其中壳斗科植物最多，有15种，如常见的红锥、锥［*Castanopsis chinensis*（Spreng.）Hance］、黧蒴锥［*Castanopsis fissa*（Champ. ex Benth.）Rehder & E. H. Wilson］等。

3.4.9　芳香植物

目前，芳香植物没有明确的定义，通常以狭义和广义的概念进行解释，狭义上芳香植物是指可散发出香气和可供提取芳香油植物的总称；广义上是兼有药用植物和香料植物共有属性的植物类型，大

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多具有较高的观赏性[33]。本文对芳香植物的筛选采用狭义的概念，封开县林木种质资源中有阴香、香叶树（*Lindera communis* Hemsl）、栀子（*Gardenia jasminoides* J. Ellis）、岗松（*Baeckea frutescens* L.）等20种芳香植物，隶属于8科14属，占总种数的5.26%。

3.4.10　有毒植物

有毒植物指含有毒素的植物[34]，毒素可能存在于植物的根、茎、叶、果实、种子、汁液等部位中。封开县林木种质资源中有毒植物有钩吻［*Gelsemium elegans*（Gardner & Champ.）Benth.］、华马钱（*Strychnos cathayensis* Merr.）、伞花马钱［*Strychnos umbellata*（Lour.）Merr.］等14种，隶属于12科13属，占总种数的3.68%。

3.4.11　香料植物

香料植物指能分泌和积累具有芳香气味物质的一类植物。本文筛选的香料植物主要包括其叶子、果实、树皮或树干切片等可以用于调味或做工业香料的植物，主要包括八角（*Illicium verum* Hook. f.）、肉桂［*Cinnamomum cassia*（L.）D. Don］、蕈树［Altingia chinensis（Champ. ex Benth.）Oliv. ex Hance］等10种，隶属于7科8属，占总种数的2.63%。

3.4.12　染料植物

染料植物是指可在其器官中提取着色物质并且能够应用于工、农业生产的一类植物。广义上凡是含有着色物质的植物都可以称为染料植物，但是作为资源而言其具有可被利用（经济和生产价值）的含义，因此染料植物资源应是其中的着色物质含量足够高、染色牢度稳定、具有可开发的蕴藏量或可人工大规模栽培的一类植物资源[35]。封开县野生林木种质资源中染料植物有铁冬青、栀子、杨梅、秋枫（*Bischofia javanica* Blume）等8种，隶属于6科7属，占总种数的2.11%。

3.4.13　防火植物

防火植物主要是指短期内不易燃烧和阻止林火蔓延，具有抗火性和耐火性，可以用来营造防火林带的树种[36]。这些树种多为常绿阔叶树种，枝叶含水率高、含油脂量少，树叶多、叶大、叶厚，树枝粗壮、燃点高等[37]。封开县野生林木种质资源中防火植物有木荷（*Schima superba* Gardner & Champ.）、银木荷（*Schima argentea* E. Pritz.）、山杜英［*Elaeocarpus sylvestris*（Lour.）Poir.］、银柴［*Aporosa dioica*（Roxb.）Müll. Arg.］、花榈木、米槠［*Castanopsis carlesii*（Hemsl.）Hayata］6种，隶属于5科5属，占总种数的1.58%。其中木荷为防火林带常用树种，且已得到大面积的应用。

3.4.14　蜜源植物

根据柯贤港《蜜粉源植物学》一书，蜜源植物指具有蜜腺而且能分泌甜液并被蜜蜂采集酿造成蜂蜜的植物[38]。封开县野生林木种质资源中蜜源植物有细齿叶柃（*Eurya nitida* Korth.）、油茶（*Camellia oleifera* Abel）、南山茶、小果蔷薇（*Rosa cymosa* Tratt.）、网脉山龙眼（*Helicia reticulata* W. T. Wang）、土蜜树（*Bridelia tomentosa* Blume）6种，隶属于4科5属，占总种数的1.58%。

3.4.15　饲料植物

饲料植物指在动物饲养中作为饲料或草料的植物，按照获取的便捷程度从简单到复杂主要分三种程度的提取利用，分别是饲用植物干燥粉、饲用植物粗提物、饲用植物精粗提物[39]。封开县野生林木种质资源中饲料植物有青冈、苎麻［*Boehmeria nivea*（L.）Gaudich.］、锐尖山香圆［*Turpinia arguta*（Lindl.）Seem.］、八角枫［*Alangium chinense*（Lour.）Harms］4种，隶属于4科4属，占总种数的1.05%。

4　讨论

4.1　封开县野生林木种质资源组成

本次调查共记录广东省肇庆市封开县林木种质资源83科209属380种。植物类型中，被子植物比例最高，记录有81科207属377种，占总种数的99.21%。科级数量中，寡种科有47科，占比最高，达56.63%；寡种科和中等科所含种数占比达78.69%，是封开县林木种质资源的主要组成部分。在植物生活型划分中，乔木种数189种，灌木种数141种，合计占总种数的86.84%，是封开县野生林木种质资源中的优势生活型。

4.2　封开县野生林木种质资源植物区系特点

封开县自然条件优渥，充沛的水热条件孕育了丰富多彩的植物世界，促使植物区系分布多样化。封开县野生林木种质资源中，热带分布区类型（2～7型）共54科163属328种，分别占非世界广布类型科、属、种总数的81.82%、79.13%、87.70%，占绝对优势，进一步说明了封开县野生林木种质资源种区系以热带成分为主，与热带亚洲（印度–马来西亚）分布类型有着较深的联系。而温带分布区类型

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(8～14型)有12科42属31种,分别占非世界广布科、属、种总数的18.18%、20.39%、8.29%。封开县野生林木科、属、种地理分布型以热带型为主,逐渐向亚热带过渡,这与梁国华等[40]在肇庆鼎湖山自然保护区及林伟通等[41]在肇庆星湖湿地的研究结果相符。

4.3 封开县野生林木种质资源应用与保护建议

野生林木种质资源品种纯正且抗逆性强[42],但随着温室效应的加剧和农业生产开发的不断深入,野生林木面临着生存的威胁,为降低物种损失的风险,应加强对野生林木的保护,特别是蕴含重要利用价值和潜在价值的野生林木。本研究根据林木的应用类型,将封开县380种野生林木种质资源植物划分为药用、观赏、材用、食用等15个应用类型。其中存在一种植物拥有多方面应用价值,应结合生产实际,在保护物种的同时谋求更好的开发利用,从而提高封开县植物资源的经济效益和生态效益。在调研中发现已有部分物种用于经济种植且成为当地的特色经济作物,如肉桂、乌榄等,但也存在野生林木被过度采集的现象,如土茯苓(*Smilax glabra* Roxb.)等。建议当地相关部门加大对野生植物保护宣传力度,增强群众保护意识,对经济利用价值较高的物种采取相关的种植补贴举措,以提高当地野生林木的经济效益。

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Tree Physiology, 2024, **44**, tpad141
https://doi.org/10.1093/treephys/tpad141
Advance access publication date 6 December 2023
Research paper

Vein hierarchy mediates the 2D relationship between leaf size and drought tolerance across subtropical forest tree species

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Handling Editor: Frederick Meinzer

Previous studies have observed a 2D relationship (i.e. decoupled correlation) between leaf size (LS) and leaf economics as well as a tight correlation between leaf economics and drought tolerance. However, the underlying mechanism maintaining the relationship between LS and drought tolerance remains largely unknown. Here, we measured LS, water potential at 50% loss of hydraulic conductance, hydraulic safety margin and different orders of vein traits across 28 tree species in a subtropical forest in Southern China. We found that LS and drought tolerance were in two independent dimensions ($R^2 = 0.00$, $P > 0.05$). Primary and secondary vein traits (i.e. vein diameter and density) explained the variation of LS, with R^2 ranging from 0.37 to 0.70 (all Ps < 0.01), while minor vein traits accounted for the variation of leaf drought tolerance, with R^2 ranging from 0.30 to 0.43 (all Ps < 0.01). Our results provide insight into the 2D relationship between LS and drought tolerance and highlight the importance of vein hierarchy in plant leaf functioning.

Keywords: hydraulic safety margin, leaf function, minor vein, trait dimension, vein density.

Introduction

Leaf drought tolerance is crucial for plant survival, distribution and species composition in natural forests, particularly in the context of climate change (Bartlett et al. 2012, R. Li et al. 2015, Anderegg et al. 2016). Xylem embolism resistance thresholds, such as leaf water potential at 50% loss of hydraulic conductance (P_{50}) and hydraulic safety margin (HSM), represent the vulnerability of water transport system to drought-induced embolism (Choat et al. 2012, Urli et al. 2013). These two critical leaf drought tolerance traits are directly related to species death and fitness in the forest community (Adams et al. 2017, Choat et al. 2018). For example, recent studies showed that both P_{50} and HSM could influence the species' biogeographical distribution, and HSM was used to predict the risk of drought-induced tree mortality and biomass loss in Amazon forests (Liu et al. 2023, Tavares et al. 2023).

Various combinations among plant functional traits (i.e. multiple trait dimensions) enable species adaptations to heterogeneous resources and facilitate species coexistence (L. Li et al. 2015). Previous studies have shown that leaf drought tolerance traits, such as turgor loss point and xylem cavitation vulnerability, are closely related to leaf economics traits due to their shared link with leaf density (Zhu et al. 2018, Chen et al. 2021, Nadal et al. 2023). In principle, since leaf economics traits are correlated with leaf drought tolerance traits and vary in two dimensions (i.e. decoupled correlation) with leaf size (LS) (Díaz et al. 2016, Joswig et al. 2022), it is expected that LS would be associated with leaf drought tolerance in two dimensions. Alternatively, LS variation has been found to be associated with rainfall and temperature variation, with smaller-leaved species observed at dry, hot sites (Wright et al. 2017, Baird et al. 2021). In that sense, LS is related to drought tolerance. However, there have been few studies examining the relationship between LS and drought tolerance.

Leaf vein hierarchy represents a strategy of plant carbon allocation in different orders of veins and is crucial to the diversity of plant functions (Scoffoni et al. 2011, Sack and Scoffoni 2013). Some studies have found that primary and secondary vein traits, such as vein density and diameter, are associated with the leaf mechanical properties and LS. For example, species with higher primary and secondary vein densities showed smaller leaves, but higher leaf strength (Sack et al. 2012, Kawai and Okada 2016). Meanwhile, minor

Received: June 14, 2023. **Accepted:** December 1, 2023
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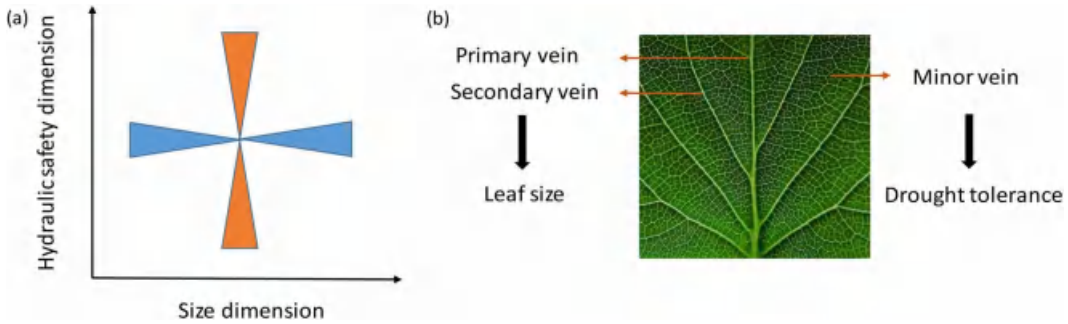


Figure 1. Conceptual framework for the 2D relationship between LS and drought tolerance and the determinants of this relationship. (a) The LS dimension and drought tolerance dimension are in two independent axes; (b) leaf vein hierarchy influence leaf functions. Primary and secondary veins affect LS, while minor vein affects leaf drought tolerance.

vein traits are related to leaf photosynthesis and hydraulic conductance. For instance, species with higher minor vein density had higher photosynthetic rate and hydraulic conductivity (Walls 2011, Scoffoni et al. 2016). However, other studies have reported somewhat different findings. For instance, minor vein traits, such as vein density, rather than primary and secondary vein traits, were found to be correlated with leaf mechanical properties across 58 species in a subtropical forest (Hua et al. 2020). Furthermore, leaf hydraulic conductance was correlated with primary vein traits, but not minor vein traits, across 44 species grown in common gardens (Sommerville et al. 2012). Therefore, the effects of vein hierarchy on leaf functions are not consistent across studies.

Despite considerable attention paid to the two dimensions between LS and leaf economics traits in previous studies (Bruelheide et al. 2018, Thomas et al. 2020, Joswig et al. 2022), there have been few studies that have simultaneously investigated the correlations between LS and drought tolerance traits and their underlying determinants. In this study, we examined leaf traits and their relationships in a sample of 28 dominant woody species from a subtropical evergreen forest in Southern China. We had two chief questions. (i) What is the relationship between LS and drought tolerance traits, such as P_{50} and HSM? As LS can be affected by various environmental factors, such as rainfall, temperature, light and nutrient conditions, whereas leaf drought tolerance traits are primarily shaped by the local water availability at a given site. In cases where LS is constrained by selection pressures unrelated to rainfall, the LS might be expected to vary independently from the leaf drought tolerance traits (Blackman et al. 2018; Figure 1a). (ii) How does vein hierarchy affect this relationship? Since LS is intricately connected to lower-order vein traits due to vein packing constraints during leaf development and for achieving an optimal leaf water transport efficiency (Sack et al. 2012), while the fatal acceleration of dehydration in plant leaves aligns with the occurrence of higher-order vein cavitation (Tonet et al. 2023), we hypothesized that primary and secondary vein traits, such as vein diameter (VD) and vein density, are tightly associated with LS, whereas minor vein traits are critical to leaf functions such as drought tolerance (Figure 1b).

Materials and methods

Study site

The study site is located within the Dinghushan Biosphere Reserve (23°09′ 21″–23°11′30″ N, 112°32′39″–112°35′41″ E) in Southern China. The region experiences a typical southern subtropical monsoon climate, with an annual average precipitation of 1678 mm. Around 80% of this precipitation falls from April to September, resulting in a distinct seasonality of precipitation (Zhou et al. 2011). The mean annual temperature is 21.4 °C, and monthly temperatures range from 12.6 °C in January to 28.0 °C in July (He et al. 2022). The plot's altitude ranges from 230 to 470 m, and the soil is primarily composed of lateritic red and mountain yellow brown soil. The dominant families in this forest are Fagaceae, Lauraceae and *Myrtaceae*, with the most prevalent species being *Castanopsis chinensis*, *Schima superba*, *Cryptocarya chinensis* and *Syzygium levinei* (Zhu et al. 2013, He et al. 2019). We selected 28 dominant tree species from this forest, which exhibited a wide variation in LS (Table 1).

Leaf size

Fifty fully expanded and healthy sun leaves were selected from five individuals of each species, with ~10 leaves per individual. The sun leaves were sampled from the top of the forest canopy. After removing the leaf petioles and/or rachis, we measured the LS (cm^2) using a leaf area meter (Li-3000A, Li-Cor, USA).

Hydraulic safety traits

Five to 10 terminal branches were sampled from each species during dusk. The branches were carefully sealed in black plastic bags, which contained moist towels, and were immediately transported to the laboratory. Once in the laboratory, the cut ends of the branches were recut under ultrapure water, and they were left in water overnight. To facilitate rehydration, the branches were covered with a plastic bag that contained wet towels. The following morning, one leaf each from the base and apex of the branches was selected for leaf water potential measurements using a pressure chamber (Plant Moisture Stress, Corvallis, OR, USA). For each species, the study used 5–10 rehydrated branches to measure the leaf hydraulic conductance (K_{leaf}). The evaporative flux method, as described by Sack and Scoffoni (2012), was used to measure K_{leaf}. A stable leaf transpiration rate (E, mmol m^{-2} s^{-1}) was recorded under an illuminance of 1200 μmol m^{-2} s^{-1} and a room temperature of 28 °C. Subsequently, the leaf was sealed in a previously evacuated bag for a minimum of 20 min to achieve water potential equilibrium. The final leaf water potential (Ψ_{leaf}, MPa) was measured using a pressure chamber, and K_{leaf} (mmol m^{-2} s^{-1} MPa^{-1}) was calculated as the ratio of E to the absolute value of Ψ_{leaf}. All K_{leaf}

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Table 1. Description of traits measured for all species in this study.

Traits	Code	Unit	Min	Max	Mean	CV
Leaf size	LS	cm^2	12.38	173.96	45.55	89.46
Water potential at xylem conductivity loss 50%	P_{50}	MPa	−4.42	−1.61	−2.98	26.82
Hydraulic safety margin	HSM	MPa	0.85	4.02	2.22	39.00
Primary vein diameter	1° VD	mm	0.41	1.78	0.93	43.63
Primary vein density	1° VLA	mm mm^{-2}	0.01	0.07	0.04	42.85
Secondary vein diameter	2° VD	mm	0.11	1.07	0.27	74.12
Secondary vein density	2° VLA	mm mm^{-2}	0.06	0.75	0.17	76.71
Minor vein diameter	VD_{min}	mm	0.01	0.05	0.03	40.26
Minor vein density	VLA_{min}	mm mm^{-2}	2.10	8.03	4.65	29.98
Leaf force to tear	F_t	kN m^{-1}	0.12	1.11	0.45	46.06
Specific tearing strength	F_t/LMA	N g^{-1} m	2.39	10.18	5.82	36.11

Min, minimum value; Max, maximum value; Mean, mean value; CV, coefficient of variation.

values were standardized to 25 °C to account for water viscosity. The study used leaf water potential at 50% loss of maximum hydraulic conductance (P_{50}, MPa) to estimate the leaves' vulnerability to hydraulic dysfunction, following the method described by Sack and Scoffoni (2012). A minimum of 30 leaves were employed to assess the relationship between K_{leaf} and the declining leaf water potential. In case of severely dehydrated leaves, an initial high flow rate was observed, which gradually decreased until reaching a stable state, a process that took a minimum of 30 min. The flow rate during this steady phase was utilized to calculate leaf transpiration rate. The response of K_{leaf} to declining leaf water potential was determined for each species, and the leaf vulnerability curves were plotted and fitted (Figure S1 available as Supplementary data at *Tree Physiology* Online).

To measure the midday leaf water potential (Ψ_{md}), representative sunny days were selected between 12:00 h and 14:00 h from mid-wet to mid-dry seasons. We removed the sun-mature leaves from canopy branches, immediately sealed them in bags and stored them in darkness for a minimum of 20 min to achieve water potential equilibration, prior to measuring their water potential. The lowest values during the measurement period were used to determine the minimum leaf water potential (Ψ_{min}). The leaf HSM (MPa) was then calculated using the formula: $HSM = \Psi_{min} - P_{50}$ (Zhu et al. 2019).

Vein traits

In this study, we assessed two leaf vein traits: VD (mm) and vein density (VLA, mm mm^{-2}). This part of data and the data of leaf mechanical strength (F_t, kN m^{-1}) were from our published studies (He et al. 2019, Hua et al. 2020). To determine these traits, we selected five leaves per species from five individuals and scanned them using a CanoScan LiDE 100 scanner (Canon, Tokyo, Japan) to determine the total length of the 1° and 2° vein per leaf. The diameter of the 1° vein (1° VD, mm) was measured from the central part of the mid-vein for each leaf. For the 22° VD (mm), we selected two secondary veins from the top, middle and bottom of the leaves and measured their diameters centrally, averaging all the measurements.

Following this, three rectangular sections (at least 1 cm^2) located at the top, middle and bottom of the same leaves were obtained. These sections were soaked in a 5% w/v $NaOH/H_2O$ solution for 2–10 days, depending on the species. The leaves were then rinsed in water and soaked in a commercial bleach solution (6% w/v $NaClO/H_2O$) for ∼15 min. After a second rinse in water, the leaves were stained with a 1% w/v safranin/ethanol solution for 10 min and were kept for 20 min in 100% ethanol before being returned to water for imaging. The sections were rescanned, and an optical microscope with a digital camera (Leica ICC50 W) was used to capture images of each section for minor vein trait measurements. The magnification is 100, and three fields of view for each leaf (i.e. 15 fields of view in total for each species) were measured. For each vein order, vein density was calculated as vein length divided by leaf area (Scoffoni et al. 2011).

Statistical analyses

All traits, except for P_{50} and HSM, were log_{10}-transformed to satisfy the assumptions of normality and homogeneity of residuals (Kerkhoff and Enquist 2009). The relationships between pairs of traits were investigated using Pearson's correlation and linear regression, with a significance level of $P < 0.05$. Analyses were conducted using R software (version 4.3.0, R Core Team 2018). Multivariate associations among all traits were analyzed using principal component analysis (PCA) with the SPSS version 22.0 software package (SPSS, Chicago, IL, USA).

Results

As expected, we found no significant correlation between LS and either P_{50} ($R^2 = 0.001$, $P = 0.882$; Figure 2a) or HSM ($R^2 = 0.001$, $P = 0.847$; Figure 2b) across the studied species. The results showed that LS had a significant correlation with both primary and secondary vein traits (all Ps < 0.001; Figure 3a–d). Specifically, LS was found to be positively correlated with 1° VD ($R^2 = 0.413$; Figure 3a) and 2° VD ($R^2 = 0.366$; Figure 3c), while it was found to be negatively correlated with 1° VLA ($R^2 = 0.696$; Figure 3b) and 2° VLA ($R^2 = 0.528$; Figure 3d). However, LS was unrelated to the diameter and density of minor veins (all Ps > 0.05; Table 2).

By contrast, the leaf drought tolerance traits were significantly correlated with minor vein traits (all Ps < 0.01; Figure 4a–d). Specifically, P_{50} was negatively correlated with VD_{min} ($R^2 = 0.425$, $P < 0.001$; Figure 4a), and it was positively correlated with VLA_{min} ($R^2 = 0.410$, $P < 0.001$; Figure 4b). The HSM was positively correlated with VD_{min} ($R^2 = 0.374$; Figure 4c), and it was negatively correlated with VLA_{min} ($R^2 = 0.300$, $P = 0.003$; Figure 4d). However, both

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Table 2. Pearson's correlations among plant functional traits for all species.

	LS	P_{50}	HSM	1° VD	1° VLA	2° VD	2° VLA	VD_{min}
P_{50}	0.03							
HSM	0.04	**−0.95*****						
1° VD	**0.64*****	−0.12	0.11					
1° VLA	**−0.84*****	−0.18	0.12	**−0.72*****				
2° VD	**0.61*****	0.33	−0.23	**0.42***	**−0.61*****			
2° VLA	**−0.73*****	−0.34	0.32	**−0.51****	**0.79*****	**−0.46***		
VD_{min}	−0.06	**−0.65*****	**0.61*****	0.31	0.11	−0.05	0.31	
VLA_{min}	0.01	**−0.64*****	**−0.55***	−0.21	−0.12	**0.43***	−0.13	**−0.62*****

Correlation coefficients are given lower left of the diagonal. Bold indicates significant correlation. Trait abbreviations are the same as those mentioned as in Table 1. Values of LS and vein traits were log-transformed. $^{*}P < 0.05$. $^{**}P < 0.01$. $^{***}P < 0.001$.

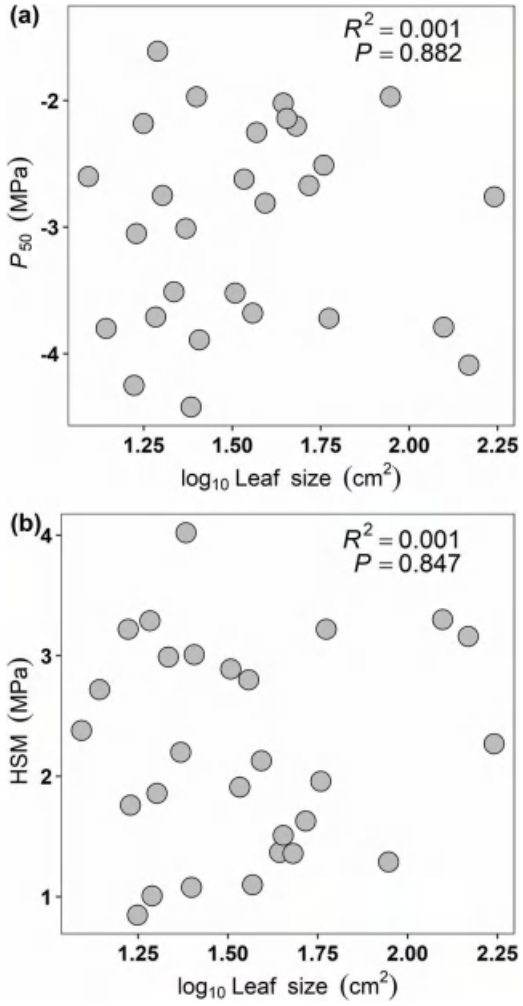


Figure 2. Relationships between LS and drought tolerance traits. (a) The LS and P_{50}; (b) LS and HSM. The R^2 and P-values are reported. Trait abbreviations are the same as those mentioned in Table 1.

P_{50} and HSM were non-significantly correlated with primary and secondary vein traits (all Ps > 0.05; Table 2).

The association of nine traits across the 28 species was evaluated with a PCA. The first axis of the PCA accounted for 43% of the variation in plant traits, while the second axis accounted for 33% of the variation (Figure 5). Two independent dimensions of trait variation stand out clearly within this plane. One dimension (lower left to upper right in Figure 5, more strongly associated with PC1 than PC2) runs from small LS species tending to have higher 1° VLA and 2° VLA to large LS species tending to have wider 1° VD and 2° VD. The other (upper left to lower right in Figure 5, more strongly associated with PC2 than PC1) runs from drought-tolerant species with wider VD_{min} to drought-vulnerability species with higher VLA_{min} (Figure 5; Table S1 available as Supplementary data at *Tree Physiology* Online).

Discussion

We conducted an analysis of the relationship between LS and drought tolerance across 28 dominant subtropical woody species and examined the impact of various vein traits on this relationship. Our findings indicate that LS and drought tolerance vary independently in this forest ecosystem. Additionally, we observed that the primary and secondary vein traits, specifically VD and density, were more strongly correlated with LS than the minor vein traits. Conversely, minor vein traits were found to significantly influence leaf drought tolerance traits, while primary and secondary veins had no significant impact.

Decoupled relationship between LS and drought tolerance

We first asked whether LS and drought tolerance varied independently with each other. Our results confirmed our expectation that LS was not associated with drought tolerance (Figure 2a and b) and that LS and drought tolerance were independent dimensions (Figure 5). These findings indicated that, within a given site, LS was not a predictor of leaf drought tolerance even though, 'globally', species with smaller leaves tend to grow at drier sites (Wright et al. 2017, Baird et al. 2021). These results were consistent with a study that investigated five genotypes from 4 coffee species (Mauri et al. 2020), yet these were inconsistent with a study of 10 species sampled in university campus and park, which found that smaller leaves were more tolerant of embolism (Scoffoni et al. 2011). The independent relationship between LS and drought tolerance may be explained by the vein hierarchy, as shown in our results (Figures 3–5). This finding may be advantageous for species as follows.

First, multiple trait dimensions are critical to plant growth, survival and reproduction (Díaz et al. 2016). These trait dimensions can enhance species adaptations to diverse niche conditions, facilitate a variety of plant strategies and promote species coexistence (L. Li et al. 2015, He et al. 2019). For instance, drought tolerance traits play a crucial role in species survival during drought stress, while LS is essential in capturing light, particularly for species inhabiting forest understories. The decoupled relationship between LS and drought tolerance allows for flexibility in LS without affecting drought tolerance.

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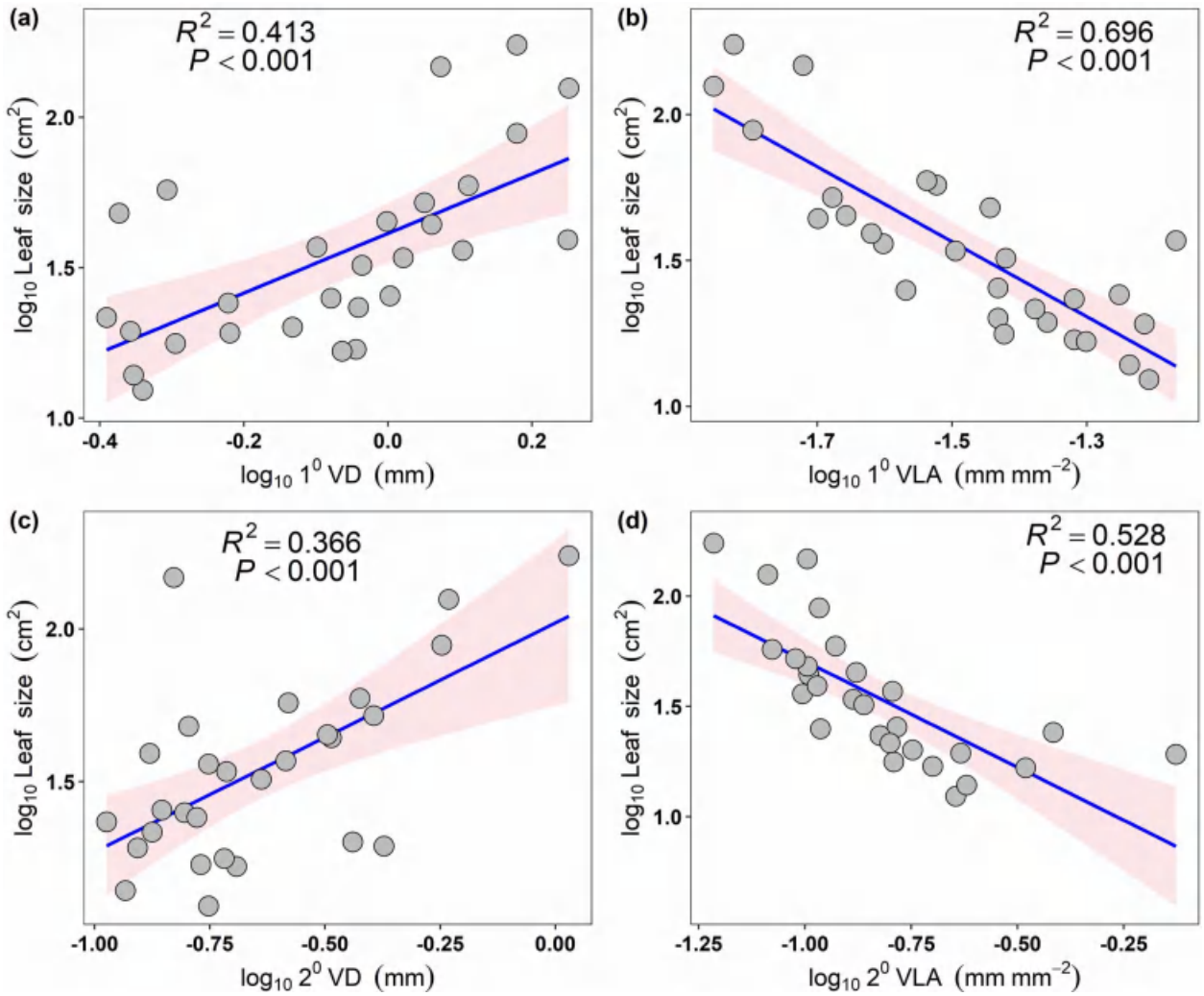


Figure 3. Relationships between LS and lower-order vein traits. (a) The LS and 1° VD; (b) LS and 1° VLA; (c) LS and 2° VD; and (d) LS and 2° VLA. Shaded areas indicate confidence intervals. The R^2 and *P*-values are reported. Trait abbreviations are the same as those mentioned in Table 1.

Second, the independent relationships among traits have the potential to influence species' responses to climate change. The shifts in climate may limit certain combinations of traits while allowing others to vary more freely (Joswig et al. 2022, Thomas 2022). For example, as droughts are predicted to increase in duration and severity (Sheffield and Wood 2008, Klein and Hartmann 2018), the leaf drought tolerance traits may shift accordingly, while LS may remain constant, thereby avoiding carbon cost in constructing LS. For subtropical forests, such as the one in this study, which are threatened by the changes in rainfall patterns, resulting in an increased number of rain-free days and reduced soil water content (Zhou et al. 2011), the independent relationships between drought tolerance traits and other traits may benefit the species living in this forest.

Primary and secondary veins affect LS

Our second question concerned how vein hierarchy explained the relationship between LS and drought tolerance. Our findings revealed that the diameter of primary and secondary veins (i.e. lower-order veins) was positively correlated with LS (Figures 3), while lower-order vein density was negatively correlated with LS (Figure 3). These results are consistent with previous studies (Sack et al. 2012, Scoffoni et al. 2011, Mauri et al. 2020).

There are two possible interpretations for these results. First, larger leaves may require larger lower-order veins for biomechanical support, which would arise from the linked development of lower-order veins and LS (Sack et al. 2012). Robust leaf structures are necessary to mechanically support photosynthetic tissues as leaves increase in surface area (Niklas 1999), and the cells of the primary and secondary veins contain a substantially higher proportion of sclerenchyma, collenchyma and fibers, all of which are lignin-rich around the vascular bundle. These properties contribute to efficient biomechanical support (Kawai and Okada 2016). Our data also supported that species with larger veins had higher leaf mechanical strength both on leaf area and mass basis (Table S2 available as Supplementary data at *Tree Physiology* Online). Second, leaves that develop a substantial vascular system can maintain hydraulic supply for stomatal conductance to water and the transport of photosynthate (Brodribb et al. 2007, Murphy et al. 2014). Lower-order veins have high axial conductance and relatively small radial permeability, allowing water to reach distal areas of the leaf

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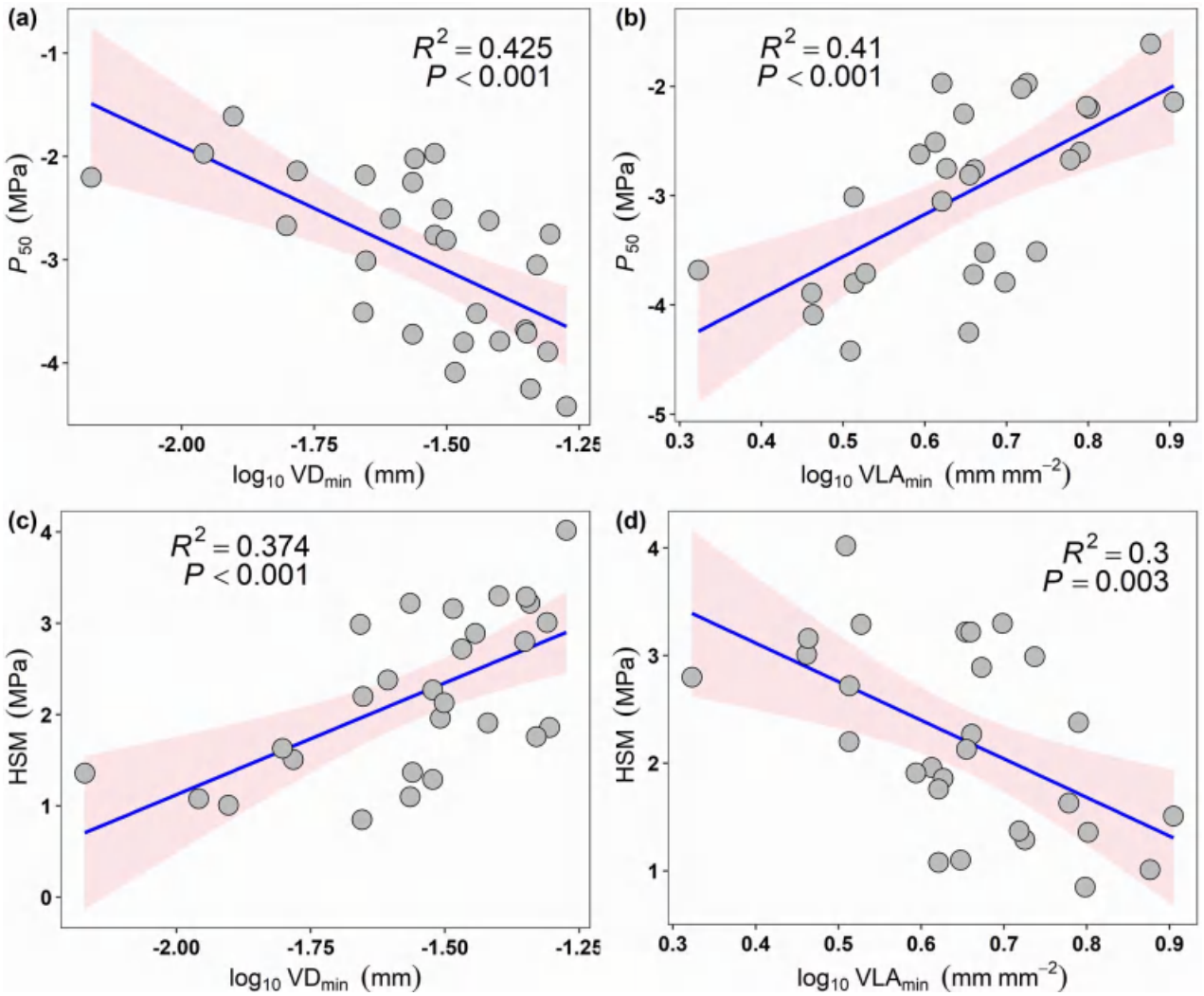


Figure 4. Relationships between leaf drought tolerance traits and minor vein traits. (a) The P_{50} and VD$_{min}$; (b) P_{50} and VLA$_{min}$; (c) HSM and VD$_{min}$; and (d) HSM and VLA$_{min}$. Shaded areas indicate confidence intervals. The R^2 and *P*-values are reported. Trait abbreviations are the same as those mentioned in Table 1.

with only a small loss of water potential (Zwieniecki et al. 2002).

We found that minor VD and density were independent of LS (Table 2), which is consistent with previous studies conducted at local and global scales (Sack et al. 2012, Scoffoni et al. 2011, Mauri et al. 2020). This could be due to the fact that leaf minor veins occupy a relatively smaller volume within the lamina and thus play a smaller role in leaf support (Sack and Scoffoni 2013). Additionally, minor veins lack rigid cells around the vascular bundle, and their cell walls are thinner, containing lower amounts of lignin and cellulose to compose conduits (Kawai and Okada 2016). These anatomical and chemical properties of minor veins are more adapted to distribute water to the mesophyll and stomata for photosynthesis rather than providing support to the leaf (Zwieniecki et al. 2002). Indeed, our data also showed that there were significant correlations between minor vein traits and leaf hydraulic properties (Table S3 available as Supplementary data at *Tree Physiology* Online), including leaf hydraulic conductance (K_{leaf}), leaf xylem hydraulic conductance ($K_{leaf\text{-}x}$) and leaf outside-xylem hydraulic conductance ($K_{leaf\text{-}ox}$).

Minor vein affects leaf drought tolerance

We found that minor VD was significantly and negatively correlated with P_{50} and was positively correlated with HSM (Figure 4a and c), while the minor vein density was significantly and positively correlated with P_{50} and was negatively correlated with HSM (Figure 4b and d). This suggests that leaves with wider minor VD and higher minor vein density were more tolerant of embolism. Previous studies have also shown that higher-order vein traits (e.g. the ratio of xylem conduit wall thickness to lumen breadth) tend to be more related to hydraulic resistance than lower-order veins (Zwieniecki et al. 2002, Blackman et al. 2010). However, many studies have found that minor vein traits (e.g. minor vein density) do not correlate with leaf hydraulic resistance or hydraulic conductance (Sommerville et al. 2012, Caringella et al. 2015, Mauri et al. 2020).

We found that primary and secondary vein traits were not correlated with leaf drought tolerance, which suggests that these veins may not play a significant role in the drought tolerance of the species studied (Table 2). However, this finding is inconsistent with a study conducted across eight species in

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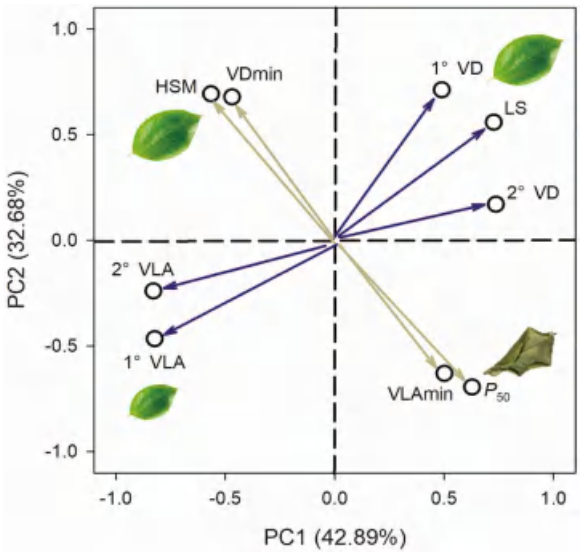


Figure 5. The PCA for plant functional traits for the first two axes. Trait abbreviations are the same as those mentioned in as in Table 1.

a university campus and park (Scoffoni et al. 2017), which found that the decline of leaf xylem hydraulic conductance during dehydration was driven by embolism initiating in petioles and primary veins and that xylem vulnerability was strongly correlated with petiole and primary vein conduits.

Our results may be interpreted in three ways. First, minor veins play a more significant role in determining leaf hydraulics than primary and secondary veins, as they provide more water-flow pathways and are less prone to drought damage (Brodribb et al. 2007, McKown et al. 2010). On the other hand, primary and secondary veins are more structurally reinforced by surrounding fibers, making them more susceptible to cavitation than collapse (Blackman et al. 2010). Second, runaway cavitation triggered by the failure in the minor vein network is the critical factor determining the vulnerability of plant leaves to damage during drought. The initial stages of cavitation occurring in the midrib and major veins are unlikely to disrupt water delivery significantly. This is due to the substantial redundancy present in the larger veins. Even when up to 50% of these larger veins become cavitated, the water transport capacity to the mesophyll remains sufficient. However, a consequence of cavitation in the minor veins during water stress is the gradual severing of the local water supply to specific leaf regions, resulting in rapid desiccation and damage to downstream photosynthetic tissue (Sack et al. 2008, Tonet et al. 2023). Lastly, it has been reported that minor VD is determined by the vessel wall thickness and lumen breadth and that the conduit reinforcement such as vessel wall thickening could provide a degree of safety from vessel collapse under tension (Blackman et al. 2010, 2018). Therefore, it is plausible that hydraulic safety increases with minor VD.

Conclusion

Our work has made a significant progress in elucidating the physiological mechanisms underpinning the relationship between LS and drought tolerance. By identifying minor veins as the key determinants of leaf drought tolerance and lower-order veins as the key determinants of LS, we have shed light on an aspect of this relationship that has previously been poorly understood. Moving forward, using a linear mixed-effects model, including within-species data, would be helpful to further identify the correlations between the leaf structure and function (Isasa et al. 2023). Moreover, the inclusion of natural biomes, such as grasslands, tundra and deserts, into these efforts will improve our understanding of LS–drought tolerance linkages and ultimately enhance our ability to predict the plant's form and function in the face of climate change.

Acknowledgments

We are grateful to the Editor and reviewers for their constructive suggestions and comments on an earlier version of this manuscript. We thank Ian J. Wright for his comments on this manuscript and Xiaorong Liu for her help on plant trait measurements.

Supplementary data

Supplementary data for this article are available at *Tree Physiology* Online.

Conflict of interest

None declared.

Funding

This work was funded by the National Natural Science Foundation of China (32001106 and 32371641).

Authors' contributions

P.H., Q.Y. and X.Q. conceived the idea. P.H. analyzed the data. P.H., L.H., Q.L. and S.Z. carried out plant trait measurements. P.H. and Q.Y. wrote the initial manuscript. H.L., X.Q., Q.N. and Q.H. contributed to revisions.

Data availability statement

The data that support the findings of this study are not currently provided. Upon acceptance, data will be provided in Zenodo repository.

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检索证明

根据委托人提供的论文材料，委托人华南农业大学林学与风景园林学院 秦新生 7篇论文收录情况如下表。

序号	论文名称	发表刊物及发表的年月卷期/页码等	作者排名	论文等级	作者文中单位	收录情况	影响因子	中科院大类分区
1	Delineating the Area for Sustainable Cultivation of Morinda officinalis Based on the MaxEnt Model	AGRONOMY-BASEL 出版年：2024 出版日期：JUN 卷期：14 6 页码：- 文献号：1134 文献类型：Article	通讯作者	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=3.4 IF5-year=3.8 （2024）	农林科学 2区 Top期刊：否 （2025）
2	Research progress on Brassicaceae plants: a bibliometrics analysis	FRONTIERS IN PLANT SCIENCE 出版年：2024 出版日期：JAN 31 卷期：15 页码：- 文献号：1285050 文献类型：Review	通讯作者	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=4.8 IF5-year=5.7 （2024）	生物学 2区 Top期刊：否 （2025）
3	Ophioglossum hongii (Ophioglossaceae), a new species from Xizang, China	PHYTOTAXA 出版年：2024 出版日期：DEC 10 卷期：676 2 页码：169-180	共同通讯作者(倒数第一)	B类	华南农业大学林学与风景园林学院	SCI	IF2-year=1.0 IF5-year=1.0 （2024）	生物学 4区 Top期刊：否 （2025）
6	Vein hierarchy mediates the 2D relationship between leaf size and drought tolerance across subtropical forest tree species	TREE PHYSIOLOGY 出版年：2024 出版日期：FEB 6 卷期：44 1 页码：- 文献类型：Article	共同通讯作者（倒数第一）	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=3.7 IF5-year=4.1 （2024）	农林科学 2区 Top期刊：是 （2025）
7	Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in Phyllostachys propinqua McClure across Northern China	FORESTS 出版年：2023 出版日期：NOV 卷期：14 11 页码：- 文献号：2243	共同通讯作者（倒数第一）	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=2.4 IF5-year=2.7 （2023）	农林科学 2区 Top期刊：否 （2023）

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Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in *Phyllostachys propinqua* McClure across Northern China

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Abstract: Spatial patterns of leaf carbon (C), nitrogen (N), and phosphorus (P) stoichiometry play a pivotal role in the comprehension of terrestrial ecosystem dynamics, nutrient cycling, in responses to contemporary global climate change, and the evolutionary trajectories of leaf morphology and function. These patterns are not only solely shaped by plant and community composition, but also are profoundly influenced by environmental factors. Therefore, there is a compelling need for an in-depth investigation into individual species to discern the intricate impacts of soil and climate on leaf stoichiometry. In this study, we assessed the C, N, and P concentrations of mature leaves from 20 *Phyllostachys propinqua* populations in the urban forest across northern China covering a substantial latitudinal gradient. Our findings revealed that the average leaf concentrations of C, N, and P in *P. propinqua* were recorded at 0.46 g g^{-1}, 23.19 mg g^{-1}, and 1.40 mg g^{-1}, respectively. Notably, we observed that leaf C and P concentrations, as well as the C:N ratios, exhibited significant increases with rising latitude. Conversely, leaf N concentrations and N:P ratios exhibited a marked decline with increasing latitude. These patterns were primarily driven by climate factors such as mean annual temperature (MAT) and lowest temperature (LT). In contrast, we found that only leaf C concentrations were correlated with soil N levels. These results underscored the differential spatial distribution of leaf C, N, and P stoichiometry in urban forest across northern China, predominantly instigated by climatic factors, particularly in regions characterized by lower temperatures. Our findings further suggest that *P. propinqua* enhances its adaptability to low-temperature environments by elevating leaf C and P concentrations.

Keywords: bamboo; spatial pattern; climate factors; plant nutrient; urban forest

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Citation: Chen, L.; Li, L.; Pei, N.; Zhu, L.; Li, S.; Li, X.; Zhang, X.; Li, J.; Huang, B.; Qin, X. Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in *Phyllostachys propinqua* McClure across Northern China. *Forests* **2023**, *14*, 2243. https://doi.org/10.3390/f14112243

Academic Editor: Surendra Pratap Singh

Received: 18 October 2023
Revised: 6 November 2023
Accepted: 9 November 2023
Published: 14 November 2023

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1. Introduction

Carbon, nitrogen, and phosphorus represent fundamental plant nutrients that profoundly influence plant nutrient use efficiency, growth, and nutrient limitations [1–4]. These elements also serve as indicators of a plant's adaptive capacity in response to global climate change [5–8]. Previous studies have primarily examined plant stoichiometry at the community level in various terrestrial ecosystems, focusing on how changes in plant stoichiometry at the tree and shrub layers reflect shifts in ecosystem structure and function [9–11]; the differential responses of individual plant species to environmental changes have become increasingly evident [12]. Consequently, there is a growing need to

investigate species-specific changes in stoichiometry to capture their unique responses and adaptations to environmental shifts [13–15].

Leaves are the fundamental structural and functional units of plants and the primary sites for energy absorption and nutrient utilization [16–18], and they play a pivotal role in understanding terrestrial ecosystem dynamics, nutrient cycling, responses to contemporary global climate change, and the evolutionary paths of leaf morphology and function [19,20]. While stoichiometric homeostasis theory posits that plant species can maintain consistent levels of nitrogen (N) and phosphorus (P) in their leaves [21,22], emerging evidence suggests that C, N, and P stoichiometry, as well as their ratios, are influenced by a combination of phylogenetic, genetic [23–25], and environmental factors [7,26,27]. Notably, environmental factors may exert a more substantial impact on stoichiometric traits than phylogeny [28,29]. Understanding the relationships between leaf traits and the environment is instrumental in predicting how environmental shifts affect plant life. It is essential to recognize that plant leaf stoichiometry is sensitive to variations in latitude, longitude, and altitudes, as these shifts involve changes in both soil and climatic factors [30–32].

On a global scale, nutrient distribution in soils is uneven, with P often limiting plant growth in older tropical soils and N serving as the primary limiting nutrient in younger temperate and high-latitude soils [27], and this pattern also holds true in China [33,34]. The disparities and efficiency of nitrogen and phosphorus supply in soils have a marked impact on plant C, N, and P stoichiometry [35,36]. Therefore, N and P ecological stoichiometry, nutrient uptake, or their interactions are widely used to identify nutrient limitation and distribution in plants [37–39]. However, most studies of plant nutrient limitation at regional or larger scales have focused on the community level [27,37], and thus correlations between soil and leaf stoichiometry have been analyzed at the species and genus levels.

Among climatic factors, temperature and precipitation significantly influence plant stoichiometry [37,40,41]. Nonetheless, studies have yielded conflicting results concerning the effects of temperature and precipitation on plant stoichiometry. Some research suggests that increased water deficit may reduce nutrient uptake and transport by plants, thereby decreasing leaf N and P stoichiometry [42–44]. However, in arid environments, heightened plant physiological activity is observed to maintain water availability, conversely [32,45] resulting in increased N and P concentrations [40,46]. For temperature, the temperature–plant physiological hypothesis posits that plants boost nutrient concentrations to compensate for metabolic inefficiency at low temperatures, leading to elevated N and P concentrations in plant leaves under cold conditions [27,47]. Similar results were found in studies of global terrestrial plants and the leaves of 753 terrestrial plant species in China [33]. However, it has also been argued that low-temperature environments reduce plant physiological activity and their demand for N and P, with increased temperatures leading to the opposite effect [48]. Therefore, investigating plant stoichiometry under changing climatic conditions is pivotal for a more nuanced understanding of plant adaptations to the environment.

Bamboo, a widespread and ecologically significant forest taxon, occupying approximately 31.5 million hectares or 0.8% of the global forest area [49,50], is primarily distributed in tropical and subtropical regions [51]. Some bamboo species, including *Phyllostachys propinqua*, have been introduced to northern China urban forest for their ornamental, ecological, and economic value, making them integral to urban park landscapes [52,53]. Despite their benefits, some *P. propinqua* exhibit poor growth, such as yellowing and desiccation, during widespread cultivation. Therefore, this study investigates the spatial patterns of C, N, and P stoichiometry in *P. propinqua* leaves and their relationships with environmental factors, including climate, soil, latitude, and longitude, to address the following objectives: 1. To determine the spatial patterns of C, N, and P stoichiometry in *P. propinqua* leaves; 2. To assess the impacts of major environmental variables on C, N, and P stoichiometry in *P. propinqua*; 3. To establish associations between C, N, and P stoichiometry in *P. propinqua* and its adaptation to the environment of urban forest in northern China. The study of fully grown sympatric populations across multiple geographical gradients facilitates a more comprehensive understanding of plant adaptation to environmental shifts.

2. Materials and Methods

2.1. Study Area

This study encompassed five provinces in northern China (Figure 1). These provinces are the primary regions for *P. propinqua* cultivation, extensively employed in urban and rural greening initiatives [53]. The study area extended from approximately 110.92 to 121.46° E longitude and 34.81 to 40.91° N latitude, with altitudes ranging from 3 to 788 m. The prevailing climate is characterized by a temperate monsoon climate, featuring a mean annual precipitation (MAP) ranging from 418.82 to 666.5 mm and a mean annual temperature (MAT) varying from 9.00 to 15.40 °C. (Table 1). Soil types in the area are primarily Fluvisols in the WRB system, with sparse understory vegetation.

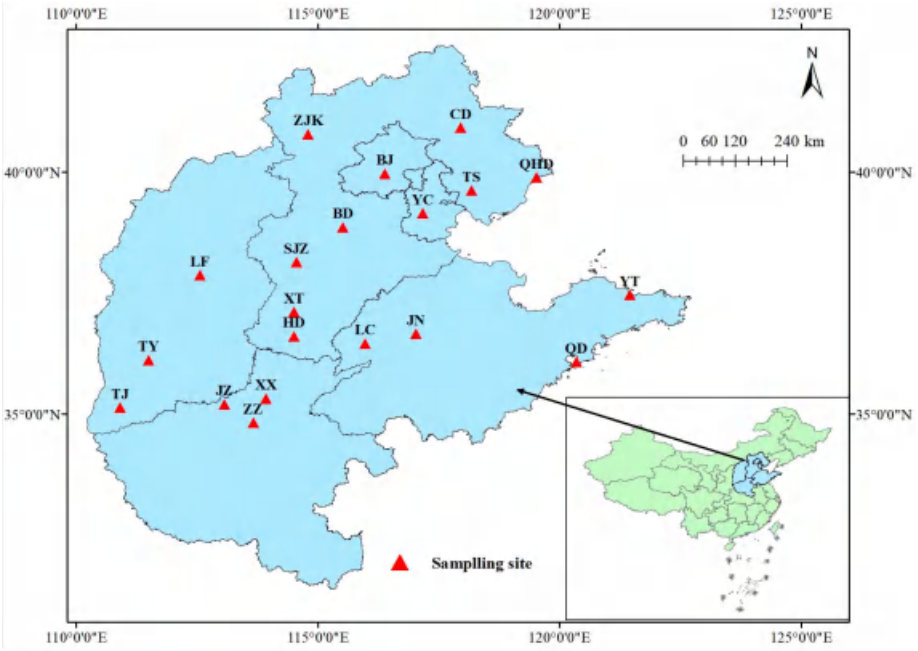


Figure 1. Distribution of sampling sites of *P. propinqua* sites. The identification letters of locations are found in Table 1.

Table 1. Location and climate conditions of sampled stands.

Site	LON (°)	LAT (°)	ALT (m)	MAT (°C)	LT (°C)	MAP (mm)	AE (mm)	AI	AQC	NHS (h)
QD	120.35	36.07	52.00	13.30	−15.10	666.50	1612.00	2.42	3.66	2550.70
QHD	119.53	39.88	5.00	11.60	−13.40	610.50	1800.70	2.95	4.25	2590.20
TY	111.51	36.10	432.00	13.80	−17.00	453.75	1798.20	3.96	5.24	2460.00
LC	115.98	36.45	34.00	13.70	−18.80	573.85	1882.00	3.28	4.39	2567.00
CD	117.96	40.91	308.00	9.00	−27.00	533.33	1466.10	2.75	3.80	2411.20
TS	118.18	39.61	12.00	12.10	−25.50	564.21	1852.20	3.28	5.00	2352.90
XX	113.93	35.31	70.00	15.10	−13.10	594.58	1908.70	3.21	4.80	2460.00
BJ	116.39	39.96	46.00	12.90	−19.40	537.62	1842.20	3.43	3.64	2502.00
HD	114.51	36.60	59.00	14.70	−16.10	503.91	1997.50	3.96	4.81	2557.00
JZ	113.07	35.19	132.00	15.30	−12.90	536.84	2006.30	3.74	4.80	2484.00
TJ	110.92	35.12	391.00	14.50	−15.30	485.26	1779.50	3.67	4.50	2521.80
ZZ	113.68	34.81	89.00	15.40	−14.30	619.38	1476.20	2.38	4.43	2400.00
YC	117.18	39.14	3.00	13.30	−16.10	534.00	2134.50	4.00	4.32	2630.00
LF	112.57	37.86	788.00	10.90	−23.30	440.59	2043.00	4.64	5.12	2353.90
SJZ	114.57	38.13	73.00	14.30	−15.80	503.33	1681.40	3.34	4.89	2412.00
XT	114.51	37.10	67.00	14.60	−13.40	507.27	1862.40	3.67	4.73	2305.40

Table 1. *Cont.*

Site	LON (°)	LAT (°)	ALT (m)	MAT (°C)	LT (°C)	MAP (mm)	AE (mm)	AI	AQC	NHS (h)
ZJK	114.80	40.78	724.00	9.30	−25.80	418.82	1983.00	4.73	3.10	2667.40
YT	121.46	37.45	6.00	13.00	−14.40	617.00	1927.90	3.12	3.58	2488.90
BD	115.52	38.85	14.00	13.30	−18.30	498.75	1747.50	3.50	4.80	2511.00
JN	117.04	36.65	141.00	14.50	−18.40	601.67	1909.60	3.17	4.70	2616.80

Abbreviations of the site names are given. QD, Qingdao; QHD, Qinghuangdao; TY, Taiyuan; LC, Liaocheng; CD, Chengde; TS, Tangshan; XX, Xinxiang; BJ, Beijing; HD, Handan; JZ, Jiaozuo; TJ, Tianjing; ZZ, Zhengzhou; YC, Yuncheng; LF, Lingfeng; SJZ, Shijiazhuang; XT, Xingtai; ZJK, Zhangjiakou; YT, Yantai; BD, Baoding; JN, Jinan. LAT, Latitude; LON, longitude; ALT, altitude; MAT, Mean annual temperature; LT, lowest temperature; MAP, mean annual precipitation; AE, annual evapotranspiration; AI, aridity index; AQC, air quality composite index; NHS, number of hours of sunlight per year.

Latitude (LAT), longitude (LON), and altitude (ALT) data for each sampling site were recorded using the Global Positioning System (GPS MAP 621sc), and summarized in Table 1. Climate data, including MAT, lowest temperature (LT), MAP, annual evapotranspiration (AE), aridity index (AI), air quality composite index (AQC), and number of hours of sunlight per year (NHS) were obtained from the WorldClimate website (http://www.Worldclim.org/, accessed on 12 July 2022) at a 1 km × 1 km resolution, and the China Meteorological Data Service Centre website (http://data.cma.cn/, accessed on 18 May 2023).

2.2. Experiment Design and Sample Collection

A survey was conducted between September–October 2022, focusing on the distribution of resource in major *P. propinqua* site cities across five provinces in northern China. Open parks were selected as survey targets. Field sampling proceeded from south to north, considering the influence of phenological variations from north to south. These plantations were consistently managed with minimal disturbance. The sampled bamboo forests had relatively uniform ages, ranging from 5 to 10 years, with an average age of about 8.5 years. The sampled bamboos were between 2 and 3 years old. Sites chosen for sampling were under fixed management, with no fertilizer application in the previous 5 years.

In the open park, a *P. propinqua* forest with a total area of not less than 100 m^2 was selected for the study with consistent environmental conditions. 2 × 2 sample plots were randomly established, 5–6 well-grown *P. propinqua* were randomly selected, and mature leaves were took from the canopy and mixed them to form a single sample of about 10 leaves from each sample site.

Considering that the park's soil layer is relatively shallow, and the majority of the root system is situated in the upper soil layer, topsoil samples were collected from a depth of 0–20 cm using a soil auger. A five-point sampling method was applied to eliminate understory plants and surface apomictic material. This process was repeated three times to obtain a total of 60 samples (3 samples per site). The horizontal separation between adjacent sample sites exceeded 20 m.

2.3. Sample Preparation and Chemical Analyses

All leaf samples were dried to constant weight at 70 °C, subsequently ground (Shanghai, China, DS-T350). The organic carbon concentration in each sample was determined through potassium dichromate oxidation external heating method. The N and P concentrations in each sample were determined through the wet digestion with sulphuric and perchloric acid method [41].

Soil samples were air-dried after being sieved (2 mm mesh), and chemical analysis was conducted using a 60-mesh sieve (0.25 mm diameter). Soil organic carbon was determined through the potassium dichromate oxidation external heating method. Soil N concentration was determined through the Kjeldahl method, continuous flow analyzer and element analyzer. Soil P concentration was determined through the alkali melting method and

the acid dissolving method. Soil pH value was determined through the potentiometric method [41]. The soil conditions of sampled stands were listed in Table 2.

Table 2. Soil conditions of sampled stands.

Site	Soil C (g kg^{-1})	Soil N (g kg^{-1})	Soil P (g kg^{-1})	C:N Ratio	C:P Ratio	N:P Ratio	Soil pH
QD	8.95	1.09	0.70	7.50	15.62	2.08	6.91
QHD	7.71	1.03	0.63	8.71	14.30	1.64	7.41
TY	8.59	0.98	0.61	9.19	14.00	1.52	7.85
LC	8.54	1.01	0.74	7.64	9.52	1.25	7.72
CD	8.33	1.16	0.74	6.31	11.13	1.76	6.82
TS	8.41	1.11	0.76	9.35	11.80	1.26	7.83
XX	8.97	1.09	0.78	7.22	10.72	1.48	7.32
BJ	8.88	1.14	0.76	7.81	11.55	1.48	7.18
HD	7.80	1.01	0.79	7.93	9.50	1.20	7.81
JZ	8.67	1.20	0.72	8.68	13.66	1.57	7.57
TJ	7.66	0.95	0.66	7.46	10.10	1.35	7.29
ZZ	8.70	1.12	0.71	9.09	12.56	1.38	7.23
YC	8.70	0.99	0.78	9.02	14.13	1.57	7.60
LF	7.48	1.06	0.73	6.65	9.23	1.39	7.18
SJZ	8.45	0.92	0.72	10.11	13.73	1.36	7.58
XT	7.59	1.00	0.66	7.94	9.74	1.23	7.74
ZJK	7.60	0.96	0.77	8.52	9.68	1.14	7.68
YT	8.06	0.89	0.70	10.09	13.60	1.35	7.43
BD	7.72	1.12	0.85	7.04	10.07	1.43	7.52
JN	8.70	0.97	0.73	9.83	12.93	1.31	7.54

The identification letters of locations are found in Table 1.

2.4. Data Analyses

One-sample *t*-test was used to analyze differences between leaf carbon, nitrogen, phosphorus and their ratios. Regression analysis was employed to establish the relationship between leaf stoichiometry and latitude; Pearson correlation was used to investigate associations between leaf stoichiometry, climate, and soil nutrient variables. Hierarchical partitioning (HP) was applied to explore the effects of climatic and soil factors on leaf stoichiometry. From the Pearson correlation analysis, leaf stoichiometry was not significantly correlated with AQC, NHS, soil C:N, C:P, and N:P ratios (Table A1). Therefore, these factors were not used in hierarchical partitioning. All analyses were performed using the R statistical platform 3.3.0 (R Development Core Team).

3. Results

3.1. Latitudinal Patterns of Leaf C, N, and P Stoichiometry

The mean leaf concentrations of C, N and P in *P. propinqua* were 0.46 g g^{-1}, 23.19 mg g^{-1} and 1.40 mg g^{-1}, respectively. The mean leaf C:N, C:P, and N:P ratios were 20.24, 335.50 and 16.74, respectively (Table 3).

Table 3. Statistics of leaf C, N and P stoichiometry of *P. propinqua*. SE, standard error; CV, coefficient of variation.

	C (g g^{-1})	N (mg g^{-1})	P (mg g^{-1})	C:N Ratio	C:P Ratio	N:P Ratio
Average	0.46	23.19	1.40	20.24	335.50	16.74
SE	0.02	2.48	0.15	2.40	33.82	2.14
Maximum	0.50	28.38	1.84	26.51	405.86	21.09
Minimum	0.43	18.09	1.12	16.20	269.34	13.04
CV (%)	3.22	10.70	11.03	11.87	10.08	12.75

Leaf C, N, and P concentrations and the N:P ratio were significantly correlated with each other ($p < 0.05$). Moreover, leaf C concentrations exhibited a significant correlation with C:P ratios ($p < 0.01$). Leaf N concentrations were significantly correlated with P concentrations, C:N and N:P ratios ($p < 0.01$), and leaf P concentrations were significantly correlated with C:P ratios ($p < 0.01$). Moreover, leaf C:N, C:P and N:P ratios were significantly correlated with each other (Figure 2, $p < 0.05$).

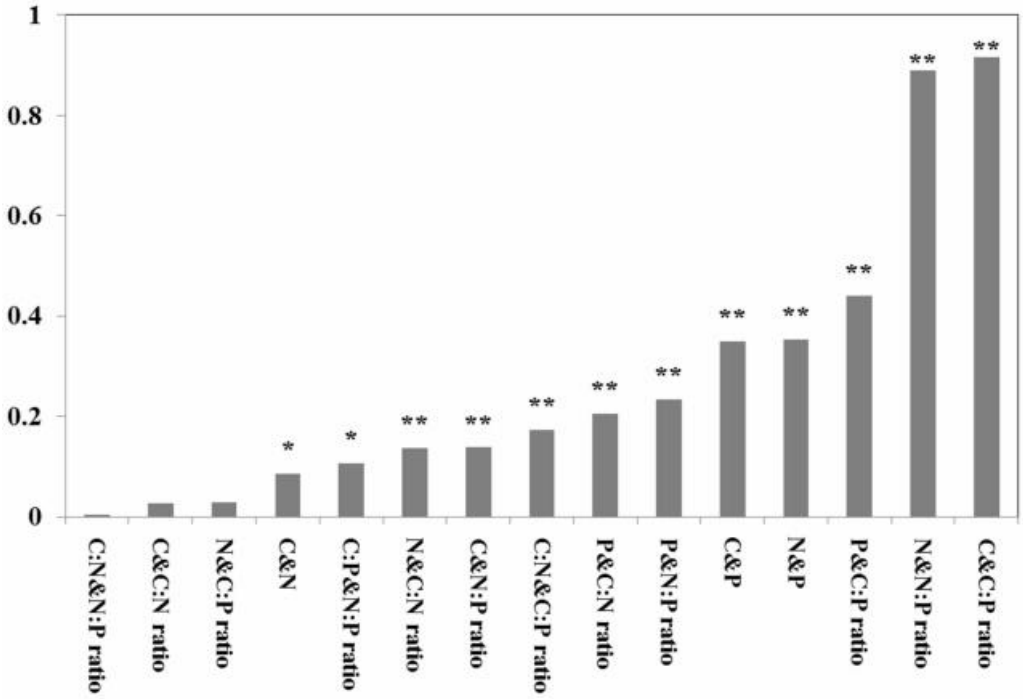


Figure 2. Correlation analysis between leaf C, N and P stoichiometry of *P. propinqua*. Note: significance at $p < 0.05$ and $p < 0.01$ are indicated by * and **, respectively.

With increasing latitude, leaf C and P concentrations, as well as C:N ratios, exhibited significant increases ($p < 0.05$), while leaf N concentrations and N:P ratios decreased significantly (Figure 3, $p < 0.05$). Conversely, leaf C, N, and P concentrations did not exhibit significant associations with altitude (Figure 3, $p > 0.05$).

3.2. Effects of Climate and Soil Nutrients Variables on Spatial Patterns of Leaf Stoichiometry

Hierarchical partitioning indicated that between 31% (in leaf C) to 73% (in N:P ratio) variations in leaf stoichiometry were accounted for by the chosen climatic and soil variables (Table 4).

Table 4. Results of hierarchical partitioning for the effects of climatic factors and soil nutrient on leaf C, N, and P stoichiometry of *P. propinqua*.

	Full Model(R^2)	Climate (%)					Soil (%)			
		MAT	LT	MAP	AE	AI	C	N	P	pH
leaf C	0.31	19.18 **	23.37 **	7.17	1.94	7.51	2.18	35.34 *	1.00	2.31
leaf N	0.34	25.73 **	9.6 *	14.43	18.56 *	10.63	5.37	4.94	1.19	9.56
Leaf P	0.51	38.94 **	26.49 **	4.75	15.93 *	9.03 *	1.00	0.35	1.84	1.67
Leaf C:N	0.36	30.81 **	14.2 **	16.93 *	15.18	9.23	3.19	0.67	0.87	8.93
Leaf C:P	0.44	39.49 **	21.41 **	6.01	18.45 *	8.4	1.49	0.79	2.28	1.68
Leaf N:P	0.73	52.44 **	25.21 **	5.3 *	2.01	4.29 *	3.66 *	1.04	0.52	5.53

Results of hierarchical partitioning are explained by the full model (R^2) and the respective contributions of the individual predictors to the overall model. Significance levels at $p < 0.05$ and $p < 0.01$ are indicated by * and **, respectively.

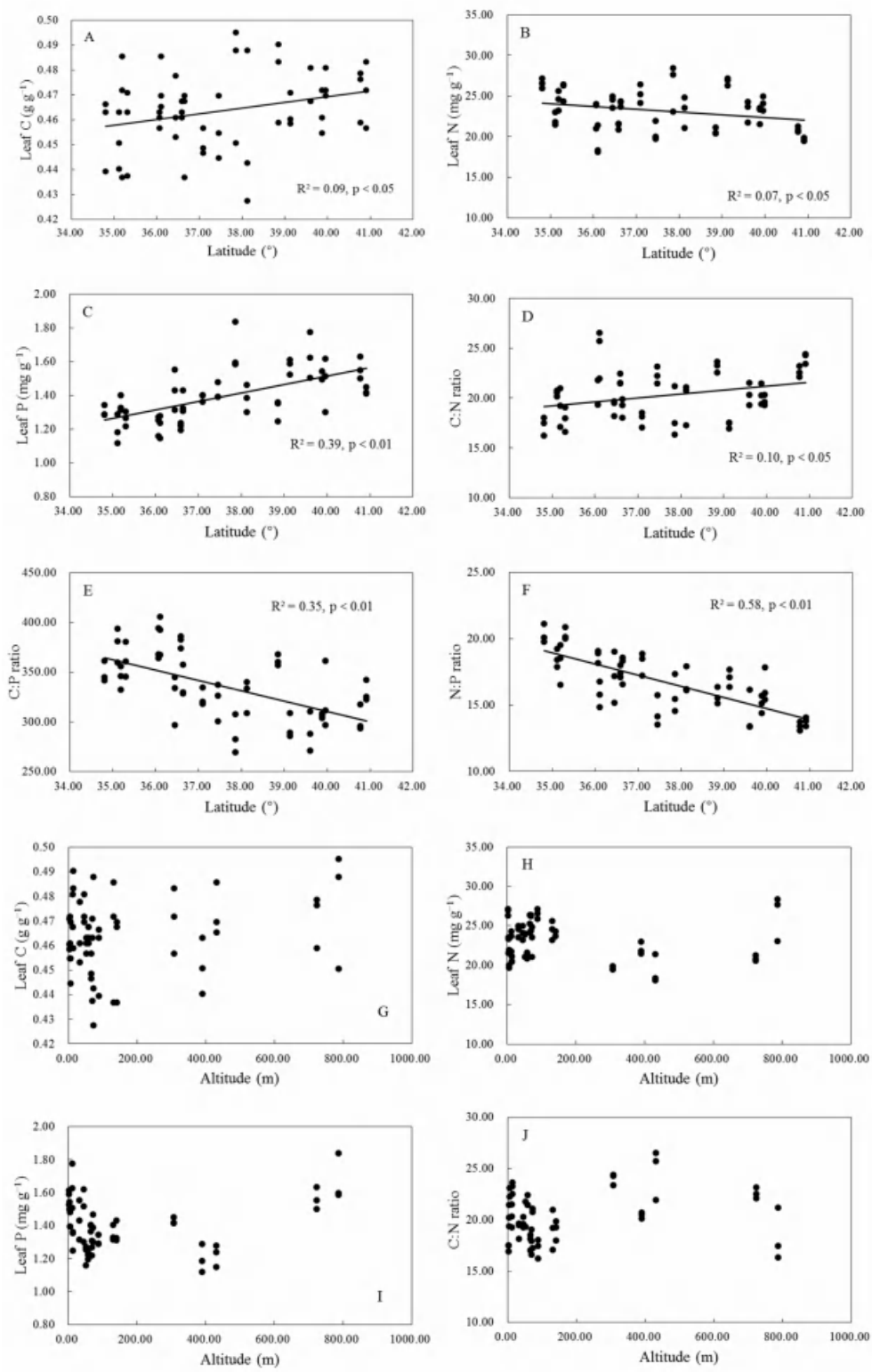


Figure 3. *Cont*.

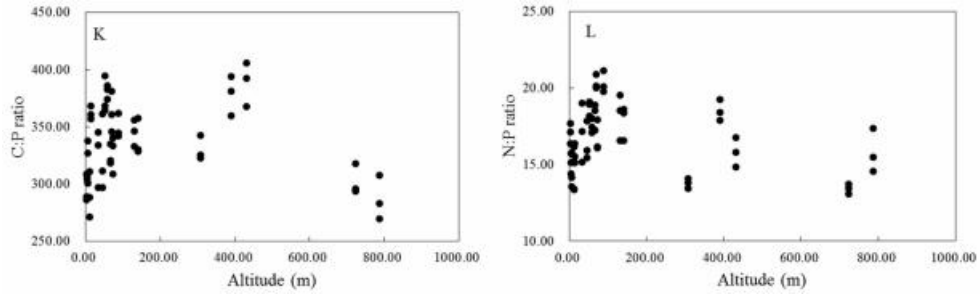


Figure 3. Latitudinal and altitude patterns of leaf C, N, and P stoichiometry for *P. propinqua*. Note: C and latitude (**A**), N and latitude (**B**), P and latitude (**C**), C:N and latitude (**D**), C:P and latitude (**E**), N:P and latitude (**F**), C and altitude (**G**), N and altitude (**H**), P and altitude (**I**), C:N and altitude (**J**), C:P and altitude (**K**) and N:P and altitude (**L**).

Leaf C, N, and P concentrations and C:N, C:P and N:P ratios were significantly associated with MAP and LT ($p < 0.05$), which accounted for 19.18% and 23.37% of total variation in leaf C concentrations, 25.73% and 9.60% of total variation in leaf N concentrations, 38.94% and 26.49% of total variation in leaf P concentrations, 30.81% and 14.2% of total variation in leaf C:N ratios, 39.49% and 21.41% of total variation in leaf C:P ratios, 52.44% and 25.21% of total variation in leaf N:P ratios. Meanwhile, leaf C:N and N:P ratios were associated with MAP ($p < 0.05$), which accounted for 5.30% of the variation in leaf N:P ratio, and 16.93% of the variation in leaf C:N ratio. Leaf N and P concentrations and the C:P ratio were also associated with AE ($p < 0.05$), which accounted for 18.56% and 15.93% of leaf N and P concentrations, and 18.45% of the variation in leaf C:P ratio. Furthermore, leaf P concentrations and the N:P ratio were associated with AI ($p < 0.05$). In contrast, except for leaf C and soil N, leaf N:P ratio and soil C, leaf C, N, and P stoichiometry were not closely associated with the soil factors ($p > 0.05$) (Table 3).

4. Discussion

4.1. Overall Patterns of Leaf C, N, P Stoichiometry in P. propinqua

Stoichiometry plays a pivotal role in elucidating a plant's nutrient acquisition capabilities and its adaptability to environmental conditions [2,7]. The study revealed that the average C concentration in *P. propinqua* leaves was 0.46 g g^{-1} (Table 3), a value close to that of the global flora (0.461 g g^{-1}) [54] and the forest in China (0.455 g g^{-1}) [32], and similar to the C concentrations of bamboo leaves in subtropical regions [55,56]. This suggests the presence of internal homeostasis in the C stoichiometry of bamboo.

The average N and P concentrations of *P. propinqua* leaves reached 23.19 mg g^{-1} and 1.40 mg g^{-1}, respectively (Table 3). They were higher than those of the vegetation in China and in the world [33,54], but leaf N concentrations were close to the values reported in previous studies on bamboo leaves in subtropical regions [56,57], while for leaf P, the concentrations were generally higher than those reported in previous studies on P concentrations of bamboo leaves in subtropical regions [56,57]. This discrepancy of P concentrations might be attributed to nutrient limitation arising from differences in soil P concentrations between southern and northern China [33]. Previous studies have demonstrated severe soil P deficiency in southern China, resulting in significantly lower P concentrations in plants [34].

The ratios of C, N, and P In leaves typically reflect relative nutrient shortages. In this study, the C:N ratio was 20.24 and the C:P ratio was 335.50 (Table 3), which was lower than that of the previous study on Chinese fir, in which the C:N ratio was 37.60 and the C:P ratio was about 482.73 in the leaves [41]. Furthermore, these ratios were lower than those in the vegetation in China and in the world [32,54]. This result is related to the relatively high N and P concentrations and relatively close C concentrations in the leaves of *P. propinqu*, which implies a relatively adequate nutrient supply for N and P. Due to the lower soil P concentrations in southern than northern China, the N:P ratio in this study was

16.74 (Table 3), which was lower than that of bamboo leaves in subtropical regions [54,56]. This suggests that the N and P stoichiometry of the plants in our study was more balanced compared to that of plants in subtropical regions [58].

C, N, and P are crucial elements for plant growth, constituting essential components of substances like proteins, nucleic acids, and carbohydrates within plant leaves [3,4]. These elements also underpin the construction of plant morphology and structure [17,21]. As a result, there was a significant correlation among C, N and P in this study ($p < 0.05$). In addition, our study showed that C:N and C:P ratios in leaves were more susceptible to the influence of N and P, which was consistent with the observations for woody species [41]. This phenomenon can be attributed to the relatively stable nature of C concentrations in plant leaves, while N and P concentrations exhibit greater variability.

Regarding the N:P ratio, previous studies on certain tree species in southern China showed that leaf N:P concentrations usually correlate more closely with P and less with N [41]. In contrast, our study found a significant correlation between the N:P ratio and both N and P ($p < 0.05$). This shift may be due to the generally high soil P content and low soil N in northern China [33,34], which leads to plant growth being restricted by P. In addition, the N:P ratio was relatively balanced, suggesting that N and P limitations during growth are determined by a joint influence on N and P leaf concentrations.

4.2. Latitudinal Patterns, Climatic and Soil Factors of Leaf C, N, P Stoichiometry

Correlations between phytochemical stoichiometry and latitude have been observed across studies spanning various scales [10,12]. This pattern arises from the interaction of climatic and soil factors [11,30,44]. In our study, we also observed significant correlations between C, N, P, and their ratios with latitude (Figure 3, $p < 0.05$). Hierarchical partitioning analysis suggested that MAT and LT were the primary factors affecting C, N, P, and their ratios (Table 4). However, among the soil factors, only soil N (35.34%) had an effect on leaf C concentrations (Table 4, $p < 0.05$). This finding implies that variations in C, N, P concentrations and their ratios with latitude are driven more by climatic factors than by soil factors. This result is similar to those of the stoichiometric study of Chinese fir and *Metasequoia glyptostroboides* in subtropical China [41,59]. The main reason is that bamboo is distributed in tropical and subtropical regions around the world [51], and only a few bamboo species have been introduced to temperate regions [52], where climatic factors, such as temperature, vary drastically, which ultimately affects C, N, and P stoichiometry. This result also indicates the sensitivity of C, N, and P stoichiometry to climate change.

In our study, we found a significant increase in leaf C concentrations with rising latitude (Figure 3, $p < 0.05$). This result aligns with the trend observed in leaves of *Quercus* spp. [60], but is opposed to previous findings in evergreen broadleaved forests, where leaf C concentrations decreased with increasing latitude [61]. This increase may be attributed to the significant elevation of various sugars and fibers in leaves of bamboo when exposed to cold stress. Such stress leads to higher C concentrations in the leaves, a phenomenon supported by research related to cold resistance in bamboo and other plants [62,63]. Meanwhile, the significant correlation between soil N and Leaf C concentrations also suggests that fertile soil can enhance plant leaf growth and cold resistance [31,64].

According to the temperature–plant physiological hypothesis, plants tend to increase physiological activity at low temperatures, resulting in higher N and P concentrations and demand [27]. However, leaf N concentrations exhibited a decreasing trend with increasing latitude, while leaf P concentrations increased (Figure 3, $p < 0.05$). It was because as temperatures further decrease, the permeability of cell membranes as well as the viscosity of water molecules in plants decreases, which indirectly affects the transport efficiency of nutrients and further hinders the transport of N [27]. In addition, some studies also showed that low temperatures limit N mineralization in the soil, which reduces the soil's N effectiveness and subsequently affects N concentrations in leaves [33,64]. In contrast to N, plants generally have lower demand for P [41,59], and thus lower transport efficiency under cold conditions can meet the plant's P needs but not its N requirements. These

factors contributed to the decreasing N concentrations in *P. propinqua* leaves with increasing latitude while P concentrations exhibited an upward trend.

Among the climatic factors, in addition to temperature, atmospheric humidity factors also affect plant stoichiometry. In our study, AE significantly affected leaf N and P stoichiometry, and AI also significantly affected leaf P stoichiometry ($p < 0.05$). This is consistent with previous studies in some plants such as *Quercus* spp. [59]. It was concluded that AE enhances plant transpiration, facilitating the transport of nutrients like N and P [65]. In arid environments, heightened plant physiological activity increased N and P concentrations [40,46]. This underscores the correlation between AE, AI and leaf N, P concentrations.

5. Conclusions

In conclusion, our study delved into the spatial pattern in leaf C, N, and P stoichiometry of *P. propinqua* across northern China. The results showed the following results: (1) The mean leaf concentrations of N and P in *P. propinqua* were higher than those in the vegetation in China and in the world, and leaf C, N, and P concentrations were significantly correlated with each other ($p < 0.05$). (2) Our study illuminated discernible latitudinal patterns in leaf C, N, and P concentrations; leaf C and P concentrations, as well as C:N ratios, significantly increased with increasing latitude ($p < 0.05$), but leaf N concentrations and N:P ratios decreased significantly ($p < 0.05$). (3) Leaf C, N, and P concentrations and their ratios were significantly associated with climate factors, such as MAT and LT ($p < 0.05$), and leaf P concentrations were also associated with AE and AI ($p < 0.05$). (4) In soil factors, only leaf C concentrations displayed a significant correlation with soil N. Overall, these results collectively signify that the spatial configurations of *P. propinqua* leaf stoichiometry in urban forest across northern China are predominantly driven by climatic variances, especially those linked to lower temperatures. These insights offer valuable perspectives of the adaptive strategies employed by widely distributed and introduced plant species in the context of changing environmental conditions. These findings contribute to the broader understanding of how plants respond to environmental shifts and highlight the importance of considering nutrient stoichiometry when assessing ecological adaptations.

Author Contributions: Conceptualization, L.C., N.P., L.L., L.Z., X.L. and X.Q.; methodology, L.C., L.L., N.P. and X.Q.; software, L.L., L.Z. and X.Z.; validation and formal analysis, L.C., L.Z., X.Q. and J.L.; investigation and data curation, L.C., S.L., J.L. and B.H.; writing—original draft preparation, L.C., N.P., L.L., L.Z. and X.Q.; writing—review and editing, L.C., N.P., L.L. and X.Q.; visualization, L.L., L.Z. and X.Z.; supervision and project administration, N.P., L.L., L.Z., X.L. and X.Q. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China (grant number: 31971737); Fundamental Research Funds of ICBR (grant number: 1632020026); Forestry Science and Technology Innovation Project of the Guangdong Forestry Bureau (grant number: GDZ-ZDC20228703).

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy.

Acknowledgments: The authors thank Ziyun Dai from Beijing Institute of Landscape Architecture for his help in the investigation processing.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A.

Table A1. Correlation analysis between leaf stoichiometry, climate and soil factors of *P. propinqua*.

	Climate										Soil			
	MAT	**LT**	**MAP**	**AE**	**AI**	**AQC**	**NHS**	**C**	**N**	**P**	**C:N**	**C:P**	**N:P**	**pH**
leaf C	−0.329 *	−0.375 **	−0.231	0.079	0.214	0.001	0.020	0.006	0.307 *	0.092	−0.238	−0.070	0.154	0.052
leaf N	0.344 **	0.262 *	0.222	0.244	−0.020	0.222	−0.160	0.201	0.120	0.068	−0.001	0.036	0.027	−0.062
Leaf P	−0.572 **	−0.514 **	−0.173	0.334 **	0.310 *	−0.142	−0.064	−0.136	0.015	0.164	−0.110	−0.232	−0.124	0.050
Leaf C:N	−0.416 **	−0.353 **	−0.296 *	−0.209	0.094	−0.181	0.125	−0.182	−0.036	−0.044	−0.067	−0.047	0.013	0.069
Leaf C:P	0.501 **	0.411 **	0.079	−0.308 *	−0.225	0.180	0.071	0.138	0.065	−0.156	0.034	0.230	0.177	−0.035
Leaf N:P	0.764 **	0.638 **	0.342 **	−0.085	−0.285 *	0.242	−0.080	0.289 *	0.091	−0.082	0.091	0.228	0.129	−0.103

Significance at $p < 0.05$ and $p < 0.01$ are indicated by * and **, respectively.

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SCAULIB202519467

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1	Delineating the Area for Sustainable Cultivation of Morinda officinalis Based on the MaxEnt Model	AGRONOMY-BASEL 出版年：2024 出版日期：JUN 卷期：14 6 页码：- 文献号：1134 文献类型：Article	通讯作者	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=3.4 IF5-year=3.8 （2024）	农林科学 2区 Top 期刊：否 （2025）
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3	Ophioglossum hongii (Ophioglossaceae), a new species from Xizang, China	PHYTOTAXA 出版年：2024 出版日期：DEC 10 卷期：676 2 页码：169-180	共同通讯作者(倒数第一)	B类	华南农业大学林学与风景园林学院	SCI	IF2-year=1.0 IF5-year=1.0 （2024）	生物学 4区 Top 期刊：否 （2025）
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7	Latitudinal Patterns of Leaf Carbon, Nitrogen, and Phosphorus Stoichiometry in Phyllostachys propinqua McClure across Northern China	FORESTS 出版年：2023 出版日期：NOV 卷期：14 11 页码：- 文献号：2243	共同通讯作者（倒数第一）	A类	华南农业大学林学与风景园林学院	SCI	IF2-year=2.4 IF5-year=2.7 （2023）	农林科学 2区 Top 期刊：否 （2023）

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Statistics and Analysis of Digital Information on Vascular Plant Specimens and the History of Plant Collecting in Guangzhou, China

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Abstract: This paper presents a comprehensive analysis of digitized specimen data and relevant literature to investigate the vascular plant diversity in Guangzhou City, China. Specimen data were collected from various sources, including the China Digital Herbarium (CVH), the National Specimen Resource Sharing Platform (NSII), Global Plants on JSTOR, and the Global Biodiversity Information Facility (GBIF). Following data standardization, the study identified 41,890 vascular plant specimens, encompassing 248 families, 1563 genera, and 4536 species, including subspecies and cultivated plants. Among them, the native plants of Guangzhou city accounted for 60.6% of the species. The temporal analysis identified three distinct peaks in specimen collection: 1916–1920, 1928–1936, and 1950–1964. Collection activities were primarily concentrated between the months of April and November. The distribution of collected specimens exhibited significant variation among different species, with families such as Fabaceae, Poaceae, and Myrtaceae having the highest number of specimens. Similarly, genera such as *Eucalyptus*, *Ficus*, and *Citrus* were well-represented. The most frequently collected species included *Litchi chinensis*, *Eucalyptus robusta*, and *Cycas taiwaniana*. Remarkably, 21 species had specimen counts exceeding 100. Unfortunately, approximately three-quarters of the species had fewer than 10 recorded specimens. Alarmingly, 1220 species were represented by only one specimen. Geographically, the majority of specimens originated from the former suburbs of Guangzhou, Conghua Delta Mountain, and Liuxi River areas, while other regions had limited representation. In terms of specimen collections, the Herbarium of South China Botanical Garden of the Chinese Academy of Sciences (IBSC) recorded the highest number of specimens (13,828 specimens), followed by the Tree Herbarium of South China Agricultural University (CANT; 3869 specimens) and the Herbarium of Sun Yat-sen University (SYS; 3654 specimens). The collection history in Guangzhou spans nearly 300 years and can be broadly divided into two distinct periods. The first period extends from the late 13th century to 1949, primarily encompassing the collection efforts of foreign visitors in Guangzhou, and represents the pioneering phase of plant taxonomy research in China. The second period, from 1949 to the present, is characterized by extensive investigations and collection activities conducted by local scholars, with a specific emphasis on native plant resources. By meticulously organizing and verifying information derived from historical documents and specimens, the paper effectively summarizes the plant collection and research history of Guangzhou, providing detailed profiles of the key collectors. These findings furnish reliable historical reference materials for the study of plant taxonomy and diversity in Guangzhou.

Keywords: Guangzhou; digital plant specimen information; vascular plant resources; plant collection history

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Citation: Liang, M.; Qin, X. Statistics and Analysis of Digital Information on Vascular Plant Specimens and the History of Plant Collecting in Guangzhou, China. *Plants* **2023**, *12*, 3325. https://doi.org/10.3390/plants12183325

Academic Editor: Daniel Potter

Received: 2 September 2023
Revised: 18 September 2023
Accepted: 19 September 2023
Published: 20 September 2023

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1. Introduction

Guangzhou is situated in the southern region of China, specifically in the lower reaches of the Pearl River basin, and is located in close proximity to the South China Sea.

It is geographically positioned between 112°57′~114°3′ E and 22°26′~23°56′ N, which shares maritime boundaries with Hong Kong and Macao. It is intersected by the Tropic of Cancer and falls within the South Asian tropical monsoon climate zone; both the ocean and the mainland have a significant impact on the climate of Guangzhou. The exceptional natural conditions and intricate geological landforms of Guangzhou have fostered the development of a wide array of plant species and diverse natural vegetation. The region boasts a remarkable forest cover of 42.14% [1]. The predominant zonal vegetation found in Guangzhou is the South subtropical monsoon evergreen broad-leaved forest (Figure 1). These forests are renowned for their lush foliage and abundant biodiversity. Guangzhou also stands out as one of the areas in China with the most abundant fruit tree resources, further exemplifying its ecological richness and agricultural significance [2]. Moreover, Guangzhou holds the distinction of being among the inaugural group of renowned national historical and cultural cities in China. It also stands as a prominent point of origin along the historic Maritime Silk Road, earning it the reputation as a "commercial capital with a legacy spanning millennia". Throughout antiquity, Guangzhou has served as a hub for the convergence and fusion of Chinese and foreign cultures, establishing itself as the birthplace of Guangfu culture.

Specimens serve as crucial records and custodians of plant collection history, offering direct and objective insights into vegetation status, collection activities, distribution, phenological expression at exact times, and other pertinent information, thereby holding significant importance for scientific research. In the present era, the advancement of computer and internet technologies, as well as the widespread application of information technology in the life sciences, has propelled the process of specimen library informatization. The digitization and informatization of plant specimens have ushered in a new era, ensuring the permanent preservation of essential information pertaining to plant morphology and distribution. This has greatly enhanced information sharing, facilitating the provision of phenology, morphology, distribution, and historical change data to scientific researchers and individuals from diverse backgrounds. These data play a crucial role in understanding the impacts of climate change on plant species [3,4], assessing the spread and ecological influences of invasive species [5,6], and formulating effective conservation strategies. Overall, specimen data serve as a critical tool for advancing scientific knowledge and addressing pressing environmental challenges.

Guangzhou, as a significant trading port, holds the distinction of being the pioneering region where plant collection and research were initiated in China. With a rich history spanning nearly 300 years, Guangzhou's contributions to plant collection and research have played an exceptionally pivotal role in the field of plant taxonomy, both domestically and globally. The historical significance of plant collection and research in this area remains highly influential, shaping the trajectory of scientific investigations in the realm of plant taxonomy within China and across the world.

This study aims to comprehensively examine the digitalization status of vascular plant specimens in Guangzhou and assess the collection status of plant specimens in the region. The research methodology involves reviewing and referencing relevant literature, consulting university and herbaria archives, and utilizing digitized specimen data available in prominent network databases. By collating and statistically analyzing the specimen information, as well as incorporating data gathered from literature sources, the study presents a comprehensive overview of the research process of plant collections in Guangzhou. Additionally, supplementary details are provided to ensure a comprehensive understanding of the current state of digitalization of vascular plant specimens and the collection status of the area. The findings of this study serve as a valuable scientific foundation for effectively organizing future specimen collection efforts and prioritizing digitization initiatives. Furthermore, the results offer reliable historical reference materials that contribute to the study of plant taxonomy and diversity in Guangzhou.

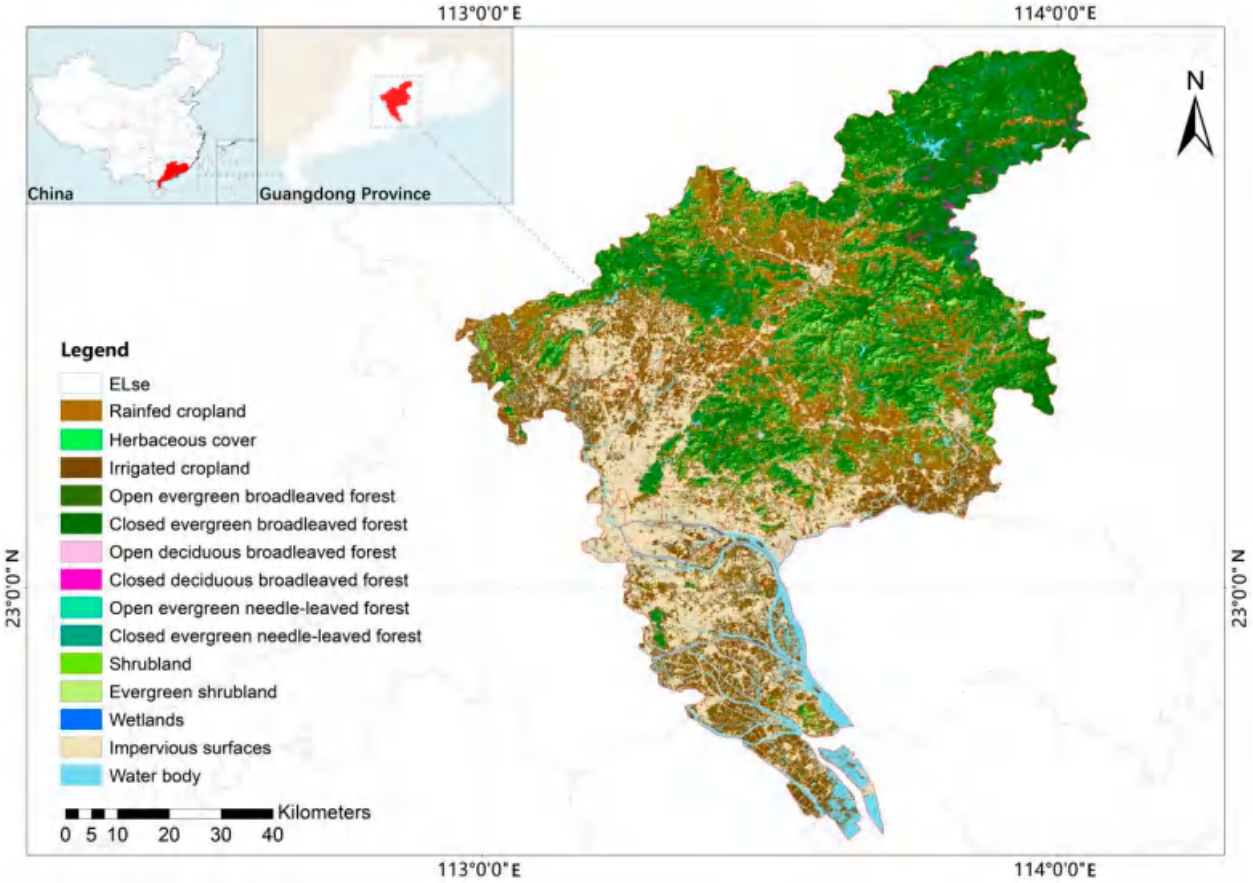


Figure 1. The location and land cover type within and surrounding Guangzhou (Data derived from Liu and Zhang [7]).

2. Materials and Methods

2.1. Data Source

The digital specimen information mainly comes from the Chinese Virtual Herbarium (CVH, http://www.cvh.ac.cn/; last date of access 13 June 2023), the National Specimen Information Infrastructure (NSII, http://www.nsii.org.cn/2017/query.php?kingdom=plant; last date of access 9 June 2023), Global Plants on JSTOR (https://plants.jstor.org/; last date of access 25 June 2023), and the Global Biodiversity Information Facility (GBIF, https://www.gbif.org/; last date of access 1 July 2023). The literature data mainly come from Web of Science (WOS, https://www.webofscience.com/; last date of access 15 July 2023), CNKI (http://www.cnki.net/; last date of access 20 July 2023), the Biodiversity Heritage Library (BHL, https://www.biodiversitylibrary.org/; last date of access 18 July 2023) and Tropicos (https://www.tropicos.org/; last date of access 18 July 2023). A total of 109,288 specimen records collected in Guangzhou between the years 1751 and 2020 have been obtained (Table 1).

Table 1. Data source.

Websites	Search Condition	No. of Specimens
CVH, http://www.cvh.ac.cn/ (accessed on 13 June 2023)	Country = China, Province = Guangdong, County = Guangzhou/Conghua/ Zengcheng/Huangpu/Panyu/Tianhe/ Yuexiu/Huadu/Haizhu/Nansha/ Baiyun/Liwan/Canton. Country = China, Province = Guangdong, Location cite = Guangzhou/Conghua/ Zengcheng/Huangpu/ Panyu/Tianhe/Yuexiu/Huadu/Haizhu/Nansha/ Baiyun/Liwan/Canton.	34,059
NSII, http://www.nsii.org.cn/2017/query.php?kingdom=plant (accessed on 9 June 2023)	Location = Guangzhou/Conghua/Zengcheng/ Huangpu/Panyu/Tianhe/Yuexiu/ Huadu/Haizhu/Nansha/Baiyun/Liwan/Canton.	55,632
JSTOR, https://plants.jstor.org/ (accessed on 25 June 2023)	Country = China, Locality = Guangzhou/Canton;	307
GBIF, https://www.gbif.org/ (accessed on 1 July 2023)	Scientific name = Plantae, Basis of record = Preserved specimen, Country or area = China, Administrative areas = Guangzhou-CHN.6.4.1	19,290

2.2. Specimen Data Correction

The original specimen data underwent organization using Excel 2021, whereby duplicate records and specimens collected outside the administrative area of Guangzhou were eliminated. Subsequently, the reorganized data will be submitted to the iPlant (http://www.iplant.cn/pnc; last date of access 10 July 2023) and the Taxonomic Name Resolution Service (TNRS, https://tnrs.biendata.org/; last date of access 10 July 2023) for the purpose of correcting and updating specimen scientific names. Finally, the data will be summarized, with angiosperms classified according to the APG IV classification system, gymnosperms classified according to the Gymnosperms classification system, and ferns classified according to the Taxonomic system of stone pines and ferns.

2.3. Type Specimen Examination

Utilizing the resources provided by the International Plant Names Index (IPNI, https://www.ipni.org/; last date of access 13 July 2023) and Tropicos (2023), the collection of type specimens from Guangzhou was facilitated. Each type specimen collected from Guangzhou was individually examined and studied, enabling a meticulous analysis of the type species specific to the region.

2.4. Standardization of Specimen Data

The standardization of data organization holds tremendous significance within the academic realm. Digitization and organization of specimens occur across various specimen museums, often resulting in disparate data representations and the potential for errors in data entry. Common issues encompass Latin name misspellings, errors in specimen identification, and inconsistencies between webpage data and the original specimen data. Even when recorded by the same individual, discrepancies may arise. For example, the 1974 Guangdong Timber Survey was documented in various formats, such as those of Guangdong Timber, the Guangdong Timber Survey Team, and the Guangdong Timber Survey Team. Complex fonts and illegible handwriting have led to incorrect specimen entries. Notable examples include K.K. Tsoong, misspelled as K.K. Toong, and C.O. Levine, mistakenly listed as Coo. Levine. Furthermore, each database employs distinct input formats. This article undertook the standardization and organization of specimen data collected from the Guangzhou area between 1751 and 2020, utilizing existing data and

eliminating duplicates. The processed data facilitated analyses of the collection status of specimens obtained from Guangzhou city, the temporal distribution of plant specimens, and the collection trends among different taxonomic groups. Additionally, the study explored the functional utilization of plants and examined the principal plant collection activities during various periods.

3. Results

3.1. Temporal Collection Patterns of Specimens in Guangzhou: Yearly and Monthly Variations

Following the standardization of collection dates, a comprehensive dataset comprising 35,149 specimen records with detailed collection dates was obtained. Additionally, 4509 specimens included collection year and month information, 680 specimens solely indicated the year, while 1651 specimens did not have recorded dates. Analysis of the collection years demonstrated distinct patterns of periodicity. Specifically, two minor peaks were observed during 1916–1920 and 1928–1936, while a major peak occurred between 1950 and 1964 (Figure 2). The remaining years exhibited scattered collection patterns without significant periodic trends. Upon consulting relevant literature, significant historical events and large-scale specimen collection activities were identified during the three periods of extensive collection. For instance, in 1916, the establishment of the Agricultural Department at Lingnan School, under the directorship of George W. Groff (1884–1954), facilitated the collection of plant specimens [8]. In 1928, Chen Huanyong was appointed as a professor at the School of Science, National Sun Yat-sen University, and established the "Plant Research Laboratory". Subsequently, in 1929, the Agricultural and Forestry Plant Research Institute of Agricultural College, National Sun Yat-sen University, established the Plant Herbarium (now known as IBSC) under the directorship of Chen Huanyong, implementing a four-year collection plan [9]. Furthermore, in 1950, the first national conference on plant classification was held in Beijing to discuss the nationwide collection of plant specimens in preparation for the compilation of the Chinese flora. The largest scale of collection occurred in 1958, coinciding with the Sino-German joint investigation conducted during that period [8].

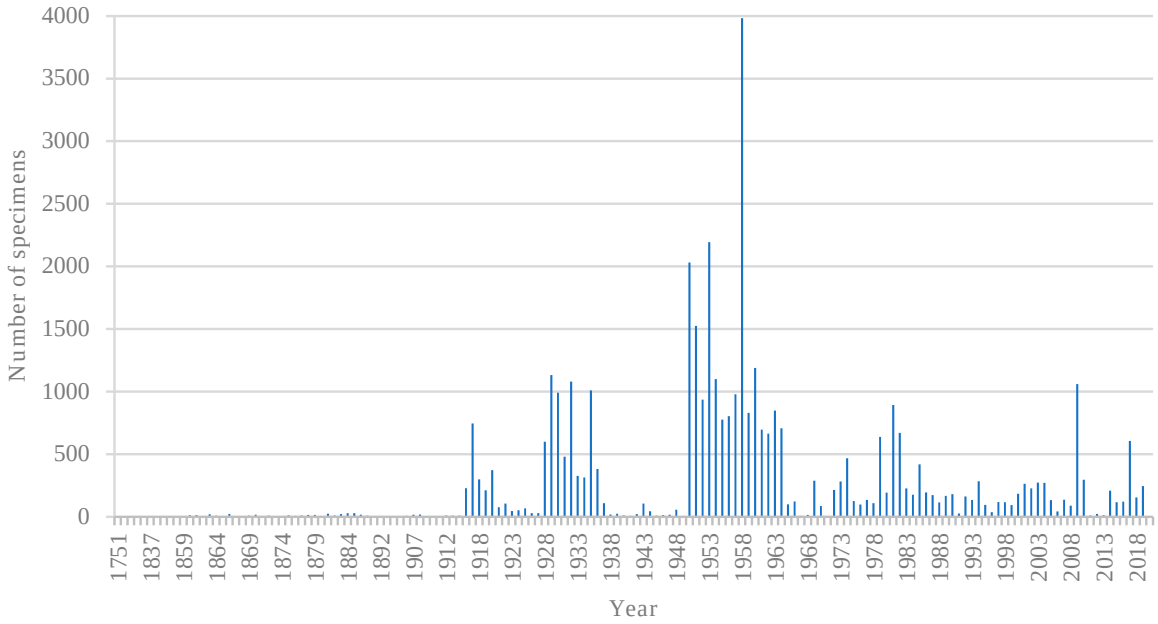


Figure 2. Variation in Yearly Specimen Collection Count in Guangzhou.

The collection of specimens in Guangzhou exhibits a predominant trend from March to November, with the highest collection rates observed from April to May and October to November. Conversely, there are fewer records during January and February. Excluding these two months, the number of specimens collected in other months exceeds 2000

(Figure 3). This pattern is closely intertwined with plant phenology, as specimens often require crucial identification features such as flowers or fruits. The flowering and fruiting stages of plants primarily occur in spring, summer, and autumn, making this period the peak season for specimen collection. In contrast, the relatively cold climate in Guangzhou during January and February results in fewer specimens with distinct characteristics, accompanied by a decrease in plant investigation activities. In general, specimen collection in Guangzhou remains active throughout the year.

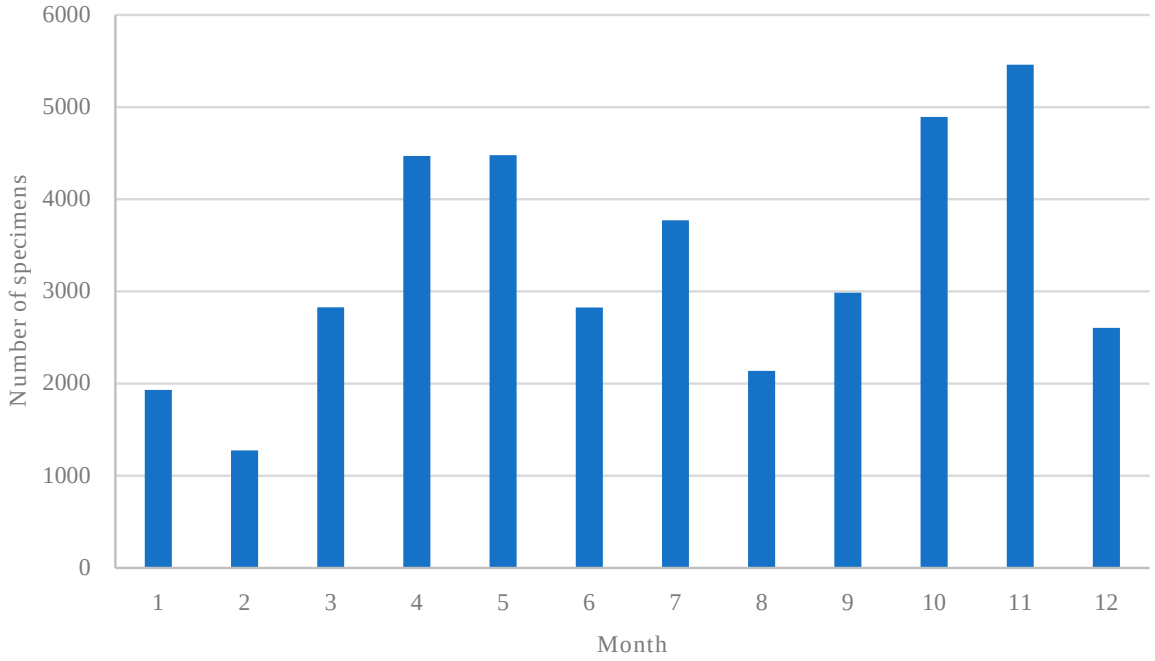


Figure 3. Variation in Monthly Specimen Collection Count in Guangzhou.

3.2. Taxonomic Diversity of Specimen Collection in Guangzhou

After conducting a thorough name check, a total of 41,890 records of vascular plant specimens were obtained. These records were identified at the species level, encompassing subspecies and cultivated plants. The dataset comprises specimen information for 4536 plant species belonging to 1563 genera and 248 families. Among the specimens, pteridophytes are represented by 28 families, 90 genera, 302 species, and 1761 records. Gymnosperms include 8 families, 30 genera, 83 species, and 1286 records. Angiosperms exhibit the highest diversity, with 212 families, 1443 genera, 4151 species, and 38,843 records (Figure 4). The families with the highest number of specimens include the Fabaceae, Poaceae, Myrtaceae, Asteraceae, and Rubiaceae (Figure 5). Similarly, the genera with notable collection records are *Eucalyptus*, *Ficus*, *Citrus*, *Litsea*, and *Bambusa* (Figure 6). Moreover, the species with the most collection records are *Litchi chinensis*, *Eucalyptus robusta*, *Cycas taiwaniana*, *Eucalyptus camaldulensis*, *Citrus maxima*, and others (see Figure 7).

Among the Pteridophyte specimens, the families Pteridaceae (368 specimens), Athyriaceae (170 specimens), Thelypteridaceae (155 specimens), Polypodiaceae (142 specimens), Dryopteridaceae (118 specimens), and others stand out as having the highest number of standardized specimens. Notably, *Adiantum flabellulatum* (66 specimens), *Palhinhaea cernua* (63 specimens), *Cyclosorus parasiticus* (58 specimens), *Deparia petersenii* (57 specimens), and *Pteris vittata* (55 specimens) represent the species with the largest number of specimens in the collection.

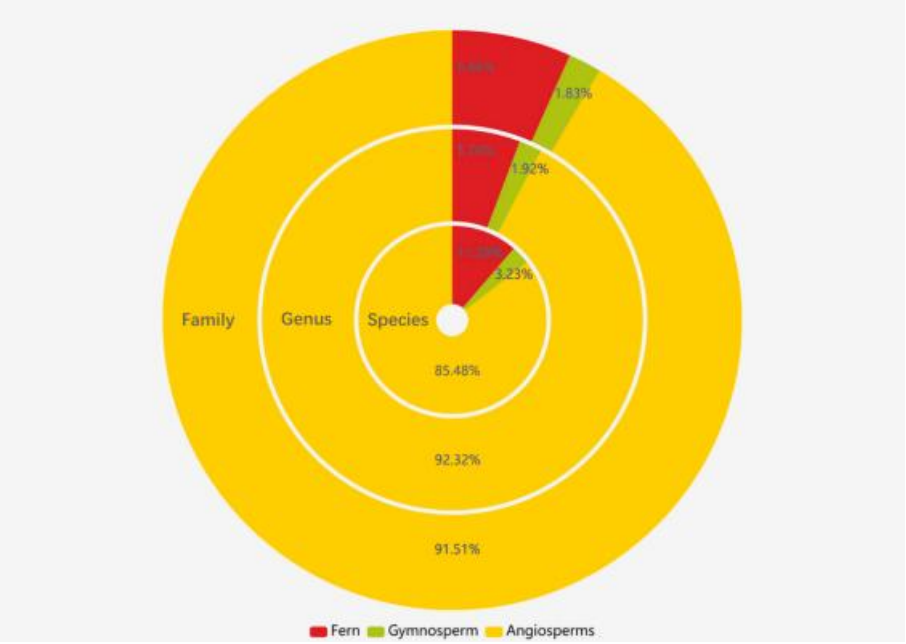


Figure 4. Distribution of vascular plant quantity of Guangzhou.

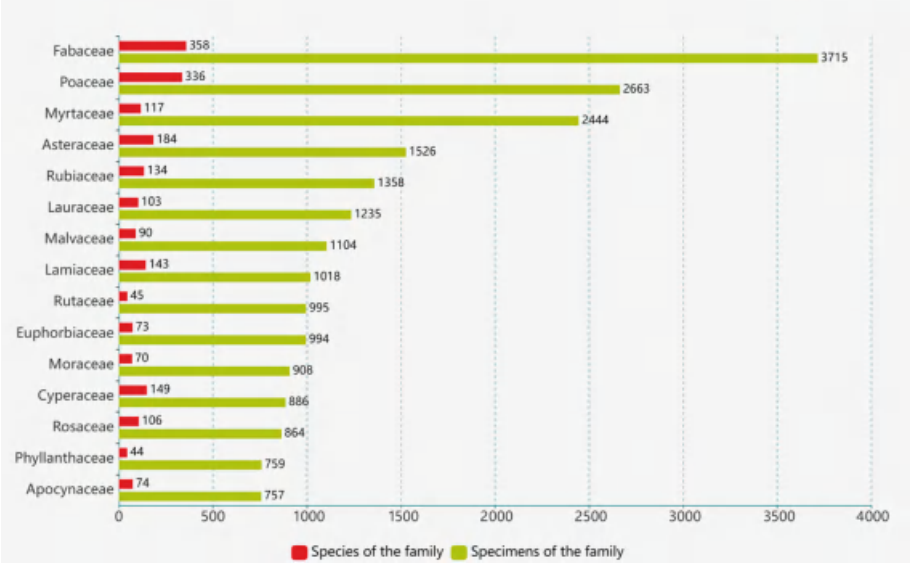


Figure 5. Major Families in the Digital Plant Specimens of Guangzhou.

Among the gymnosperm specimens, the greatest representation of collections are from the families Cupressaceae (420 specimens), Cycadaceae (419 specimens), Pinaceae (155 specimens), and Podocarpaceae (118 specimens). Notably, *Cycas taiwaniana* (162 specimens), *Cycas szechuanensis* (88 specimens), *Glyptostrobus pensilis* (83 specimens), *Pinus massoniana* (65 specimens), and *Cunninghamia lanceolata* (62 specimens) are the species with the highest number of specimens.

Among the angiosperm specimens, the families Fabaceae (3175 specimens), Poaceae (2663 specimens), Myrtaceae (2444 specimens), and Asteraceae (1526 specimens) are the most abundant in terms of representation. Notably, the genera *Eucalyptus* (1579 specimens), *Ficus* (682 specimens), and *Citrus* (466 specimens) have the highest number of collections at the genus level. Furthermore, species such as *Litchi chinensis* (222 specimens), *Eucalyptus robusta* (204 specimens), *Eucalyptus camaldulensis* (155 specimens), *Citrus maxima* (140 specimens), *Melastoma malabathricum* (132 specimens), *Litsea glutinosa* (124 specimens),

and *Cinnamomum burmanni* (121 specimens) exhibit the most abundant representation at the species level.

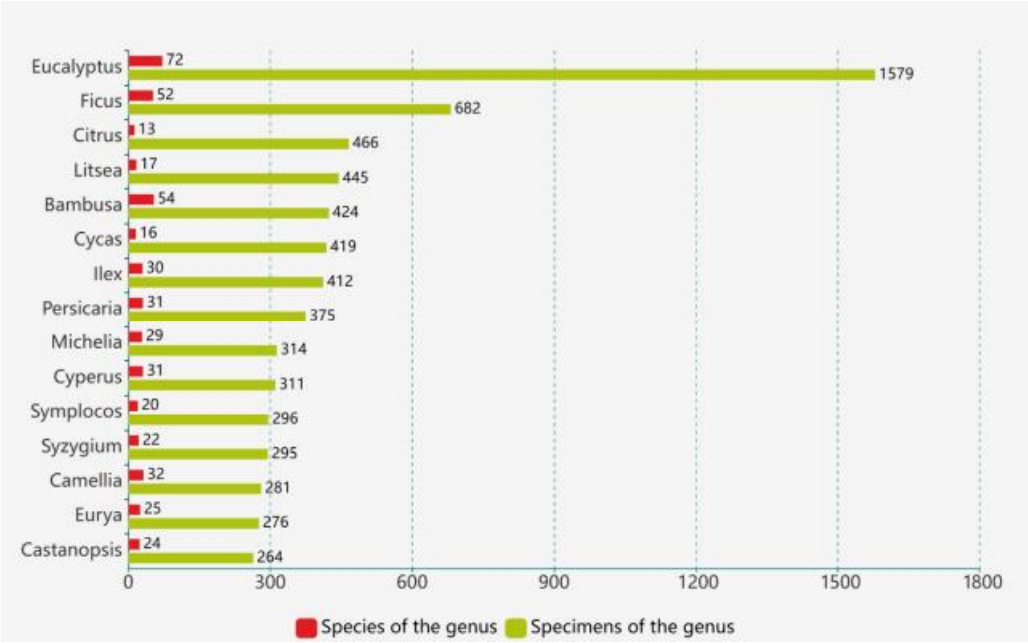


Figure 6. Major Genera in the Digital Plant Specimens of Guangzhou.

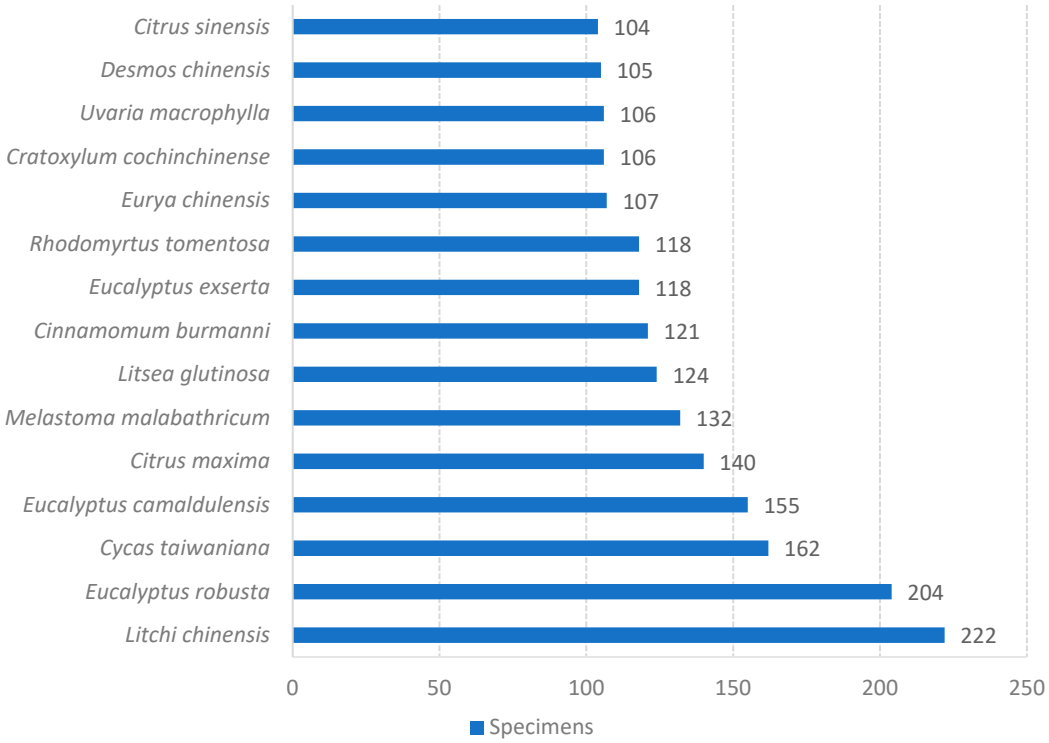


Figure 7. Species with more than 100 Specimens of Guangzhou.

In the entire collection of specimens, there are 53 families with fewer than 10 specimens and 9 families with only 1 specimen. Similarly, there are 791 genera with fewer than 10 specimens and 217 genera with only a single collection. Nearly three-quarters of the species have fewer than 10 specimens, with 1220 species represented by only one specimen, accounting for 26.89% of the total species, indicating a low representation. Taxonomic

groups or species with a higher number of specimens are often associated with a wider distribution range, making them more likely to attract the attention of collectors.

3.3. Analysis of the Diverse Utilization of Native Plants in Guangzhou Based on Specimens

Native plants are defined as plant species that naturally occur in specific regions without human intervention [10]. Based on the geographic distribution of vascular plants, they have been categorized into two distinct groups: native plants and exotic/cultivated plants. In Guangzhou, the database contains 2732 species of native plants, which accounts for 60.2% of the total plant species recorded, with a corresponding collection of 28,759 specimens. Conversely, there are 1804 species of non-native plants, accompanied by 13,131 specimens, representing approximately one-third of the total specimen count (Table 2).

Table 2. Collection of Native Plant Specimens in the Guangzhou.

	Ferns	Gymnosperms	Angiosperms	Total
Families	28	5	184	217
Genera	83	10	964	1057
Species	248	15	2469	2732
Specimens	1634	391	26,734	28,759

Plant resources encompass the flora that is accessible, potentially exploitable by humans, and also that which can be conserved and stewarded within the constraints of socioeconomic and technological circumstances. As the cultural hub of Lingnan, Guangzhou possesses a reservoir of traditional knowledge within the local populace concerning the management, conservation, and utilization of plant diversity. Native plants in Guangzhou have been categorized into eight distinct classifications based on their utilization methods and purposes: edible (starchy), medicinal, toxic, fodder (grazing grass/honey source), fiber, timber, ornamental landscaping, and oil (essential oil/resin/tannin). Empirical research findings exemplify the diversity of functional anthropocentric uses exhibited by indigenous plants in Guangzhou (Table 3). Examples encompass 269 species of edible (starchy) plants, 1395 species of medicinal plants, 67 species of toxic plants, 148 species of taxa used for fodder (grazing grass/honey sources), 109 species of fiber plants, 277 species of timber plants, 647 species of ornamental landscaping plants, and 193 species of oil/fat (or containing essential oil/resin/tannin) plants. Numerous plants in the region possess both nutritional and medicinal value, with 204 species concurrently exhibiting these dual attributes, presenting substantial potential for their horticultural or agricultural development and utilization.

Table 3. Main uses of native plants in Guangzhou.

	Ferns	Gymnosperms	Angiosperms	Total
Edible (Starchy)	10	2	257	269
Medicinal	142	10	1243	1395
Toxic	3	0	64	67
Fodder (Grazing grass/Honey source)	2	0	146	148
Fiber	1	3	105	109
Timber	0	12	265	277
Ornamental landscaping	63	13	571	647
Oil (Essential oil/Resin/Tannin)	0	9	184	193

3.4. Specimen Collection Sites in Guangzhou

Via verification and organization, a total of 18,916 specimen records containing detailed collection site information were obtained. Visualization of the collection site information reveals that the majority of the specimens were collected from the old outskirts of Guangzhou

and places such as Sanjiao Mountain in the Liuxi River of Conghua district (Figure 8). Due to the process of rapid urbanization, previously, suburban areas have been transformed into urban districts. Many of the historically suburban collection sites mentioned in the specimen records, such as Wushan, Shipai, Dongshan, and Kangle Village, now lie within a maze of high-rise buildings. Currently, there are more collection records from sites where vegetation is relatively well-preserved, such as Baiyun Mountain, South China Botanical Garden, and Longyandong Forest Park. Notably, a significant number of specimens were collected near roadsides. The distribution of collection sites provides valuable primary data for understanding the vegetation status and its history in the region and offers a reference for subsequent studies.

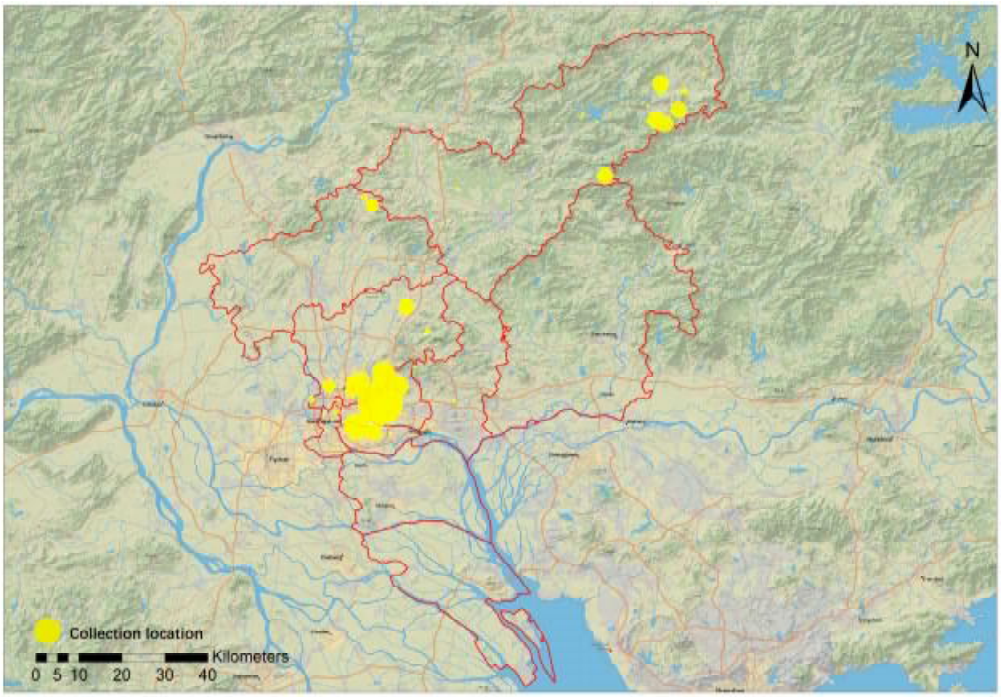


Figure 8. Distribution of the primary specimen collection sites in Guangzhou.

3.5. Major Herbaria in Which Relevant Collections Are Represented

Based on the currently recorded specimen data, the Herbarium of South China Botanical Garden, Chinese Academy of Sciences (IBSC), holds the foremost position with a collection of 13,829 plant specimens from Guangzhou city. The Plant Herbarium of South China Agricultural University (CANT) curates 3869 collections, and the Herbarium of Sun Yat-sen University (SYS) has 3654 specimens from Guangzhou. The British Museum of Natural History (BM), Muséum National d'Histoire Naturelle in France (NHMUK), Arnold Arboretum (A), New York Botanical Garden Herbarium (NY), Royal Botanic Garden Edinburgh Herbarium (E), and the Missouri Botanical Garden Herbarium (MO) also hold a substantial number of specimens collected from Guangzhou city (Table 4). The significance of these institutions' collections is closely intertwined with the historical establishment of their herbaria.

Table 4. A list of herbaria harbors more than 1000 specimens from Guangzhou.

Herbarium Name (International Code)	Specimens
Herbarium of South China Botanical Garden, Chinese Academy of Sciences (IBSC)	13,829
Plant Herbarium of South China Agricultural University (CANT)	3869
Herbarium of Sun Yat-sen University (SYS)	3645
Herbarium, Institute of Botany, Academia Sinica (PE)	3271
Herbarium of College of Life Sciences, South China Normal University (SN)	2471
Herbarium of Guangxi Institute of Botany (IBK)	1961
Herbarium of Kunming Institute of Botany, Chinese Academy of Sciences (KUN)	1806

3.6. Guangzhou Municipal Type Specimen Examination

Based on the compiled specimen data and literature information, statistical analysis was conducted on the type specimens of vascular plants collected from Guangzhou, resulting in a catalog of type specimens of vascular plants from Guangzhou. A total of 509 type specimen records were compiled, of which only 185 specimens clearly indicate the type categories, while the remaining specimens either state "Type" or do not specify the categories (Table 5). A total of 332 species, belonging to 95 families and 231 genera, are represented by type specimens collected in Guangzhou. Families to which the type specimens belong include the Poaceae (32 species, 42 specimens), which has the highest representation, followed by Lauraceae (25 species, 42 specimens) and Euphorbiaceae (21 species, 24 specimens). The Phyllanthaceae also had a relatively large number of type specimens, with 20 species and 26 collections. In terms of the number of type specimens held by herbaria, the British Museum of Natural History (BM) ranked first with 115 specimens, followed by the Herbarium of South China Botanical Garden, Chinese Academy of Sciences (IBSC), which housed 66 specimens. More than 2/5 of the type specimens were stored in foreign herbaria or museums. Regarding the collection years and collectors, the highest number of type specimens were collected by Yongquan Li, who collected 29 species between 2005 and 2007. F.A. McClure collected 25 species in the 1930s, followed by W.T. Tsang, with 21 species in 1932 and 1935, and Yourun Lin, who collected 21 species in 1960–1961. Additionally, Millett, Charles, H.F. Hance, and C.O. Levine also contributed a significant number of collections. In terms of the original publications where the type specimens were described, the primary journals and monographs include the Journal of Botany, British and Foreign (40 species), Philippine Journal of Science (27 species), The Botany of Captain Beechey's Voyage (22 species), Species Plantarum (21 species), and Acta Phytotaxonomica Sinica (18 species). These types of specimens and their data provide fundamental information for biodiversity research in Guangzhou city.

Table 5. Categories of Type specimens in Guangzhou.

Categories	Number
/	152
Type	169
Isotype	95
Holotype	34
Syntype	30
Paratype	9
Lectotype	6
Isoneotype	4
Neotype	4
Typus	3
Isosyntype	2
Isolectotype	1

4. Brief History of Plant Collection in Guangzhou City and Its Surroundings

As the cultural center of Lingnan and the sole port for foreign trade during the Qing Dynasty, Guangzhou holds significant importance in the study of Chinese plant taxonomy. Given that plant taxonomy is a product closely aligned with human societal development, this article aims to organize and provide a concise supplement to the botanical collection history of Guangzhou in chronological order by analyzing specimens and reviewing relevant literature while considering the developmental stages of Chinese society and beginning with the year 1949 the date of the establishment of the People's Republic of China. The botanical collection history of Guangzhou city can be divided into two distinct periods. The first period extends from the late 13th century up until 1949, primarily characterized by the collection activities of foreigners in Guangzhou and the pioneering phase of Chinese plant taxonomy research. The second period encompasses the time from 1949 to the present, primarily focusing on the extensive investigations and collection activities carried out by Chinese scholars independently in relation to indigenous plant resources [11].

4.1. History of Plant Collection in Guangzhou before 1949

4.1.1. The Contribution of Westerners to the Plant Collection History of Guangzhou

Before the Opium Wars (1839 and 1856), the scope of activities for Westerners in China was very limited, especially after 1757, when Guangzhou became the sole port for foreign trade. Consequently, the plant collection areas for plant collectors were confined to the southeastern coastal region, primarily centered around Guangzhou. Before the mid-18th century period, individuals such as missionaries (including those associated with the court) and diplomatic envoys who engaged in plant collection endeavors in Guangzhou were not specialized botanists. Nonetheless, they had received exceptional education in the humanities and languages, enabling them to engage in exchanges with the imperial court, scholars, and various societal strata in China. Plant collection activities were ancillary to cultural and religious communication, with specialized endeavors in plant collection being relatively scarce. From the latter half of the 18th century onwards, numerous nations began dispatching plant hunters to Guangzhou for the purpose of botanical collection. Most of the plant hunters underwent specialized training in the fields of botany and horticulture and were employed by European scientific establishments, botanical commercial networks, East India companies, and other analogous institutions. Their motivations were driven by both commercial interests and the acquisition of knowledge, with cultural exchange playing a less prominent role. Although most of them engaged only in scattered collection activities in Guangzhou, influential collectors emerged among them, opening the door to understanding Chinese plants for the world. Portuguese missionary J. Loureiro developed an interest in plants during his missionary work in southern China in 1743. In 1779, he spent three years in Guangzhou collecting and studying plants, and upon his return to Portugal in 1782, he published the *Flora Cochinchinensis* [12], which included 539 species of Chinese plants. P. Osbeck, a student of Carl Linnaeus, arrived in Huangpu, Guangdong, on a Swedish East India Company merchant ship in August 1751. He collected plants in the port city for four months, obtaining 244 species with 438 collections. He later gave his collections to Linnaeus, who described 37 species based on Osbeck's specimens in Species Plantarum. Osbeck himself described 21 new species, including the new genus *Osbeckia* L. and the new species *Clematis chinensis* Osbeck. To further expand commercial opportunities in China, the United Kingdom dispatched diplomatic missions to the country in 1792. Since then, the recorded collection has shown a significant increase in the number of British collectors. Among them, J. Reeves of the British East India Company, who served as a tea inspector in Guangzhou from ca. 1812 to the 1840s, collected a large number of botanical specimens and sent them to relevant experts and societies in Britain during his nearly 20-year stay in China. Additionally, he introduced a large number of garden plants from the outskirts of Guangzhou to Britain, earning great respect from the British scientific community [13]. German naturalist F.J.F. Meyen collected as many as 244 plant specimens

(preserved in Berlin) during his voyage on the Prinz ship from 1830 to 1832, including *Clematis meyeniana* Walp., during his time in Guangzhou (Figure 9).

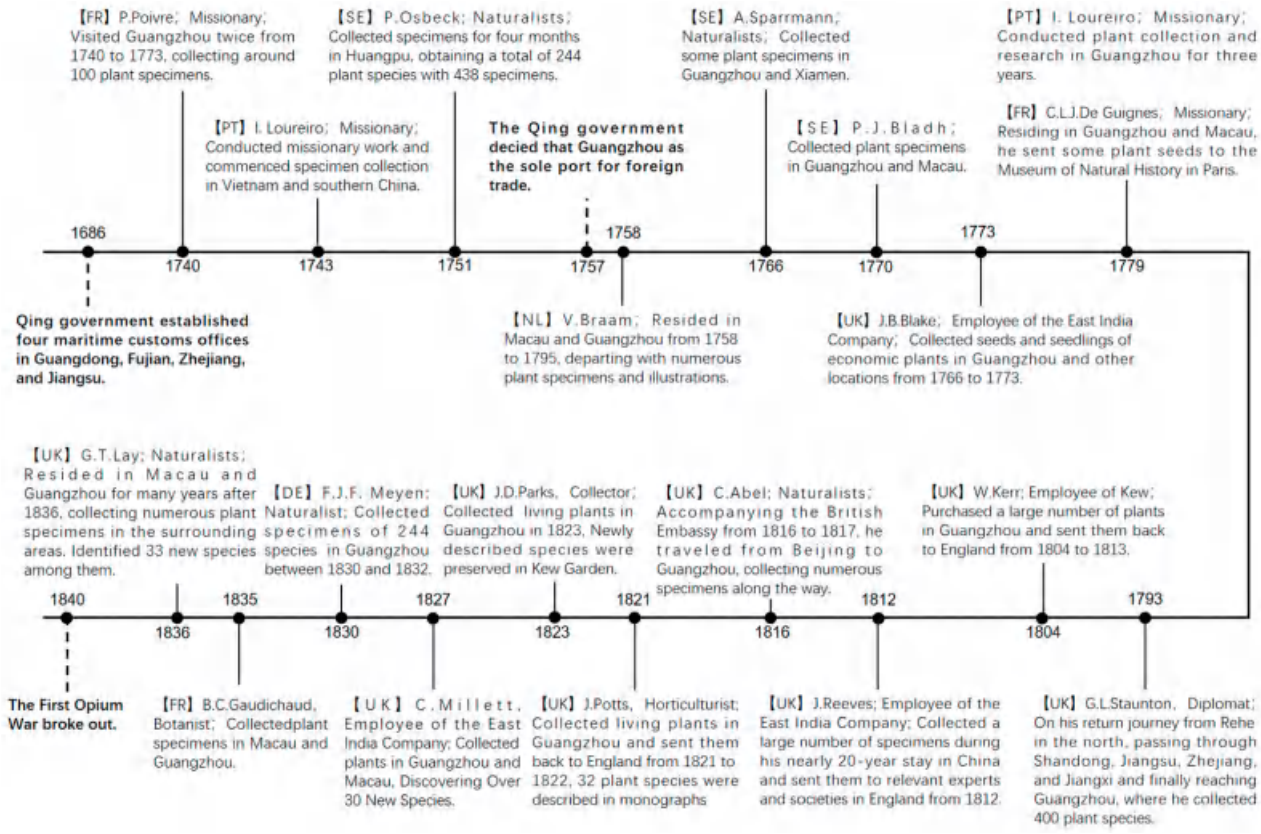


Figure 9. Collection History of Westerners in Guangzhou before the First Opium War. Boldface characters represent historical events. DE = Germany, FR = France, NL = Netherlands, PT = Portugal, SE = Sweden, UK = United Kingdom.

After the Opium War, China initiated the process of territorial cession, compensation, and tariff negotiations with foreign powers. This period witnessed China's transformation into a semi-colonial and semi-feudal society, resulting in the erosion of its independent status. Concurrently, Westerners gradually gained unrestricted mobility within China, facilitating their unrestricted travel throughout mainland China. Capitalizing on this exceptional opportunity, Western individuals were dispatched to China not only to introduce valuable plant resources but also to undertake botanical investigations in accessible cities and their surrounding environments. Among these individuals, H.F. Hance, the British Consul in Huangpu, emerged as a notable figure. Combining his roles as a British diplomat and a plant taxonomist, Hance actively engaged in the extensive collection of plants in southern China, playing a pioneering role in botanical collection endeavors. Joining the Guangzhou Consulate in 1856, he subsequently resided in Huangpu, Guangzhou, for 25 years after his arrival in Xiamen in 1857. Hance succeeded in persuading numerous Westerners residing in China to assist him in procuring plant specimens, resulting in the establishment of a substantial collection network that encompassed individuals such as F. Parry, R.J.C. Nevin, E.H. Parker, T. Sampson, H. Wawra, and others [13]. Between 1843 and 1857, Dr. M. Yvan from the French Embassy in China undertook an extensive collection of plant specimens in Guangzhou and its nearby areas, organizing local individuals to participate in the collection efforts, and a total of 850 species of specimens (excluding ferns) were amassed during this period (Figure 10).

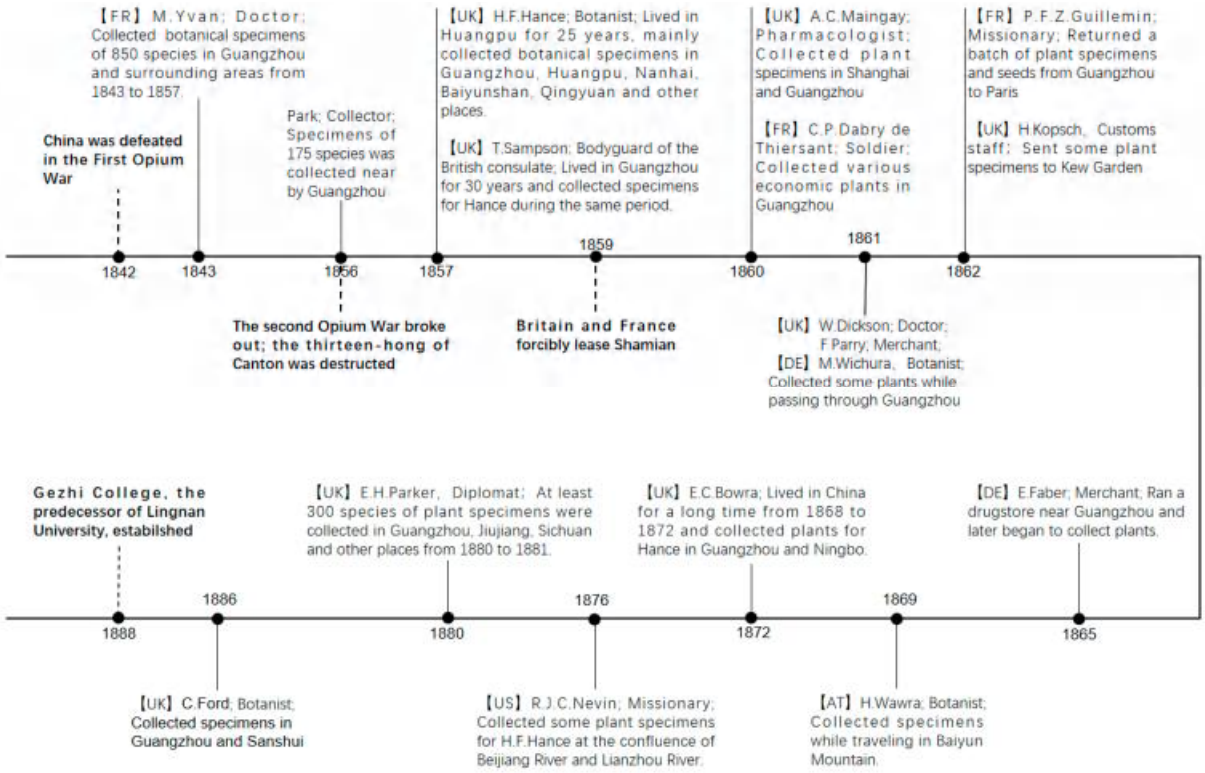


Figure 10. Collection History of Westerners in Guangzhou after the First Opium War. Boldface characters represent historical events. AT = Austria, DE = Germany, FR = France, UK = United Kingdom, US = United States.

Influenced by botanical collection activities conducted by Britain, France, and other countries, the United States embarked on its own collection endeavors in China. During the early 20th century, a large-scale agricultural missionary movement was carried out by the United States. The American government invited experienced plant hunters and botanists to conduct extensive collection activities in China. Many American scholars carried out their botanical research and plant specimen collection in Guangzhou, with Lingnan University serving as their primary base of operations. E.D. Merrill, a renowned botanist and Dean of the School of Agriculture at the University of California, USA, is among the most distinguished scholars in the field of Chinese plant studies. He arrived in Guangzhou in 1916 and led a group of teachers and students from Lingnan University to collect numerous specimens in the vicinity of Guangzhou, Huangpu, and Luofu Mountain. These collections later formed the foundation of Lingnan University's specimen room [13]. Another significant scholar is George W. Groff. In 1916, the Agronomy Department of Lingnan School was established, with Groff serving as its director, and oversaw the collection of plant specimens in Guangzhou and Guangxi. An American botanist named F.A. McClure, also known as Mo Guli in Chinese, taught at Lingnan University for many years. Beginning in 1924, he dedicated three consecutive years to collecting bamboo specimens in Guangdong and Guangxi, delving into bamboo research. During this period, McClure visited various districts in Guangzhou city, including Baiyun, Haizhu, Huangpu, and Liwan, and established the Lingnan Bamboo Garden on the campus of Guangzhou Kangle Lingnan University (now known as Sun Yat-sen University). From 1929 to 1938, many specimens of bamboo and other plants were collected by McClure in different districts of Guangzhou (Figure 11).

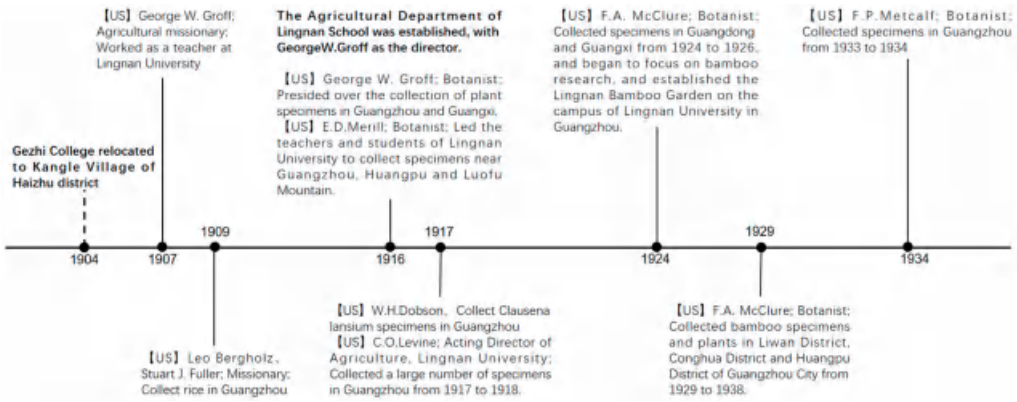


Figure 11. Collection History of Westerners in Guangzhou after 1900. Boldface characters represent historical events. US = United States.

The endeavors of plant collectors traversing the lands of China and successfully transporting plants to the West via Chinese Customs are intricately linked to the protection and advancement of Western powers in China. This symbiotic relationship between foreign plant collection and the expansion of Western influence in China underscores the unique context of species migration during this period. The impact of foreign collectors' plant collection efforts in Guangzhou, in particular, has been substantial. Over 30 individuals from eight different countries have amassed and exported a significant number of Chinese plant specimens from Guangzhou, including seeds, underground stems, roots, and live plants. Consequently, a vast collection of China's earliest plant specimens, including type specimens, now reside abroad, with the majority of identifications being conducted by foreign experts. This inevitably led to the initial dissemination of a considerable amount of botanical literature abroad. Furthermore, the introduction of numerous economic plants from Guangzhou has facilitated their dissemination to various regions across the globe. Firstly, ornamental plants, including flowers, hold a prominent position. Guangzhou, renowned as the "Flower City," boasts a flourishing flower horticulture industry. Prior to the Opium War, the southeastern outskirts of Guangzhou featured a sizable garden area known as Flower Land, which served as a prominent trading hub for flower seedlings and bonsai. Consequently, among the early Western introductions of garden plants, flowers from Flower Land constituted a significant proportion. Secondly, fruit trees also played a vital role. As early as the first half of the 16th century, the Portuguese brought high-quality sweet oranges from China back to Lisbon for cultivation as fruit trees. Another highly sought-after plant was tea. Swedish botanist A. Sparrmann collected over 20 plant species, including rice, camellia, and oranges, from the coasts of Guangdong and Macao. In 1780, ships of the East India Company transported a small quantity of tea from Guangzhou to India for cultivation, marking the first instance of tea cultivation in India. By 1820, China's tea exports accounted for three-quarters of its overall exports. In that year, the value of Guangzhou's export trade to Britain and the United States amounted to 13,616,691 yuan, with tea contributing 8,757,471 yuan [14].

4.1.2. Collection History of Chinese Scholars in Guangzhou

Before the Opium War, numerous foreigners arrived in China to explore and collect plants, while they did not impart modern plant taxonomy to the Chinese. Following the signing of the Treaty of Nanjing in 1842, Western culture began to make its way into China. Nonetheless, throughout the 19th century, the Chinese did not actively engage in the collection and research of modern plant taxonomy. It was not until the early 20th century that significant strides were made in this field. From the early 20th century until 1949, pioneers of plant taxonomy in China embarked on extensive specimen collection efforts and conducted preliminary botanical research.

K.K. Tsoong was the first Chinese scholar to systematically investigate and collect higher plants using scientific methods. His collection of plant specimens from 1918 to 1921 marked the inaugural large-scale collection effort undertaken by Chinese scholars. He selected collection sites that were pivotal for foreign collectors, including Guangzhou, Fuzhou, Xiamen, and others. These collections provided Chinese scholars with firsthand data for comprehending the distribution of vegetation in China, particularly in the southern regions [15]. In 1918, botanist W.T. Swingle employed W.S. Kwok, a graduate of Lingnan University, as an assistant to aid in surveying the resource distribution of wild citrus in the Lingnan area [16]. During this period, W.S. Kwok amassed a significant number of citrus specimens. In 1927, Chen Huanyong joined Sun Yat-sen University as a professor. That year, he conducted specimen collection expeditions to northern Guangdong, Guangzhou, Dinghushan, Hong Kong, Guangxi, Guizhou, and other locations. Through his diligent efforts, the Agricultural College of Sun Yat-sen University established the first professional herbarium in South China in 1928. Subsequently, the Plant Research Office of Sun Yat-sen University (later renamed the Institute of Agricultural and Forestry Plant of Sun Yat-sen University) was established, which served as the precursor to the current South China Botanical Garden of the Chinese Academy of Sciences. With the objective of compiling the Guangdong Flora, a four-year plant collection plan for Guangdong Province was formulated by Chen Huanyong. According to the initial five-year report of the Institute of Agriculture, Forestry, and Plants of National Sun Yat-sen University in 1934, collection teams were dispatched to Hainan Island, Hong Kong, and Guangdong 109 times between 1927 and 1933. Following the establishment of the Plant Research Laboratory in 1928, the collection work was primarily undertaken by Y.Tsiang and C.L.Tso. As the institute expanded, the team size grew, with notable collectors including Y.Tsiang, C.L.Tso, N.K.Chun, C.Wang, S.P.Ko, F.C.How, and others (Table 6). This period marked the transition to large-scale collection efforts, with numerous specimens being gathered in Guangzhou between 1928 and 1936 by these collectors and their teams [17].

Table 6. Main Chinese collectors before 1949.

Year	Collector	Collection Site
1918–1919	K.K.Tsoong = Guanguang Zhong	Baiyun Mountain
1919–1920	W.S. Kwok = Huaxiu Guo	Panyu
1929	C.L.Tso = Jinglie Zuo	Baiyun Mountain
1930	N.K.Chun = Nianqu Chen	Near Longan Cave
1929–1930	C.Wang = Zhi Wang	Baiyun Mountain, Longan Cave
1930	S.P.Ko = Xipeng Gao	Baiyun Mountain
1930	H.Y.Liang = Xiangri Liang	Baiyun Mountain
1927–1931	W.Y.Chun = Huanyong Chen	Near Longan Cave, Lingnan University (near Kangle Village, Haizhu District)
1930–1931	C.P.Lau = Zhuobin Liu	Near Dongshan, Sun Yat-sen University
1932, 1935	W.T.Tsang = Huaide Zeng	Conghua Sanjiao Mountain, Zengcheng
1928–1929, 1935–1937	Y.Tsiang = Ying Jiang	Conghua, Near Longan Cave, Baiyun Mountain
1937	S.Wang = Xiao Wang	Yuexiu
1937	S.K.Liou = Xinqi Liu	Panyu
1934, 1943–1944	F.C.How = Kuanzhao Hou	Baiyun Mountain

4.2. History of Plant Collection in Guangzhou after 1949

After the establishment of the People's Republic of China, the investigation, collection, and research of plant resources in the country entered a highly dynamic phase charac-

terized by unprecedented scale and diverse forms and contents of activities. In 1958, a Sino-German expedition jointly organized by the Chinese Academy of Sciences and the German Democratic Republic conducted specimen collection in Conghua. Subsequently, in 1959, in line with the directives outlined in the report on the comprehensive survey and utilization of wild economic plant resources and the compilation of economic flora by the Chinese Academy of Sciences and the Ministry of Commerce, a nationwide general survey of wild economic plant resources was initiated. The South China Institute of Botany participated in the investigation of Guangdong and Hunan provinces. The primary investigation site in the Guangzhou area was Conghua, and the collector assigned to this region was Shaoqing Chen. In the 1970s, a nationwide campaign was launched to investigate the resources of Chinese herbal medicine. The investigation in Guangdong involved the participation of several dozen personnel from the South China Institute of Botany of the Chinese Academy of Sciences. In Guangzhou, collection activities were conducted by the Chinese Herbal Medicine Group, Guangzhou Medicine Group 1, Guangzhou Medicine Group 2, and other teams. In 2004, the Guangzhou Forestry Bureau officially initiated a comprehensive background survey of terrestrial wildlife resources in Guangzhou, which spanned nearly four years. This survey represented the most extensive and systematic assessment of terrestrial wildlife resources since the establishment of the People's Republic of China. During this period, over 1500 plant specimens were collected, contributing to a comprehensive understanding of the status of terrestrial wildlife resources in Guangzhou [18]. In 2009, the research project on the status of rural fengshui forests and zonal vegetation restoration in the nature conservation community in Guangzhou was initiated. Led by Zhengchun Xu from the School of Forestry and Landscape Architecture at South China Agricultural University, a comprehensive survey was conducted throughout Guangzhou. A total of 12,200 plant specimens were collected, with voucher specimens deposited in the Herbarium of the South China Botanical Garden of the Chinese Academy of Sciences (IBSC) and the Herbarium of South China Agricultural University (CANT) [19]. In addition to the aforementioned major national or regional survey and collection activities, numerous small-scale collection initiatives have taken place involving researchers such as Huang Zhi, Chen Shaoqing, Deng Liang, Ye Huagu, and others (Table 7) [9]. Furthermore, academic institutions in Guangzhou, including South China Normal University and South China Agricultural University, regularly lead students in collecting samples within the city. The information derived from these collected specimens serves as a foundational basis for biodiversity studies in Guangzhou.

Table 7. Main collectors/collection teams after 1949.

Year	Collector/Collection Team	Collection Site
1948–1955, 1959–1960, 1962–1963, 1964–1988	Shaoqing Chen	Shipai, Baiyun Mountain, near Kangle village, Lvtian, and other places near Guangzhou
1950–1951	Yunzhang Gao	All over Guangzhou
1951–1957	Kuanzhao Hou	Around Guangzhou
1951	Hongda Zhang	All over Guangzhou
1951	Zhengyi Wu	All over Guangzhou
1951, 1953–1954	Baohan Liang	Guangzhou
1954–1956, 1958, 1963	Cheng Huang	Huadu, The old suburbs of Guangzhou (Baiyun Mountain)
1955–1958, 1963	Chengjiu Huang	Huadu
1956–1957	Yingguang Liu	The old suburbs of Guangzhou
1957, 1959	Wantao Lin	Conghua, Panyu
1958–1959	Sino-German collection team	Conghua

Table 7. *Cont.*

Year	Collector/Collection Team	Collection Site
1958–1959, 1961–1964	Liang Deng	Conghua, The old suburbs of Guangzhou (South China Botanical Garden, Baiyun Mountain and other places)
1958	Zhi Huang	Conghua
1958	Zhaofen Wei	Zengcheng
1960–1961	Yourun Lin	Conghua
1960–1961	Mengzhen Li	Conghua
1961–1963	Ying Jiang	Around Guangzhou
1969–1970	Chinese herbal medicine group	The old suburbs of Guangzhou (Longan Cave, Huolu Mountain and other places)
1973	Xianrui Luo	Huadu
1979–1981, 2002, 2009	Huagu Ye	South China Botanical Garden, Conghua,
1981–1982	Fuwu Xing	South China Botanical Garden and nearby
1981–1982	Binghui Chen	South China Botanical Garden and nearby
2000–2008	Shijin Li	Huadu, Conghua, and other places
2001–2002	Yuehong Yan	Near Longan Cave
2002, 2004, 2005, 2009	Shixiao Luo	Guangzhou
2004	Bingqiang Xu	South China Botanical Garden
2005–2007	Shiyong Dong	All over Guangzhou
2009	Yushi Ye	All over Guangzhou

5. Discussion

The digitization of specimens serves multiple purposes in botanical research and related fields. It not only provides objective, comprehensive, and accurate data but also mitigates the risk of losing crucial information regarding habitat, ecology, geography, and other vital aspects due to specimen destruction. To ensure the meticulous digitization of specimen information, it is essential to maintain detailed and precise records and exercise caution during label recording, identification, and input of specimen data [20]. Although efforts have been made to standardize existing digital specimen information, this study reveals numerous errors and omissions in the current dataset. Examples of these discrepancies include inconsistencies between website and webpage data and specimen photos, data entry errors, blurry images, and disordered collection team or individual names. There are observed variations in the number of specimens collected across different seasons, particularly during the months of January and February. This discrepancy can be attributed to several factors, including the lower temperatures during this period, making field collection more challenging. Additionally, the occurrence of the Lunar New Year, a significant cultural holiday in the region, may lead to reduced collection efforts as researchers and collectors may have less availability or engagement during this time. Furthermore, there is a lack of uniformity in data entry standards across different data-sharing platforms. Consequently, the full potential of existing digital information remains unrealized. It is important to note that the majority of digital specimen information available in open network databases predominantly consists of data collected many years ago, with limited representation of recent years.

Despite numerous plant collection activities conducted in Guangzhou, a majority of collection sites are concentrated in easily accessible areas such as Longyan Cave, Baiyun Mountain, Sanjiao Mountain, and botanical gardens. Further, the plant habitats sampled are often in close proximity to roadsides or within the confines of these gardens. The existing

report shows that Guangzhou has various vegetation types, rich species composition, and complex community structure, with tropical and subtropical families such as Theaceae, Fagaceae, Moraceae, Lauraceae, Euphorbiaceae, and Rubiaceae as the dominant families. However, in the existing digital specimen data, the number of specimens of Theaceae, Fagaceae, Moraceae, and other plant families is much smaller than that of Poaceae, Myrtaceae, and Asteraceae [21]. The frequency of plant collections varies significantly among different species in Guangzhou, with some species having over a hundred recorded specimens. However, for 238 genera and 1222 plant species, there is only one recorded specimen. Several potential reasons may assist in explaining this disparity. Some of the genera, such as *Carex*, *Machilus*, and *Bambusa*, present challenges in terms of identification, which may result in a smaller number of collected and identified specimens for species within these genera. Secondly, there is a possibility of identification errors. Thirdly, some species may have incorrect collection location information [22]. Lastly, it may be because the habitat of some plants is dangerous, or the height under the branches of some plants is too high, which makes it difficult to collect specimens, so the number of specimens in some families is small.

Type specimens play a fundamental role in establishing the scientific names of plants. However, organizing, verifying, and digitizing these specimens still presents certain challenges. Various issues arise during the textual research and organization of type specimens. For instance, early type specimens often lack specific designations, merely indicating "Type" without specifying the particular type to which it refers. Currently, only 332 type specimens collected from Guangzhou can be found in commonly accessible databases. This limited number may be attributed to difficulties in obtaining information on overseas specimens and the incomplete digitization of domestic specimens.

6. Suggestions and Recommendations

Via the comprehensive organization and analysis of digital specimen data in Guangzhou, we have identified certain shortcomings in specimen collection practices. These findings provide valuable insights for future collection efforts. It is crucial to maintain detailed and accurate original records during the specimen collection process, as they serve as vital evidence for subsequent research. Therefore, adopting a standardized format for data entry is essential to ensure the precision of specimen data. Furthermore, it is imperative to incorporate additional specimen data from recent years to enhance the comprehensiveness of the digital collection. The advent of digital imaging has facilitated the integration of Guangzhou collections into national and international herbarium databases, thereby enabling seamless collaboration among researchers. The utilization of imaging techniques also allows for the assessment of phenological attributes, such as flowering time and other phenological characteristics. These data are invaluable for studying the impacts of climate change over time, as evidenced by observed shifts in phenological patterns. This emerging research domain has garnered international attention, with notable examples including the California Phenology Project and herbarium-based studies conducted within the California Consortium of Herbaria [23–25]. Consequently, it is imperative to expand the collection of plant specimens across various seasons, as this will further enrich the knowledge base and enhance the scope of research in this field. Further, particular attention should be given to species and taxa with limited representation in the digital records. Species with insufficient digital records should undergo re-identification annotation or have their information carefully reviewed. If the re-identification process aligns with the existing digital information, it is necessary to prioritize the collection of additional specimens for such species. Conversely, taxa with an excessive number of specimens should be subject to reduction or cessation of collection efforts. Additionally, locations with few collections of specimens but rich vegetation should be targeted for supplementary re-collection activities. Lastly, it is crucial to emphasize the collection of type specimen data stored abroad. Further in-depth research is warranted to explore and investigate type specimens in greater detail. Overall, these recommendations aim to optimize future

collection work, enhance the accuracy and comprehensiveness of the digital specimen database, and promote a more robust understanding of plant resources in Guangzhou.

7. Conclusions

Guangzhou boasts abundant plant species resources, indicating significant potential for further development and utilization. Moreover, Guangzhou's significant trading history adds to its prominence as a leading area for plant collection research in China. It has been reported that the total number of wild vascular plant species in Guangzhou is documented to be 3508, a figure that aligns with the digital specimen data available for the region, excluding cultivated species [21]. Despite the progress made in specimen collection, there are still several shortcomings that require individual attention and resolution by scholars. Addressing them will contribute to improving the overall quality and effectiveness of specimen collection efforts.

Author Contributions: M.L. conceived the ideas and wrote the manuscript; X.Q. revised the final text. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Forestry Science and Technology Innovation Project of the Guangdong Forestry Bureau (GDZZDC20228703).

Data Availability Statement: The raw data that support the findings of this study are from public databases, such as the CVH (https://www.cvh.ac.cn/, accessed on 13 June 2023), the GBIF (https://www.gbif.org/, accessed on 1 July 2023), the Global Plants on JSTOR (https://plants.jstor.org/, accessed on 25 June 2023) and NSII (http://www.nsii.org.cn/2017/query.php?kingdom=plant, accessed on 9 June 2023).

Conflicts of Interest: The authors declare no conflict of interest.

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ISSN 0479-8023
CN 11-2442/N
CODEN PCTHAP

北京大学学报

自然科学版

ACTA SCIENTIARUM NATURALIUM UNIVERSITATIS PEKINENSIS

第59卷 第6期
2023

北京大学学报（自然科学版）
第五十九卷（卷终） 第六期
二〇二三年十一月

北 京 大 学 学 报

(自 然 科 学 版)

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2023 年 11 月 20 日出版　　本期责任编辑　李亚文　张树宇　尉立肖

ACTA SCIENTIARUM NATURALIUM UNIVERSITATIS PEKINENSIS

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Published on Nov. 20, 2023

北京大学学报(自然科学版) 第 59 卷 第 6 期 2023 年 11 月
Acta Scientiarum Naturalium Universitatis Pekinensis, Vol. 59, No. 6 (Nov. 2023)
doi: 10.13209/j.0479-8023.2023.095

基于 CiteSpace 的萝芙木属植物研究知识图谱可视化分析

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摘要 为了解萝芙木属植物在中医药领域的研究热点和前沿方向, 通过检索中国知网(CNKI)和 Web of Science 数据库中 2002—2022 年萝芙木属植物的化学成分、药理活性和临床应用等相关研究文献, 利用 CiteSpace 6.1. R6 软件绘制萝芙木属植物研究的知识图谱, 对发文量、作者、研究机构和关键词等进行可视化分析。共筛选纳入中文有效文献 173 篇, 英文有效文献 356 篇, 结果显示年发文量总体上呈波动上升趋势。中、英文文献发文量最多的作者分别为曹福祥和 Stockigt J, 发文量最多的机构分别为中南林业科技大学和 Johannes Gutenberg-Universität Mainz。关键词分析结果显示, 萝芙木属植物的研究方向集中于萝芙木属植物的栽培种植和化学成分的提取鉴定及其药理活性的分析, 其中中文文献侧重于萝芙木属植物的培育, 英文文献侧重于异胡豆苷合酶等化学成分的提取鉴定和各类化学成分药理活性中的抗菌、抗氧化作用。萝芙木属植物的化学成分及其药理活性的深入研究与临床应用实践是未来主要发展趋势。

关键词 萝芙木属; 文献计量学; 药理活性; 研究趋势

Visualized Analysis of Knowledge Map for Research on the Plants of *Rauvolfia* Based on CiteSpace

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Abstract In order to understand the research hotspots and frontier directions of *Rauvolfia* in the field of traditional Chinese medicine, the literature about chemical composition, pharmacological activity and clinical application were searched in CNKI and Web of Science databases. CiteSpace 6.1.R6 was used for authors and research institutions co-occurrence, keyword co-occurrence, keyword clustering and keyword timeline mapping and analysis. A total of 173 effective Chinese articles and 356 effective English articles were included, and the annual number of articles showed a fluctuating upward trend overall. The authors with the most publications in Chinese and English were CAO Fuxiang and Stockigt J, respectively. The institutions with the most publications were Central South University of Forestry and Technology and Johannes Gutenberg-Universität Mainz, respectively. The analysis of keywords showed that the research direction of *Rauvolfia* mainly focused on cultivation, chemical composition extraction, identification and pharmacological activity analysis. Chinese literature focused on the cultivation of various *Rauvolfia*. English literature focused on the extraction and identification of strictosidine synthase and other chemical components, as well as the antibacterial and antioxidant effects of pharmacological activities of various chemical components. How to rationally use the chemical components of *Rauvolfia* and study their pharmacological activities and clinical applications are the main trends in the future.

Key words *Rauvolfia*; bibliometrics; pharmacological activity; research trends

广东省林业局林业科技创新项目(GDZZDC20228703)资助
收稿日期: 2023–06–09; 修回日期: 2023–08–13

萝芙木属(*Rauvolfia*)隶属夹竹桃科(Apocynaceae), 多为有乳胶的乔木或灌木[1], 主要分布于热带美洲、非洲、亚洲南部和东南部以及大洋洲, 全世界约有 60 种, 其中 7 种分布在中国, 分别是古巴萝芙木(*Rauvolfia cubana*)、蛇根木(*R. serpentina*)、苏门答腊萝芙木(*R. sumatrana*)、四叶萝芙木(*R. tetraphylla*)、吊罗山萝芙木(*R. tiaolushanensis*)、萝芙木(*R. verticilata*)及催吐萝芙木(*R. vomitoria*)[2]。萝芙木属植物中含生物碱、三萜、酚酸和类黄酮等化学成分, 具有抗肿瘤、抗炎、抗癫痫、抗菌和抗氧化等多种活性。有研究发现萝芙木属植物卡夫拉(*R. caffra*)的叶片可作为吲哚类生物碱的资源[3], 其中富含的单萜吲哚类生物碱在降压、抗心律失常和抗肿瘤等方面都有重要的药用价值[4]。国内外学者对萝芙木属植物化学成分进行了大量的研究, 发现一系列吲哚类生物碱[5], 其中利血平(reserpine)、阿吗灵(ajmaline)和育亨宾(yohimbine)的研究起步较早, 研究较深入, 其他生物碱的研究亦在逐步进行[6]; 三萜、类黄酮和酚酸等化学成分及其药理活性和临床应用的研究仍然处于起步阶段。伴随着各国对中草药需求量的不断增长, 天然药物的开发与利用成为未来发展趋势[7]。

近 20 年来, 国内外已发表大量有关萝芙木属植物资源、化学成分、药理和种植等方面的研究论文, 但基于文献计量学的系统分析尚无相关报道。CiteSpace 软件由美国 Drexel University (德雷塞尔大学)陈超美教授运用 java 语言开发, 将数据用图表来表达, 可对领域内的科研文献进行可视化数据分析, 并能直观地展现某领域的发展规律和当前研究热点[8]。文献计量评估能提供科学的客观的数据分析, 可帮助研究人员了解萝芙木属植物研究在中医药等领域的发展情况。

本研究基于中国知网(China National Knowledge Infrastructure, CNKI)和 Web of Science (WOS)数据库, 利用 CiteSpace 6.1.R6 软件, 对萝芙木属植物研究的中、英文文献进行可视化分析, 得到萝芙木属植物最近 20 年研究进展的分析结果, 旨在了解该领域研究作者和研究机构的合作网络、研究热点以及前沿方向, 为后续研究提供参考依据。

1 资料与方法

1.1 数据来源

研究数据分别来自中文文献收录数据库 CNKI 和外文文献收录数据库 WOS。在 CNKI 数据库中, 检索条件设置为“主题(精确)”, 检索词为“萝芙木”, 共检索出中文文献 193 篇。在 WOS 数据库中, 选择“Web of Science 核心合集”数据库, 检索条件设置为“所有字段”, 检索词为“*Rauvolfia*”, 共检索出英文文献 356 篇。按照纳入标准及排除标准进行文献的选择, 并运用 CiteSpace 6.1.R6 软件, 经数据去重, 最终筛选纳入中文有效文献 173 篇, 英文有效文献 356 篇。检索的时段为 2002 年 1 月 1 日至 2022 年 12 月 31 日。

1.2 纳入标准

纳入萝芙木属植物研究相关文献, 如中医药主题相关的药理活性、成分研究和临床应用等。中文文献限定文献类型为学术期刊和学位论文, 英文文献限定文献类型为 Article 和 Review Article。

1.3 排除标准

重复文献; 未正式出版的文献; 研究主题与萝芙木属植物无关的文献; 作者信息缺失和文章来源缺失等因信息不全而无法分析的文献; 会议论文、成果和报纸等类型的文献。

1.4 数据处理

将检索的文献经过筛选后导出, CNKI 文献选择“Refworks”导出, WOS 数据库中首先选择“Web of Science 核心合集”数据库, 然后选择“以纯文本形式”和“全记录与引用的参考文献”导出。运用 CiteSpace 6.1.R6 软件对文献数据进行可视化分析, 时间切片固定为一年, 节点类型为“Author”, “Institution”和“Keyword”, 修剪方式设置为“Pathfinder”和“Pruning sliced networks”, 最终绘制作者、研究机构和关键词等共现图谱, 节点大小与出现频次、节点相关性有关, 连线代表合作关系[9]。

在对论文作者和研究机构的分析中运用普莱斯定律, 即核心作者和核心机构的最低发文量为 $n = 0.749\times\sqrt{\max}$, 其中 max 为最高产作者或机构的发文量[10]。检验核心作者和核心机构是否形成核心群, 计算公式为 $M=(N_{\max}/N)\times100\%$, 其中 M 代表普莱斯指数结果占比, $N_{\max}$ 代表高于普莱斯定律数值频数, N 代表总词频数, $M\geqslant50\%$ 即表示已形成核心群[11]。

计算作者、机构及关键词的词频、中心性等客观数据, 若关键词中心性≥0.1, 则表明该关键词为高中介中心性[12]。

关键词聚类中，若聚类模块值(Modularity *Q*)大于 0.3，则意味着聚类结构显著，聚类平均轮廓值(Silhouette *S*)大于 0.5 则表明聚类合理，大于 0.7 则表明聚类信度较高[13]。

2 结果

2.1 发文趋势

2002—2022 年发表的萝芙木属植物中、英文文献年度发文量统计结果见图 1。近 20 年关于萝芙木属植物研究的年度发文量总体上呈上升趋势，但有轻微的波动。中文发文量 2002—2010 年呈现快速增长趋势，2008 和 2010 年达到历年之最(18 篇)；2010—2012 年呈现快速下降趋势，2012—2015 年呈现波动上升趋势，2015—2022 年呈现波动下降趋势。英文发文量 2002—2010 年呈现稳定上升趋势，2010—2022 年总体上呈现平稳波动的趋势，年平均发文量为 20.77 篇。从总体上看，近 20 年国外研究机构对萝芙木属植物保持较高的研究热度，国内研究机构对萝芙木属植物研究的热度低于国外，但研究一直在持续进行。

2.2 CNKI 中萝芙木属植物文献分析

2.2.1 作者

作者节点数量 *N*= 348，各节点连线数量 *E*= 712，Density= 0.0118，表明纳入合作网络图的作者有 348 位，作者之间的合作关系有 712 个，构成网络密度为 0.0118 的国内作者合作可视化图谱(图 2)，并由此得到发文量排名前十的作者统计结果(表 1)。根据普莱斯定律，核心作者(≥3 篇)为 31 人，共发表 51 篇文献，占文献总数的 29.48% (<50%)，可知我国近年未形成核心作者群。由图 2 可知，中文文献作者形成以曹福祥(10 篇)、刘洋洋(9 篇)、赵春杰(6 篇)和张丽霞(5 篇)等为代表的研究团队，但根据图 2 中的合作网络，发文量最高的曹福祥、刘洋洋和赵春杰等作者之间没有连线，未形成较为稳定的合作团队。

2.2.2 机构

将中文文献相关机构阈值设置为 2，得到发文机构可视化图谱(图 3)。根据普莱斯定律，核心机构(≥3 篇)为 16 个，共发表 73 篇文献，占文献总数的 42.20% (<50%)。由图 3 可见，该领域中文文献包含研究机构 159 所，形成以中南林业科技大学(10 篇)、中国科学院西双版纳热带植物园(8 篇)、中国科学院昆明植物研究所植物化学与西部植物资源持续利用国家重点实验室(6 篇)为中心的发文机构，各机构中心性低，说明机构间联系不紧密。分析发文机构的地域分布可知，各机构跨地区的合作较少，多为独立研究，虽然发文量最高的机构为高校，但我国对萝芙木属的研究模式是以高校为辅，以实验室或研究所为主。

2.2.3 关键词

通过 CiteSpace 6.1.R6 对关键词进行共现分析，绘制出 *N*= 257，*E*= 473 (Density= 0.0144)的关键词共

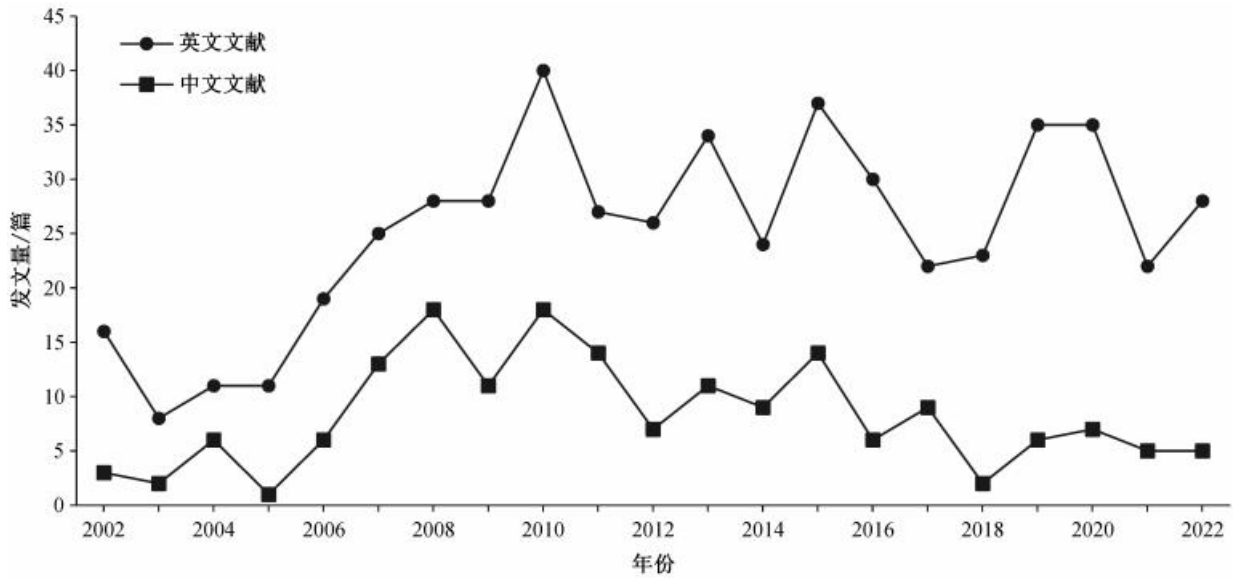


图 1　2002—2022 年萝芙木属植物研究的中、英文文献年度发文量分布

Fig. 1　Annual distribution of Chinese and English literatures on *Rauvolfia* published from 2002 to 2022



图 2 萝芙木属植物研究领域中文文献作者合作网络

Fig. 2 Network display of authors in Chinese literature on *Rauvolfia*

表 1 萝芙木属植物研究领域中文文献发文 5 篇以上的作者

Table 1 Authors of more than 5 articles published in Chinese literature on *Rauvolfia*

序号	发文量	作者	机构
1	10	曹福祥	湖南农业大学
2	9	刘洋洋	中国医学科学院、北京协和医学院药用植物研究所
3	8	刘平怀	海南大学
4	6	赵春杰	沈阳药科大学
5	6	冯蕾	上海交通大学
6	6	赵凤生	上海交通大学
7	6	蔡传涛	中国科学院西双版纳热带植物园
8	6	蓝祖裁	广西药用植物园
9	5	孙蕾	上海交通大学
10	5	张丽霞	中国医学科学院、北京协和医学院药用植物研究所
11	5	洪博	齐齐哈尔医学院

表 2 萝芙木属植物研究领域中文文献排名前 10 的关键词

Table 2 Top 10 keywords in Chinese literature on *Rauvolfia*

序号	关键词	频次	中介中心性
1	萝芙木	59	0.91
2	利血平	28	0.26
3	育亨宾	15	0.08
4	化学成分	14	0.16
5	生物碱	8	0.08
6	提取	8	0.02
7	组织培养	6	0.09
8	生物量	5	0.12
9	薄层色谱	5	0.02
10	结构鉴定	5	0.01

现图谱(图 4)。对共现图谱中出现频次排名前 10 位的关键词进行排序统计，得到表 2，当中介中心值 Centrality≥0.1 时，表明该关键词为高中介中心性。去除“萝芙木”这一常规关键词，中心性靠前的关键词是“利血平”(28 次, Centrality= 0.26)，其次是“化学成分”(14 次，Centrality= 0.16)和“组织培养”(6 次，Centrality= 0.09)。

在关键词共现网络基础上，利用 log likelihood ratio (LLR)算法对关键词进行聚类分析，展示聚类 ID 为#0~#9 的聚类标签。LLR 越大的词，越具有对所在类别的代表性，而不是单纯地按数量大小排序。由图 5 可知，Modularity Q= 0.7455>0.3，说明聚类结构显著，Silhouette S= 0.8816>0.7，说明聚类结果是可以信任的。筛选出排名前 10 位的聚类团，并

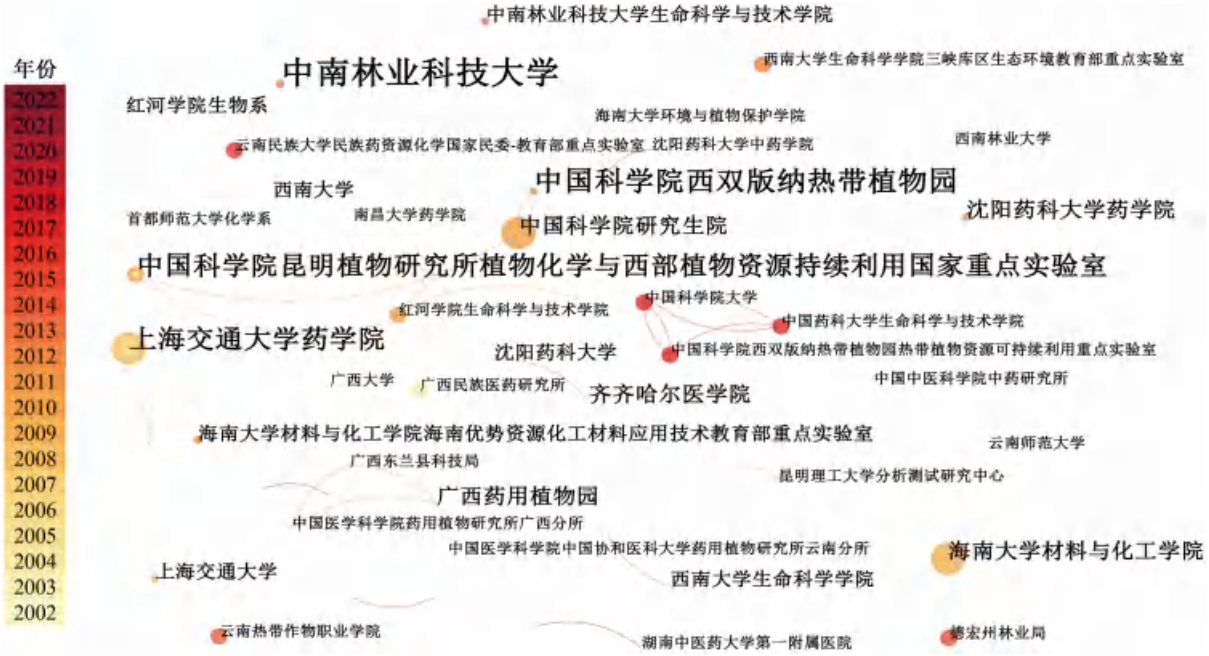


图 3　萝芙木属植物研究领域中文文献研究机构合作网络

Fig. 3　Network display of research institutions of Chinese literature on *Rauvolfia*

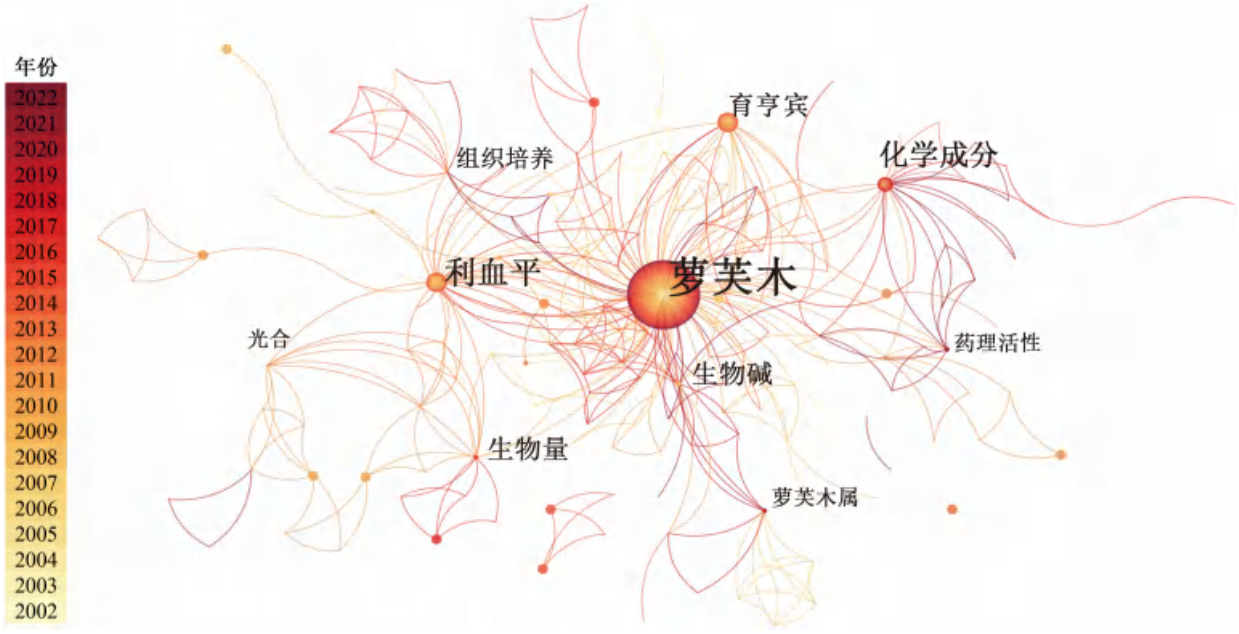


图 4　萝芙木属植物研究领域中文文献关键词共现网络

Fig. 4　Network visualization of keywords in Chinese literature on *Rauvolfia*

得到时间线视图(图 6)，相同聚类中的关键词被放置在同一水平线上，关键词出现的时间置于视图的上方。关键词越多，代表对聚类领域的研究越多，往右时间越近。时间线视图可以显示聚类研究的兴起及结束时间。结合图 5 和 6 可知，近 20 年对萝芙木属植物的繁殖栽培研究较多，对萝芙木属植物化学成分的提取分离和结构鉴定等研究也较多，特别聚焦于“育亨宾”和“利血平”，2015 年后开始聚焦于各类化学成分药理活性的研究。

2.3 WOS 中萝芙木属植物文献分析

2.3.1 作者

由于英文文献的作者数量较多，为使合作图更

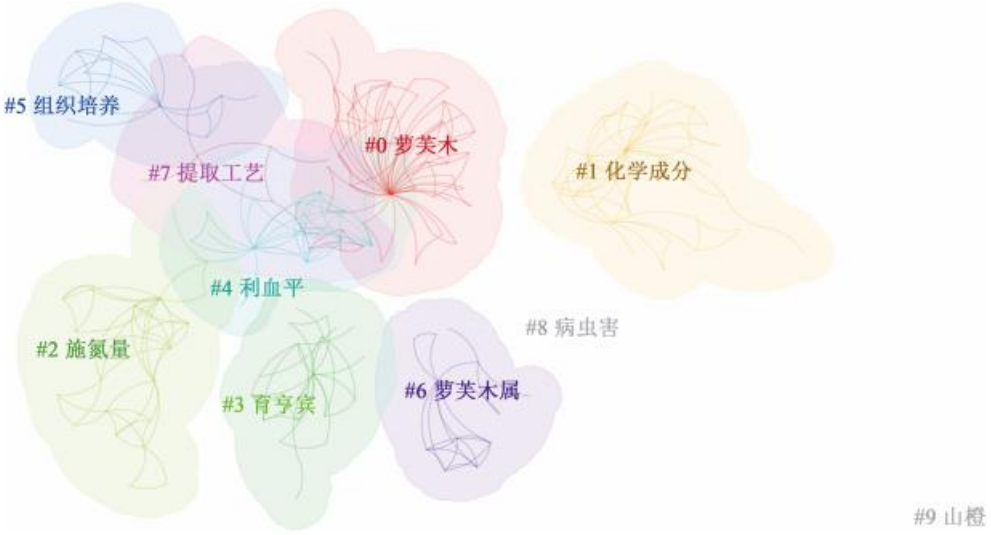
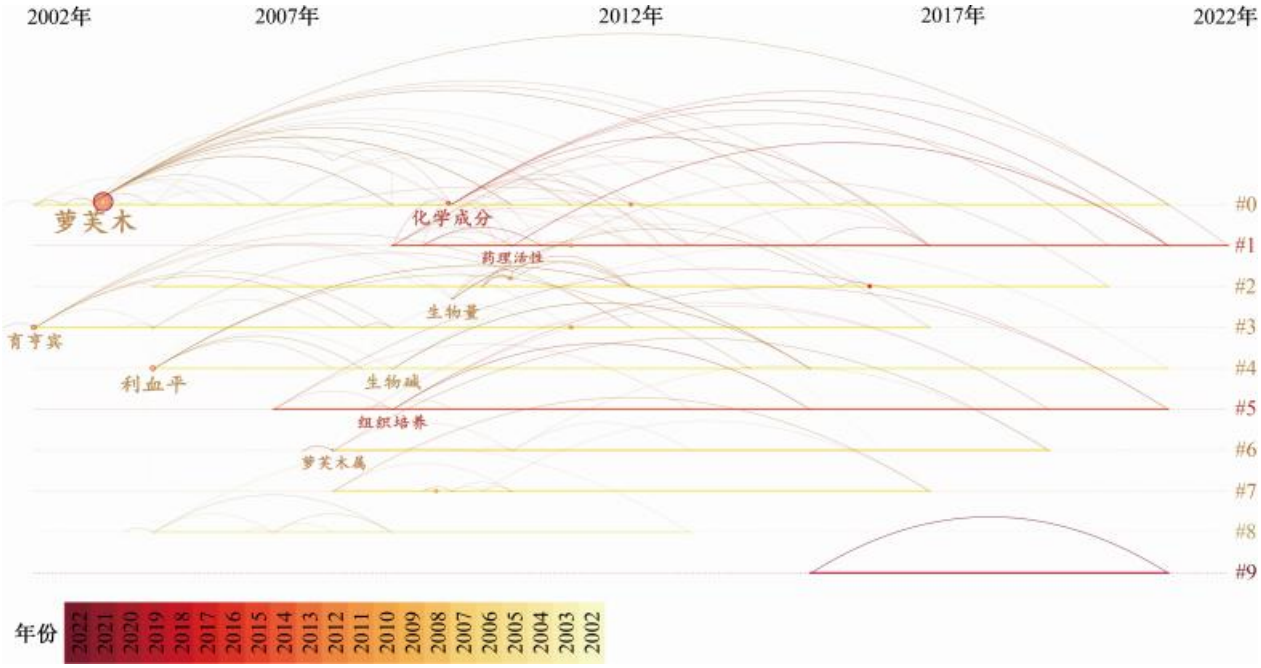


图 5 萝芙木属植物研究领域中文文献关键词聚类网络展示

Fig. 5 Network display of keywords clustering in Chinese literature on *Rauvolfia*



#0~#9 同图 5

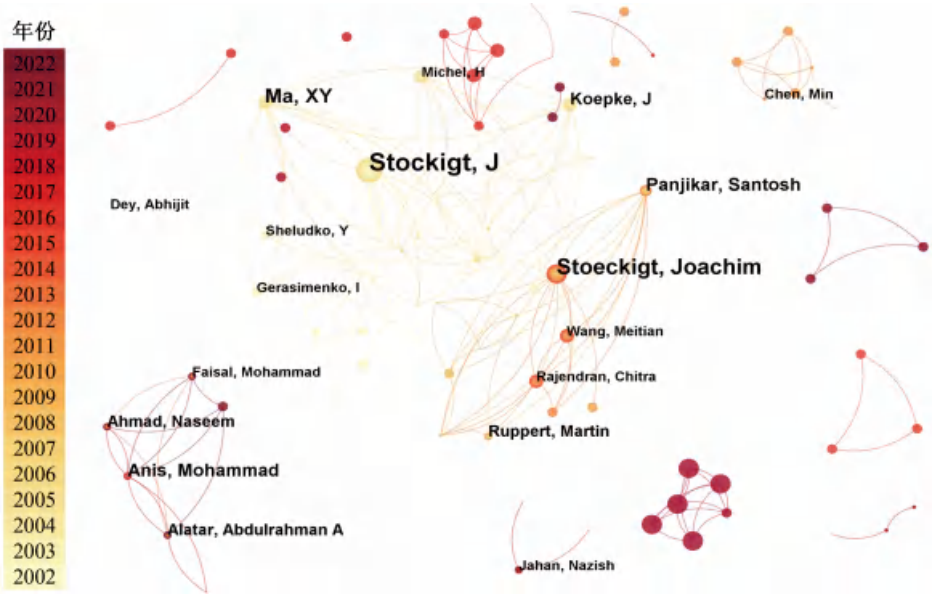
图 6 萝芙木属植物研究领域中文文献关键词时间线分布

Fig. 6 Timeline view of keywords in Chinese literature on *Rauvolfia*

加直观，将英文文献作者发文量阈值设定为 5，得到发文作者合作可视化图谱(图 7)，并由此得到发文量排名前十的作者统计结果(表 3)。根据普莱斯定律，核心作者(≥5 篇)为 26 人，共发表 71 篇文献，占文献总数的 19.94% (<50%)，可知并未形成萝芙木属植物研究的核心作者群。由图 7 可知，近 20 年形成的最大研究团队为以 Stockigt J 等为代表的团队。

2.3.2 机构

将英文文献的相关机构阈值设置为 6，得到发文机构可视化图谱(图 8)。根据普莱斯定律，核心机构(≥4 篇)为 27 个，共发表 208 篇文献，占文献总



Stockigt J 和 Stoeckigt J oachim 为同一人

图 7　萝芙木属植物研究领域英文文献作者合作网络

Fig. 7　Network display of authors in English literature on *Rauvolfia*

表 3　萝芙木属植物研究领域英文文献发文 5 篇以上的作者

Table 3　Authors of more than 5 articles published in English literature on *Rauvolfia*

序号	发文量	作者	机构
1	37	Stockigt J	Zhejiang University
2	12	Ma XY	Qingdao University
3	8	Panjikar S	Australian Synchrotron
4	8	Anis M	King Saud University
5	7	Koepke J	Leibniz University Hannover
6	6	Ruppert M	Universitair Ziekenhuis Antwerpe
7	6	Ahmad N	Integral University
8	6	Alatar A	King Saud University
9	5	Gerasimenko I	Johannes Gutenberg-Universität Mainz
10	5	Jahan N	University of Agriculture Faisalabad
11	5	Michel H	University of Wurzburg
12	5	Sheludko Y	Technical University of Darmstadt
13	5	Min C	Southwest University
14	5	Rajendran C	University of Regensburg
15	5	Meitian W	University of Konstanz
16	5	Faisal M	University of Agriculture Faisalabad
17	5	Dey A	Presidency University

数的 58.43% (>50%)，可知国外已形成高影响力的核心研究机构群。Web of Science 核心合集数据库中发文量排名前三的机构是 Johannes Gutenberg-Universität Mainz (美因茨约翰内斯古滕贝格大学 26 篇)、Zhejiang University (浙江大学 20 篇)和 King Saud University (沙特国王大学 17 篇)。截至目前，最大的合作群为 Johannes Gutenberg-Universität Mainz, Zhejiang University, Chinese Academy of Sciences (中国科学院)和 Massachusetts Institute of Technology (麻省理工学院)等，其他多为小范围合作研究或独立研究。

2.3.3　关键词

将阈值设置为 20，绘制出 N= 488, E= 1420 (Density= 0.012)的关键词共现图谱(图 9)。对共现图谱中出现频次排名前十的关键词进行统计，得到表 4。出现频次最多的关键词是“*Rauvolfia serpentina* (蛇根木)” (120 次, Centrality = 0.47)，其次是“*Catharanthus roseus* (长春花)” (39 次，Centrality = 0.14)，“indole alkaloid (吲哚生物碱)” (39 次，Centrality = 0.22)。由此可知，国内外将萝芙木属植物作为药用植物，关注其药理活性及生物合成，研究并运用最多的成分是吲哚生物碱，热门研究成分为 strictosidine synthase (异胡豆苷合成酶)，研究最多的树种为蛇根木。

在关键词共现网络基础上，利用 LLR 算法对关键词进行聚类分析，展示聚类 ID 为#0~#9 的聚类标签，时间切片为一年。根据可视化结果(图 10)，Modularity Q= 0.6411>0.3，说明聚类结构显著，Silhouette S= 0.8558>0.7，说明聚类结果是令人信服的。筛

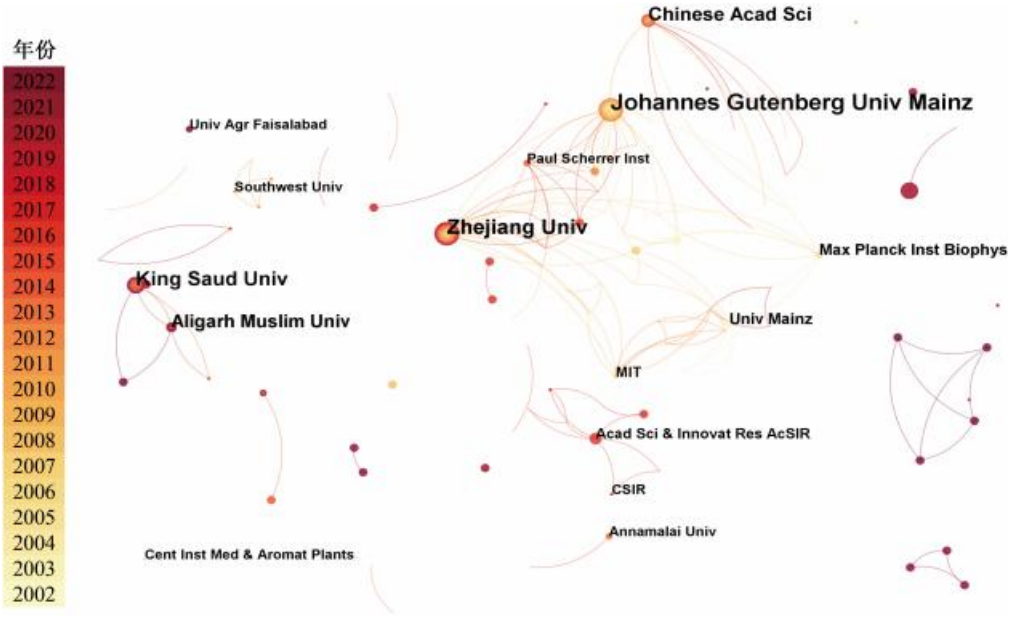


图 8 萝芙木属植物研究领域英文文献研究机构合作网络

Fig. 8 Network display of research institutions of English literature on *Rauvolfia*



图 9 萝芙木属植物研究领域英文文献关键词共现网络

Fig. 9 Network visualization of keywords in English literature on *Rauvolfia*

选出排名前十的聚类团，并得到时间线视图(图 11)。结合图 10 和 11 可知，英文文献中的热门研究物种为 *R. tetraphylla* 和 *R. micrantha*，对化学成分中的异胡豆苷合酶研究持续时间较长，但近 3 年未提到，对药理活性 antioxidant activity (抗菌活性)和 antimicrobial activity (抗氧化性活性)的研究较多。

表 4　萝芙木属植物研究领域英文文献排名前 10 的关键词
Table 4　Top 10 keywords in English literature on *Rauvolfia*

序号	关键词	次数	中介中心性
1	*Rauvolfia serpentina*	120	0.47
2	*Catharanthus roseus*	39	0.14
3	indole alkaloid	39	0.22
4	biosynthesis	32	0.21
5	medicinal plant	31	0.25
6	strictosidine synthase	27	0.10
7	expression	19	0.07
8	extract	17	0.14
9	alkaloid	16	0.20
10	plant	15	0.06

3 讨论

3.1 核心研究团队

通过 CNKI 萝芙木属植物研究合作网络分析可知，我国已形成以曹福祥和刘洋洋等为代表的萝芙木属植物研究作者群，团队与团队之间存在一定的合作关系，发文量最高的曹福祥团队主要聚焦于云南萝芙木的种植[14]、培养[15]及其生物碱的提取分离[16–17]、基因的克隆与序列分析[18–19]。但是，近年未形成核心作者群，且国内高影响力的核心机构群尚未形成，排名第一的中南林业科技大学，主要探究萝芙木属植物的种植以及对萝芙木属中有效成分的提取；中国科学院西双版纳热带植物园和中国科学院昆明植物研究所植物化学与西部植物资源持续利用国家重点实验室主要探究萝芙木属植物的生理生长特性。

WOS 合作分析网络显示，英文文献中未形成核心作者群，但已形成核心机构群。其中，发文量最高的 Stockigt J 团队聚焦于在蛇根木中寻找阿吗灵生物合成途径所需化学物质[20]；最大的机构合作群为 Johannes Gutenberg-Universität Mainz, Zhejiang University, Chinese Academy of Sciences 和 Massachusetts Institute of Technology 等，具有较强的国际影响力，其中 Johannes Gutenberg-Universität Mainz 的研究聚焦于萝芙木属植物中某些生物碱合成过程中酶的调控[21]。此外，近 5 年联系紧密且有研究成果的机构为 King Saud University (沙特国王大学)和 Aligarh Muslim University (阿里加尔穆斯林大学)，聚焦于四叶萝芙木[22]和蛇根木[23]的体外再生与遗传改良研究。

3.2 关键词分析

CNKI 中关键词“利血平”和“育亨宾”等化学成分出现次数较多，结合关键词聚类标签分析，可得研究热点为萝芙木属植物的药理活性、化学成分和临床应用等。

利血平是萝芙木属植物中较早发现并进入临床运用的成分之一，也是萝芙木属植物中药理活性极

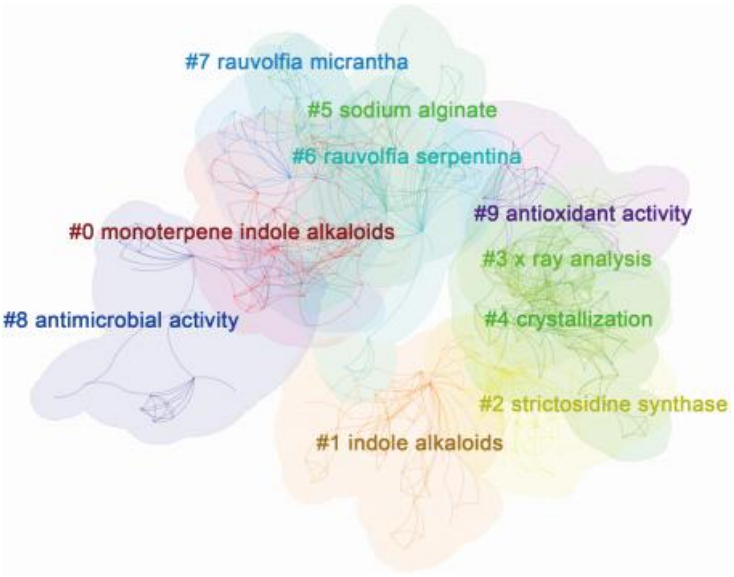
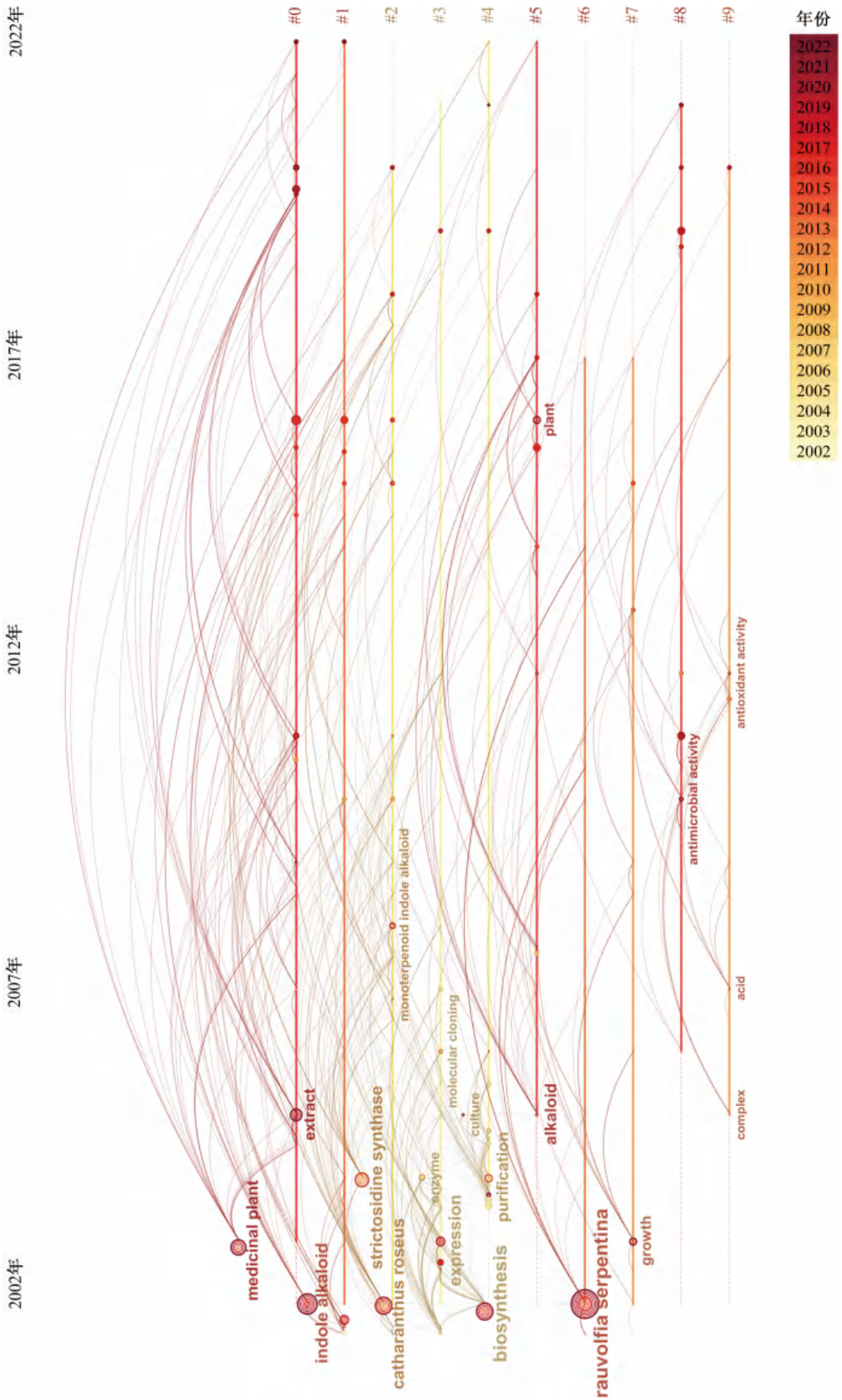


图 10　萝芙木属植物研究领域英文文献关键词聚类网络展示
Fig. 10　Network display of keywords clustering in English literature on *Rauvolfia*



#0~#9 同图 10

图 11 萝芙木属植物研究领域英文文献关键词时间线分布

Fig. 11 Timeline view of keywords in English literature on *Rauvolfia*

高的成分之一。1952 年, Müller 等[24]从蛇根木中分离出利血平, 并证明它是降血压的主要活性成分。Wu 等[25]通过实验证实, 在 100 μg/mL 的浓度下, 蛇根木提取液中的类黄酮比标准药物卡托普利具有更大的抑制血管紧张素转换酶(ACE)活性的潜力[26], 在降低血压方面具有显著的作用。2022 年的一项研究进一步表明, 从蛇根木中提取的类黄酮可以作为治疗高血压的合成药物的安全有效的替代品[27]。

萝芙木属植物不仅在降低血压方面具有极高的药理活性, 在糖尿病的治疗方面也发挥着药理作用。从萝芙木提取物中筛选得到的糖代谢通路中关键限速酶醛糖还原酶(aldose reductase)的有效抑制剂 Indobine, 可作为治疗糖尿病及其并发症的候选活性化合物[28]。通过随机和双盲试点临床试验研究用萝芙木柑橘组合茶在人类中的抗糖尿病功效, 结果表明, 组合茶显著地降低了基础磷酸化乙酰辅酶 A 羧化酶, 却没有显著地增加基础 AMP 活化蛋白激酶表达, 表明萝芙木柑橘组合茶处理可能不会通过 AMPK 活性改善 β-氧化[1]。

WOS 中关键词“*Rauvolfia serpentina*”, “medicinal plan”, “indole alkaloid”和“alkaloid”等较为重要, 结合关键词聚类标签, 可将研究热点归纳为萝芙木属植物中的热门研究物种、化学成分及药理活性。

萝芙木属植物中热门研究物种为蛇根木, 在英文文献中出现的次数最多。研究发现, 蛇根木根的甲醇提取物在质量浓度为 10 μg/mL 时, 对 HIV-1NL 4.3 的抑制率可达 40.8%, 有望成为安全的抗 HIV 药物。但是, 目前对萝芙木属植物抗 HIV 活性研究中涉及药理和病理的方面仍不够深入[28]。Sudipta 等[29]从蛇根木的叶提取物中合成银纳米颗粒(AgNPs), 发现合成的 AgNPs 对人类病原微生物具有抗菌活性, 并且显示出对 HeLa 和 MCF-7 细胞系的杀幼虫活性和细胞毒性。蛇根木种子石油醚提取物有明显的杀蚊幼虫活性, 浓度为 0.1‰的石油醚提取物可使 3 种晚期幼虫的死亡率达到 49.82%~60.84%[30], 蛇根木种子的石油醚提取物有望成为强有力的杀虫剂。

除蛇根木外, 热门研究物种还有催吐萝芙木。Oyeniran 等[31]发现催吐萝芙木叶的酚类表征表明存在更多的类黄酮, 催吐萝芙木叶的水和甲醇提取物都有抑制作用, 甲醇提取物具有更显著(p≤0.05)的自由基清除能力, 并可抑制单胺氧化酶。催吐萝芙木对神经组织有益, 但有报道称其会诱导小脑细胞损伤, 导致影响运动协调。宽叶纤冠藤(*Gongronema latifolium*)也是常见的药用植物, Moses 等[32]通过小鼠的对照实验, 证明 RV+GL 组合可以改善 RV 诱导的小脑细胞创伤, 虽然不能改善其增殖, 但也为保护小脑提供潜在的治疗方案。此外, 实验表明催吐萝芙木的有机溶剂(80%乙醇、正己烷、氯仿和醋酸乙酯)提取物在体内外均有抗丝虫病活性, 能够让活动的盘尾丝虫僵化不动, 抑制程度对浓度和时间具有依赖性[28]。

萝芙木属植物中对化学成分的研究集中在探究其药理活性方面。

萝芙木属植物多种化学成分具有很好的抗肿瘤活性, 对此研究较为深入。研究人员发现, 多种水溶性萝芙木吲哚生物碱(如育亨宾酸(yohimibinic acid)等)具有很好的抗肿瘤活性[33]。Wang 等[34]的研究表明, 萝芙木总碱 *Rauvolfia vomitoria* total alkaloids (RVA)可以显著地提高在结直肠癌(CRC)治疗中 5-氟尿嘧啶(5-FU)的敏感性, RVA 使 5-FU 增敏, 并通过影响脂质代谢和细胞能量代谢发挥抗肿瘤活性, 为中医药治疗预估结肠癌治疗效果和潜在机制提供了新的想法。2022 年, 进一步发现通过催化光氧作用从 *Rauvolfia* 生物碱(−)-利血平(Rauvolfia alkaloid (−)-reserpine)中制备的二氧利血平(Dioxyreserpine)是一种中等有效的抗肿瘤药物, 并且其结构修饰的类似物已成为包括胰腺癌在内的各种人类癌症的高效和选择性生长的新型抑制剂[35]。

对萝芙木属植物的前期研究多集中于降压作用和抗肿瘤活性, 近 5 年研究范围有所扩大, 如抗炎活性、抗癫痫活性、抗菌活性和抗氧化活性。

李思琼等[36]在海南萝芙木(*Rauvolfia verticillate*)中提取出果胶多糖(pectic polysaccharides, PP), 通过 4 组小鼠的对照实验表明, PP 治疗使得结肠组织中肿瘤坏死因子 α(TNF-α)和白介素-6(IL-6)水平显著降低, 与 SASP 治疗组小组结果类似, 因此可认为 PP 是潜在的治疗结肠炎的药物。Zhan 等[37]从催吐萝芙木的茎中分理出 5 种新的霹雳素衍生物 rauvomine C–G, 通过实验发现生物碱 rauvomine C 在 LPS 诱导的 RAW264.7 小鼠巨噬细胞中表现出显着的抗炎活性。

Chipiti 等[38]使用斑马鱼幼虫模型, 筛选南非传统上用于治疗癫痫的 20 种药用植物的抗癫痫活性,

使用PTZ测定法测量6-dpf斑马鱼幼虫模型中诱导的癫痫发作样行为，结果表明卡夫拉的甲醇提取物是斑马鱼幼虫模型中抑制PTZ诱导的癫痫发作行为的最有希望的物质。

Qin等[39]从云南萝芙木中提取出3种独特的单萜类吲哚生物碱raufiayunesins A-C (1–3)，通过3种生物碱与氨苄青霉素、小檗碱处理大肠杆菌的对比抗菌实验，检测得到生物碱1可能对大肠杆菌330的质膜有直接的损伤，导致大肠杆菌330有明显的膜固缩和穿孔。最新的研究表明，从云南萝芙木根部分离出的两种新的单萜烯吲哚生物碱3-羟基洛希纳林和10-羟基乙烯基是抗菌活性中较为重要的成分[26]。

Nair等[40]从西高止山脉南部的萝芙木属植物中选出5个种的叶片，并研究它们的抗氧化活性，用各种体外模型对5个物种的抗氧化潜力进行筛选，其中蛇根木表现出最高的1,1-二苯基-2-苦味酰肼(DPPH)自由基清除活性。这项研究证实了萝芙木属植物的抗氧化潜能，提供了一种食品和化妆品中易于获得的天然氧化剂来源的替代方案。

关键词共现及聚类分析结果显示，未来对萝芙木属植物的研究不应限于已发现的结构及功能的化学成分，可以继续分离提取研究较少的物种，多探索萝芙木属植物的药理作用，并加强萝芙木属植物临床应用的相关研究，使萝芙木属植物的研究从实验室走向临床。

3.3 研究热点的最新进展

生物碱是目前萝芙木属植物中研究得最多的化学成分，是该属植物研究的热点，至今已从萝芙木属中分离出140余种生物碱[1]。关于生物碱的研究热点，在20世纪50年代后集中于如何将利血平和育亨宾的抗高血压活性在临床应用中实现，近20年来，中文文献集中在已知化学成分分离提取方法的改良及未知化学成分的分离提取鉴定，英文文献集中在化学成分的分离提取及其药理活性的研究，如抗氧化、抗菌和抗肿瘤等活性的开发和利用。

从萝芙木属植物研究领域中文文献关键词的时间分布可以看出，关于萝芙木属植物“化学成分”的研究一直在持续进行中，除提取鉴定与结构分析外，进一步深入至药理活性的研究。2022年，Wang等[34]的研究表明萝芙木总碱有抗结直肠癌肿瘤活性，Eichhorst等[35]的研究表明*Rauvolfia*生物碱(–)-利血平中制备的二氧利血平为一种中等有效的抗肿瘤药物。可见萝芙木属的研究正从早期发现的抗高血压活性逐渐向抗肿瘤活性中转变，但如何将其投入临床运用，依旧任重道远。

3.4 研究的不足

近20年对萝芙木属的研究得到持续的发展与进步，但也存在不足：1) 有关萝芙木属植物的研究发文量总体上呈上升趋势，但近年增速较缓，关于萝芙木属植物化学成分及其药用价值等的研究热情减弱；2) 目前已发表的文献被顶级期刊收录的较少，行业影响力不高，虽然中南林业大学是中文文献发文量最高的机构，但国际影响力不足；3) 未能打破地域限制，国内外各研究机构之间合作力度不够，学术平台和各类资源未能共享；4) 成果转化欠缺，从萝芙木属中化学成分的发现以及对其药理活性的研究到相关产品投入临床应用还需很长的时间，相关研究与临床联系不够紧密；5) 国内外对萝芙木属植物中三萜、类黄酮和酚酸等化学成分的关注度不够；6) 与英文文献相比，中文文献反映的研究进展较缓慢，英文文献中已有关于萝芙木属植物中某一种植物各类成分的系统性研究，但中文文献仅局限于萝芙木属植物的栽培种植，对单一化学成分的研究和对未知化学成分的研究不够深入。

4 小结

本研究运用文献计量软件CiteSpace，对CNKI和WOS数据库中2002—2022年萝芙木属研究进展相关的文献进行可视化分析，分别从发文趋势、作者合作、机构合作以及关键词分析等方面绘制知识图谱，展示该领域的研究进程，分析当前研究现状，并对发展趋势做出预测，以期为萝芙木属植物的深入研究和产业化应用提供思路与方向。中文文献关键词共现分析结果显示利血平、育亨宾和化学成分是近年来国内关于萝芙木属研究的关键，英文文献共现分析结果提示长春花属、吲哚生物碱和生物合成是近年来国外研究的关键。综上所述，预测未来萝芙木属相关研究的重心依旧在对其有效生物碱成分的研究上，萝芙木属植物中的化学成分在临床中的应用也是植物药用开发中的热点内容，如何将萝芙木属植物已知和未知的药理活性投入临床使用中，推动植物中天然产物在中医药领域的深入阐释和创新，未来值得重点关注。

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RCCSE 中国核心学术期刊
中国科学引文数据库 (CSCD) 来源期刊
中文科技期刊数据库来源期刊

中国核心期刊（遴选）数据库来源期刊
中国学术期刊综合评价数据库来源期刊

ISSN 1006-9690

第42卷 第3期
Vol.42 No.3

中国野生植物资源
Chinese Wild Plant Resources

3
2023

主管：中华全国供销合作总社
主办：南京野生植物综合利用研究所

ISSN 1006-9690
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中国野生植物资源

第 42 卷 3 期　2023 年 3 月　总第 228 期

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doi:10.3969/j.issn.1006-9690.2023.03.002

海丰县野生林木种质资源研究

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摘 要 采用野外样线调查和文献查阅的方法对海丰县野生林木种质资源组成、区系特点、资源利用方式等进行研究。结果表明:海丰县共有野生林木种质资源238种,隶属于63科151属;乔木种类最多有123种,占总种数的51.68%;科级的主要组成部分是单种科,占总科数的41.27%;该地区野生林木种质资源区系以热带成分占据优势地位,呈现出明显的热带—亚热带属性;根据植物资源用途将海丰县野生林木种质资源划分为药用、观赏、用材、食用等13种类型,其中药用植物占优势地位,共有47科92属119种。结论:海丰县野生林木种质资源丰富,但部分植物生境人为干扰程度较严重,建议当地从实际情况出发,以保护为主,合理开发利用资源,深度挖掘木本植物资源利用价值,以促进海丰县野生林木种质资源可持续发展。

关键词 林木;植物区系;植物资源;海丰县

中图分类号:Q948.2 **文献标识码**:A **文章编号**:1006-9690(2023)03-0009-06

Research on Wild Forest Tree Germplasm Resources in Haifeng County

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Abstract A field sample line survey and literature review were used to study the composition, zonal characteristics and resource utilization patterns of wild forest germplasm resources in Haifeng County. The results showed that there were 238 species of wild forest germplasm resources in Haifeng County, belonging to 63 families and 151 genera; the largest number of tree species was 123, accounting for 51.68% of the total number of species; the main component of the family level was the single species family, accounting for 41.27% of the total number of families; the wild forest germplasm resource system in the area was dominated by tropical components, showing obvious tropical-subtropical properties. The wild forest germplasm resources of Haifeng County were classified into 13 types of medicinal, ornamental, timber and edible plants according to the use of plant resources, among which medicinal plants dominate, with a total of 119 species in 92 genera and 47 families.Conclusion: The wild forest germplasm resources in Haifeng County are rich, but some of the plant habitats are seriously disturbed by human beings. It is suggested that the local authorities should take conservation as the main consideration, reasonably develop and utilize the resources, and deeply explore the value of using woody plant resources in order to promote the sustainable development of wild forest germplasm resources in Haifeng County.

Key words Forest; Flora; Plant resources; Haifeng County

林木种质资源是维持生物多样性的核心资源,也是国家生态安全和林业经济可持续发展的基础保障[1-2]。我国林木种质资源研究始于20世纪80年代,在当时,我国木本植物资源丰富,但在资源收集和保存以及管理水平等方面,仍与世界先进水平有较大差距[3],管长岭[4]指出国内对林木种质资源的利用还

收稿日期:2022-11-23,录用日期:2023-02-12
基金项目:广东省林木种质资源调查(GDZZDC20228703)。
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远远不够充分，应当把野生种质资源的开发和利用作为研究的重点。此后，山西[5]、云南[6]、河北[7]、湖北[8]、福建[9]等各省陆续组织开展林木种质资源普查工作，极大地推动了我国林木种质资源研究进程。广东省拥有丰富的林木种质资源，但林木种质资源家底相对不清，林木种质资源利用率低等问题严重制约了广东省林业高质量发展。本研究依托广东省林木种质资源调查项目，以海丰县野生林木种质资源为调查对象，通过实地调查与文献查阅的方法对其资源组成、植物区系、生活型、植物资源利用等信息进行分析，旨在摸清当地野生林木种质资源家底，评价其物种价值的多样性，为当地制定野生林木种质资源长期保护与利用提供数据支撑。

1 研究区域概况

海丰县地处广东省东南部沿海，东与陆丰市毗邻，西与惠东县接壤，东北与陆河县接壤，东南与城区毗邻，北倚莲花山脉，南临南海。地理坐标在东经114°54′～115°37′，北纬22°37′～23°14′之间；境内地势由西北向东南倾斜，莲花山脉横贯县境北部，主峰海拔1137.3 km，中部为宽阔平原，土质肥沃，河涌交错，有赤石、大液、丽江、黄江4大江河，总长132 km，流域面积156 950 hm^2；东部濒临碣石湾，西部面向红海湾。境内有长沙湾、高螺湾、九龙湾3大海湾，海岸线116 km。属南亚热带季风气候区，海洋性气候明显，整体气候特征为雨热同季，气候温暖，光照充足，年均气温22℃，年均降水量2 389.5 mm。森林资源丰富，主要的植被类型有常绿阔叶林、落叶阔叶林、针叶林等。

2 研究方法

在2022年7月对海丰县野生林木种质资源展开野外调查，记录沿线两侧10 m范围内的木本植物（乔木、灌木、木质藤本和竹类），拍摄植物照片作为调查凭证。利用《广东植物图鉴》[10]、《广东植物志》[11]等植物学著作及中国植物志网站（http://www.iplant.cn/frps）对本次调查所得数据进行核对和分析，整理出海丰县野生林木种质资源名录。其中裸子植物按照郑万钧系统（1975）分类，被子植物按照哈钦松系统（1926～1934）分类。

3 结果与分析

3.1 野生林木种质资源组成

经调查，海丰县野生林木种质资源共有238种，隶属于63科151属。其中裸子植物1科1属2种，分别占海丰县野生林木种质资源科属种的1.59%、0.66%、0.84%。被子植物共计62科150属236种，分别占海丰县野生林木种质资源科属种的98.41%、99.34%和99.16%；其中：双子叶植物有59科144属224种，单子叶植物有3科6属12种。可见双子叶被子植物是海丰县野生林木种质资源的主要组成成分。

根据科中所含种数，可将本次记录的63科划分为大科（种数10种以上）、少种科（6～9种）、寡种科（2～5种）、单种科（1种）4个等级（表1）；其中单种科有锦葵科（Malvaceae）、交让木科（Daphniphyllaceae）等26科26属26种，占总科数比例最大；寡种科次之，包含番荔枝科（Annonaceae）、壳斗科（Fagaceae）在内共有23科46属73种，占总科数的36.51%；少种科有茜草科（Rubiaceae）、山茶科（Theaceae）、芸香科（Rutaceae）等共计10科50属72种，占总科数的15.87%；大科有大戟科（Euphorbiaceae）（12属23种）、桑科（Moraceae）（3属16种）、蝶形花科（Papilionaceae）（8属14种）、樟科（Lauraceae）（6属14种）4科，占总科数的6.35%。单种科占总科数的比例最大，表明单种科是海丰县野生林木种质资源科级的主要组成部分；而寡种科和单种科所含种数量之和为145种，占总种数60.92%，具有明显的数量优势，说明海丰县野生林木种质资源种类丰富且分化程度较高。

表1 野生林木种质资源科、属、种组成

Tab. 1 Family, genus and species composition of wild forest germplasm resources

科所含种数	科数	占比(%)	属数	占比(%)	种数	占比(%)
≥10	4	6.35	29	19.21	67	28.15
6～9	10	15.87	50	33.11	72	30.25
2～5	23	36.51	46	30.46	73	30.67
1	26	41.27	26	17.22	26	10.92
总计	63	100	151	100	238	100

3.2 植物区系成分分析

参照吴征镒等对中国种子植物科属分布区类型的划分方法[12-14]，可将海丰县野生林木种质资源61科划分为9个分布区类型，151属可划分为12个分布区类型（表2）。

3.2.1 科的区系成分分析

由表2可知，海丰县野生林木种质资源中世界分布科（1型）共有12科，如榆科（Ulmaceae）、桑科

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等；热带成分（2～7型）共42科，占总科数的82.35%（不包括世界广布型，下同），其中泛热带分布共有33科，如大戟科、防己科（Menispermaceae）、芸香科等，占总科数的64.71%，具有优势地位；温带成分（8～14型）有壳斗科、木兰科（Magnoliaceae）等9科，占总科数17.65%。表明海丰县野生林木种质资源科的热带、亚热带性质较为明显。

3.2.2　属的区系成分分析

由表2可知，海丰县野生林木种质资源中世界广布属（1型）有悬钩子属（*Rubus* L.）、茄属（*Solanum* L.）2属；热带成分（2～7型）共有119属，占总属数79.87%（不包括世界广布型，下同），以榕属（*Ficus* L.）、冬青属（*Ilex* L.）、菝葜属（*Smilax* L.）等为代表；温带成分（8～14型）有30属，占总属数20.13%，包含石斑木属（*Rhaphiolepis* Lindl.）、栎属（*Quercus* L.）、锥属[*Castanopsis*（D. Don）Spach]等。说明海丰县野生林木种质资源属级区系以热带成分占绝对优势，与热带植物区系具有更强联系。

表2　野生林木种质资源科属分布区类型

Tab. 2　Types of family and genus distribution areas of wild forest germplasm resources

分布区类型	科数	占比（%）	属数	占比（%）
1.世界分布	12	–	2	–
2.泛热带分布	33	64.71	42	28.19
3.热带亚洲和热带美洲间断分布	7	13.73	8	5.37
4.旧世界热带分布		–	16	10.74
5.热带亚洲至热带大洋洲分布	1	1.96	15	10.07
6.热带亚洲至热带非洲分布	1	1.96	8	5.37
7.热带亚洲（印度—马来西亚）分布	–	–	30	20.13
热带分布合计（2～7）	42	82.35	119	79.87
8.北温带分布	6	11.76	9	6.04
9.东亚及北美间断分布	1	1.96	12	8.05
10.旧世界温带分布	–	–	2	1.34
12.地中海区、西亚至中亚分布	–	–	1	0.67
13.中亚分布	1	1.96	6	4.03
14.东亚分布	1	1.96	–	–
温带分布合计（8～15）	9	17.65	30	20.13
总计	63	100	151	100

3.3　生活型组成

生活型是植物演化和生态学、生物学特性总特征的反映，可用于研究植物生态特性的多样性[15]。海丰县野生林木种质资源生活型可分为乔木、灌木、藤本、竹类（表3）。其中乔木种数最多，有123种，占总种数的51.68%；次之为灌木，有84种，占总种数的35.30%；藤本有25种，占总种数的10.50%；竹类则有1科4属6种，占总种数的2.52%。

表3　野生林木种质资源植物生活型构成

Tab. 3　Plant life type composition of wild forest germplasm resources

生活型	种数	占总种数的比例（%）
乔木	123	51.68
灌木	84	35.3
藤本	25	10.5
竹类	6	2.52
合计	238	100

3.4　资源利用类型

海丰县地处属南亚热带季风气候区，海洋性气候明显，具有较好的水热条件，加之北部有莲花山脉横贯，山地面积广阔，森林资源丰富，优越的自然条件孕育了海丰县丰富的野生林木种质资源（表4）。

调查发现海丰县野生林木种质资源中具有药用价值的植物有119种，隶属于47科92属；占资源植物总种数的50.00%，是该地区资源植物最主要的组成部分，包含许多我国常用中药，如亮叶猴耳环[*Archidendron lucidum*（Benth）I. C. Nielsen]、朱砂根（*Ardisia crenata* Sims）、枫香树（*Liquidambar formosana* Hance）等。

观赏植物是指姿态优美、花色艳丽、叶型独特或果实鲜艳等具有美化环境和愉悦心情作用的植物[16]，经统计，海丰县野生林木种质资源中有观赏植物39科69属106种，占该地区资源植物总种数的

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44.54%，其中深山含笑（*Michelia maudiae* Dunn）花纯白艳丽，具有极高的观赏价值；珊瑚树（*Viburnum odoratissimum* Ker.-Gawl）果实艳红亮丽，是优良的观果树种；山乌桕（*Triadica cochinchinensis* Loureiro）叶色富有变化，是海丰地区常见的彩叶植物。

挖掘更多具有材用价值的树种是提升森林资源的质量、提高森林资源总价值的重要途径[17]，也是国家重要物质战略发展的需要。经统计，海丰县野生林木种质资源中共有用材植物53种，隶属于26科45属，是该地区资源植物总种数的22.27%，生活型以乔木为主，主要有黄牛木[*Cratoxylum cochinchinense*（Lour.）Bl.]、竹节树[*Carallia brachiate*（Lour.）Merr.]、华润楠[*Machilus chinensis*（Champ. ex Beth.）Hemsl.]、红锥（*Castanopsis hystrix* J. D. Hooker et Thomson ex A. De Candolle）等，其中黄牛木材质坚硬，纹理独特，是广东地区制作雀笼的名贵木材[18]。

海丰县野生林木种质资源中有食用类植物49种，占该地区资源植物总种数的20.59%，常见的有南酸枣[*Choerospondias axillaris*（Roxb.）B. L. Burr & A.W.Hill]、桑（*Morus alba* L.）、白花酸藤果（*Embelia ribes* Burm.F.）、茅莓（*Rubus parvifolius* L.）、苹婆（*Sterculia monosperma* Ventenat），其中白花酸藤果的嫩叶可供蔬食；南酸枣果实酸甜可口，具有一定的食用和药用价值。

纤维植物可为纺织用品、绳索、纸张、塑料和炸药等提供原料，植物界中荨麻科、亚麻科、桑科和禾本科等都是植物纤维的主要来源[19]。海丰县本次调查共记录纤维类植物33种，隶属于27属18科，占该地区资源植物总种数的13.87%，包括山黄麻[*Trema tomentosa*（Roxb.）Hara]、山麻秆（*Alchornea davidii* Franch.）、白背叶[*Mallotus apelta*（Lour.）Muell. Arg.]、地桃花（*Urena lobata* L.）、八角枫[*Alangium chinense*（Lour.）Harms]等，其中地桃花富含坚韧的纤维，可作为麻类的代用品，具有广阔的开发前景。

油料植物在食品、化工、医药、能源等领域都发挥着重要的作用，当前全球对植物油脂需求量日益增加，传统的草本植物油脂无法满足人们的需要，木本植物油料资源的开发利用得到越来越多人的关注[20]。海丰县野生木本油料植物有28种，占资源植物总种数的11.76%，代表植物有核仁含油率较高，可供工业使用的山鸡椒[*Litsea cubeba*（Lour.）Pers.]和我国重要的工业油料植物木油桐（*Vernicia montana* Lour.）。

蜜源植物资源是自然资源的重要组成部分之一。经统计，海丰县有蜜源植物23种，占该地区资源植物总种数的9.66%，其中细齿叶柃（*Eurya nitida* Korthals）、木荷（*Schima superba* Gardn. et Champ.）、山矾（*Symplocos sumuntia* Buch.-Harm. ex D.Don）等是当地常见的蜜源植物，这类植物的开发利用有利于推动蜂业产业化的发展，具有重大的生态与经济意义[21]。

鞣料类植物具有的丰富鞣质，是制造栲胶的原料[18]。自然界中含有鞣质的植物如野漆[*Toxicodendron succedaneum*（L.）O. Kuntze]和山黄麻等均在本次记录的物种名录内。

芳香类植物有土沉香[*Aquilaia sinensis*（Lour.）Spreng.]、乌药[*Lindera aggregata*（Sims）Kosterm.]等共计14种野生林木种质植物，这类植物一般具有香气，或其组织及器官能够提取芳香油及其他活性物质[22]，是当前具有较大发展前景的一类植物资源。

木本饲料因其种类繁多、营养丰富和饲喂效果好等原因，被视为解决当前畜牧业快速发展所需的饲料短缺问题的一个突破口，是目前饲料行业的重点研究领域[23]。海丰县有7科7属7种野生木本饲料植物，其中桑不仅叶可作为养蚕的饲料，其根、果、枝条还能药用，树皮纤维也是作纺织原料、造纸原料植物，具有多重用途。

海丰县共有黄杞（*Engelhardia roxburghiana* Wall.）、了哥王[*Wikstroemia indica*（L.）C. A. Mey]、羊角拗[*Strophanthus divaricatus*（Lour.）Hook. et Arn.]等6科7属7种有毒野生木本植物。这类植物在很长一段时间内被人为严重破坏，大众对其片面的认识是有毒植物不受待见的主要原因[24]，而随着科技发展，人类对有毒植物的认知不再局限于其毒性，而更多的偏向其药用、观赏、食用或经济价值[25-28]，目前来看，有毒植物仍有较高的研究价值。

染料植物独特的色彩美及灵性，具有独特的文化价值，我国使用天然染料植物的传统由来已久[29]，天然染料植物具有绿色无毒、抗菌、防紫外线、驱虫等多功能属性，被广泛应用于服装业、食品业等多个领域中，具有极高的开发和利用价值[30]。海丰县共有染料类植物5科6属6种，其中栀子（*Gardenia jasminoides* Ellis）是我国重要的染黄植物；乌桕[*Triadica sebifera*（L.）Small]用途广泛，其叶为黑色染料，可染衣物；细齿叶柃枝、叶及果实均可作染料。

淀粉类植物是指体内贮存有碳水化合物的植物，果实、种子和根部是植物储存淀粉的主要部

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表4　野生林木种质资源利用类型

Tab. 4　Utilization types of wild forest germplasm resources

资源类群	科	属	种	%
药用植物	47	92	119	50.00
观赏植物	39	69	106	44.54
用材植物	26	45	53	22.27
食用植物	31	43	49	20.59
纤维植物	18	27	33	13.87
油料植物	12	21	28	11.76
蜜源植物	5	13	23	9.66
鞣料植物	13	18	19	7.98
芳香植物	9	11	14	5.88
饲料植物	7	7	7	2.94
有毒植物	6	7	7	2.94
染料植物	5	6	6	2.52
淀粉植物	3	3	5	2.10
总计	221	362	469	

注：部分植物有多种用途，因而本表中科、属、种数超过实际数量。

位[31]。海丰县野生木本植物中淀粉类植物有3科3属5种，包括白花油麻藤（*Mucuna birdwoodiana* Tutch.）、女贞（*Ligustrum lucidum* Ait.）等，其中女贞果含淀粉，可用于酿酒或制酱油。

4　结论与讨论

本次调查共记录海丰县野生林木种质资源63科151属238种，植物种类与惠州市莲花山白盆珠省级自然保护区木本植物种类[32]相似度极高，这可能是由于海丰县与惠州市同属南亚季风气候区，具有相同的气候类型，且莲花山白盆珠省级自然保护区位于惠州市与海丰县接壤处，地形地貌显著相似，因此两地之间的植物类型高度重合。科级数量中，单种科为主要成分，占总科数的41.27%，而少种科和寡种科所含的种数共有145种，占总种数的60.92%，是海丰县野生林木种质资源的主要组成成分，说明海丰县野生林木种质资源种类丰富且分化程度较高。

海丰县优越的自然条件形成了其植物区系复杂，地理成分丰富的特点。区系分布型为热带成分的科（世界分布科除外）共计40科，占区系植物的81.63%，是最主要的植物区系组成成分；属的分布型中热带成分共有119属（世界分布属除外），占区系植物79.87%，科属分布型均表现出明显的热带—亚热带性质，与陈颖等[33]在汕尾市铜鼎山风景区及吴悦宏等[34]在潮汕地区的研究结果相符。海丰县野生林木种质资源属的组成中，榕属植物的种类最多有14种，占总种数的5.88%，生活型多为乔木，在植物区系分布中属于泛热带分布，这也与本研究得出海丰县野生林木种质资源生活型以乔木为主、属的区系地理成分以热带成分为主的结果相匹配。

植物资源是生态系统的重要组成部分，开展植物资源区域性研究，可以了解研究区域种类，发掘研究区域植物药用、观赏、食用等方面的价值，将其应用于实际生产中，可以提高区域经济效益与生态效益[35]。经统计，海丰县238种野生林木种质植物可划分为药用、观赏、用材、食用等13种利用类型，表明海丰县具有丰富的植物资源，但在调查过程中发现部分植物生境人为干扰程度较严重，建议当地相关部门积极研讨相关的保护措施，增加宣传保护政策力度，增强群众保护意识；合理利用资源，深度挖掘木本植物资源利用价值，提高综合效益。

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中国野生植物资源

ZHONGGUO YESHENG ZHIWU ZIYUAN

（月刊，1982年创刊）

2023年3月　第42卷第3期（总第228期）

Chinese Wild Plant Resources

（Monthly, Started in 1982）

Vol. 42 No.3 March. 2023 (Tot. No. 228)

主　　管　中华全国供销合作总社

主　　办　南京野生植物综合利用研究所

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编辑出版　《中国野生植物资源》编辑部

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官　　网　http://zysz.cbpt.cnki.net

印　　刷　南京百花彩色印刷广告制作有限责任公司

总 发 行　江苏省邮政局

Administration All China Federation of Supply & Marketing Cooperatives

Sponsor Nanjing Institute for Comprehensive Utilization of Wild Plants

Editing & Publishing Editorial Board of *Chinese Wild Plant Resources*

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E-mail: yszw2009@vip.163.com), Tel: 025－85471187)

Chief Editor Zhang Weiming

Official website http://zysz.cbpt.cnki.net

Printing Nanjing Baihua Print Advertising Limited Liability Company

Distributor Jiangsu Post Office

中国标准连续出版物号：ISSN 1006－9690 / CN 32－1381/Q　广告发布登记通知书号：广登32000000023　邮发代号：28－245　定价：23.00元

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Species characteristics and cultural value of stone wall trees in the urban area of Macao

Meisi Chen[1], Songyi Huang[2,3]✉, Zheng Chen[2], Yemiao Xing[2], Fuwu Xing[4], KunFong Leong[5], Yaonan Yang[6], Yuan Qiu[1] & Xinsheng Qin[1]✉

The stone walls remaining in the highly urbanized Macao area provide a special habitat for plants, repair the fragmentation of the habitat caused by urbanization, and enhance the urban biodiversity. The main object of this survey are stone wall trees in Macao. The species composition, frequency of occurrence and distribution were ascertained, and the feasibility of establishing stone wall tree landscape trail systems was discussed. The results showed that there were 96 stone wall trees in Macao. Among them, 47.9% of the total in the historical center of Macao. In addition, research and analysis on the species composition, life form, frequency and similarity of the associated plants of stone wall trees were analyzed. The survey found that there were 101 species of companion plants, and herbaceous plants had the greatest growth advantage. Most of the companion species were selective and incidental to the stone wall habitat; the similarity of the companion plants in different habitats was less than 0.25, showing that the stone wall was conducive to species diversity. The results of this research aim to explore planning strategies for holistic conservation of stone wall landscape, and provide a theoretical basis for studying the biodiversity of special habitats in Macao.

Cities characterized by high-density, such as Hong Kong and Macao, have caused severe city problems, like crowded urban space, insufficient ecological green space, and deterioration in quality of residents' life[1]. These urged people to pay more attention to the development of vertical greening space. The greening form of three-dimensional space can hopefully reconcile the contradictions between city development and ecological environment. Meanwhile, walls left or under construction in the city can provide growth potential for some biological groups.

The stone wall in the city refers to the vertical or near vertical surface including retaining wall, enclosure wall, ancient city wall, etc., built by stones, bricks, mortars, concrete and other materials[2]. Urban stone wall is one of the remaining natural habitats of the city. The organisms growing on walls can adapt to urban environment and human disturbance, thereby increasing the city biodiversity, functioning in adjusting local microclimate, and reflecting certain regional characteristics of the city[3].

As early as the nineteenth century, some European scholars had begun to investigate the plants on historical sites like ancient buildings, ancient city walls, and so on. Through field research, some researches about the plants on walls or ancient buildings had been published successively in England, Italy, Rome, Poland, and Czech Republic[4]. In recent years, researches abroad on wall plants have focused on the relationship between wall habitat characteristics and plant diversity[5]. However, there is no clear definition of plants growing on artificial stones or gaps.

Wall plants were defined by Jim[6] according to the stone walls he studies in Hong Kong. He thought that wall plants referred to plants with most roots penetrating into the wall surface, gap or within the wall boundary, excluding plants with most roots not within the wall boundary and plants not attached to the wall. Stone wall trees are consistent with the definition of wall plants put forward by Jim, which accounts for the similar origins of stone wall trees in Hong Kong and Macao.

In Chinese mainland, the earliest researches on wall plants mainly focused on the ancient city walls in Jingzhou City and Nanjing City. Lei et al.[7] compiled the list of angiosperms on Jingzhou Ancient City Wall; Zhou

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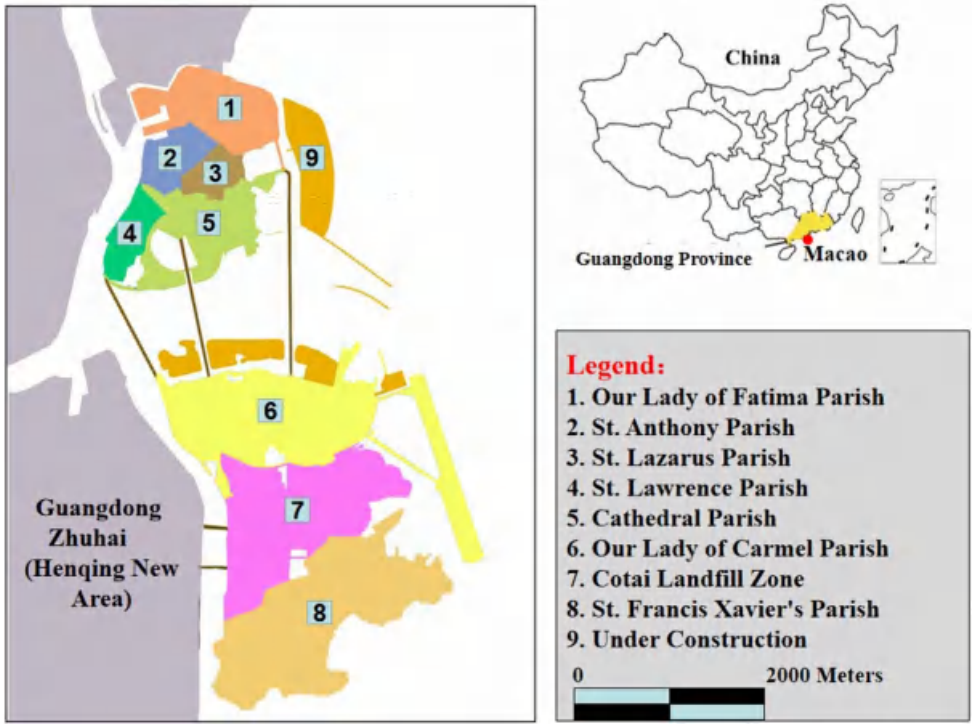


Figure 1. Location of the study area. (URL of the Chinese map: https://www.d-maps.com/m/asia/china/chine/chine48.gif; URL of the Macao map: https://www.d-maps.com/m/asia/china/macau/macau02.gif).

et al.[8] further studied the plant communities' differences due to the slope direction in the north and south section of Jingzhou Ancient City Wall. Wang[9] explored the propagation mechanism of vascular plants on the Ming Dynasty wall of Nanjing. In recent years, some researches on wall biodiversity and city habitat in Hong Kong, Macao, Pearl River Delta, Zhejiang, Chongqing, have been in an increasing trend. In terms of wall habitat, Wu [10]proposed suggestions for plant configuration on the wall by comparing the plant diversity and spatial structure of urban plant walls with the ones of rural plant walls; Li et al.[11] analyzed the reproduction characteristics of the stone wall plants, and compared the differences in species composition between cities in adjacent climate zones. The study of wall habitat began to focus on the connection between wall plants and surrounding ecological environment. Researches on wall plants in Hong Kong, Macao and the Pearl River Delta mostly focused on plant diversity. Zhang et al.[12] studied the flora and life form of wall plants in Macao. The results showed that wall plants were most herbaceous species, and had the most distribution types of tropical Asia[13]. Xie et al.[14] investigated and analyzed the drought tolerance, ornamental, and application of wall plants in the Pearl River Delta. The researches focused on the existing wall plants species and classified analysis.

As stone wall trees less distribute in the world and the traditional stone masonry technology has been lost, stone wall trees are becoming rarer. There are few studies on stone wall trees in Macao. This study is expected to acquaint the special components of urban forestry in Macao, and to provide some inspirations for the conservation of stone wall trees.

Materials and methods

Study area. This study was conducted in Macao (22°06′39″ ~ 22°13′06″N, 113°31′45″ ~ 113°35′43″E), which locates on the coast of the South Sea, connects with Zhuhai city in the north, and connects Hong Kong in the east (Fig. 1). It is sub-tropical maritime climate with mean annual temperature of 14.6 °C and mean annual precipitation of more than 2000 mm[15]. There were 1508 species under 866 genera and 2016 families, including wild plants of 812 species under 525 genera and 158 families[16].

Analytical methods. We inspected the distribution of stone wall trees in Macao, and there were a total of 31 samples. According to the *Flora of China* and *The Flora of Macao*, the species was classified and identified. The main species identifiers were Professors Xing Fuwu and Qin Xinsheng, both of whom have conducted long-term field surveys in Hong Kong, Macao and Guangdong and are familiar with the species in the region. The study used excel and GIS for data analysis and statistical integration.

1. Proportion of occurrence frequency of plants = Number of occurrence of a certain specie/total number of stone wall trees × 100%
2. Jaccard Similarity Coefficient

Family	Frequency of occurrence (%)	Genera	Frequency of occurrence (%)
Moraceae	88.5	*Ficus*	88.5
Ulmaceae	5.2	*Celtis*	4.2
Euphorbiaceae	3.1	*Bridelia*	3.1
Mimosaceae	2.1	*Leucaena*	2.1
Rosaceae	1.0	*Eriobotrya*	1.0
		Trema	1.0

Table 1. Frequency of occurrence of stone wall Trees in different families and genera.

A simpler mathematical expression of community similarity is the community coefficient of Jaccard[17]. The calculation formula is:

$$Sj = c/(a + b + c) \times 100\%$$

a: number of unique species recorded in the first sample; b: number of unique species recorded in the second sample. c:Species shared by both sites.

Results

Species composition of stone wall trees. *Families and genera of stone wall trees.* There were 96 stone wall trees belonging to 6 genera and 5 families in Macao. Among them, Moraceae and *Ficus* appeared the most frequently, both reaching 85 times, accounting for 88.5% (Table 1). It showed that Moraceae, a kind of tropical distribution family, was dominant in the stone wall trees communities, which meant that stone wall trees species in Macao appeared distinctly tropical nature[18].

Species of stone wall trees. There were 16 species of the stone wall trees in Macao including *Bridelia tomentosa*, *Celtis sinensis*, *Eriobotrya japonica*, *Ficus altissima*, *F. benjamina*, *F. elastica*, *F. hispida*, *F. microcarpa*, *F. pandurata*, *F. subpisocarpa*, *F. tinctoria* subsp. *gibbosa*, *F. rumphii*, *F. variegata*, *F. virens*, *Leucaena leucocephala*, and *Trema cannabina* (Fig. 2).

Based on the frequency of occurrence of various tree species, the frequency was concentrated in the range of 1–5%. Among them, *Ficus microcarpa* had the highest frequency, reaching 58 times, with a frequency of 60.4% (Fig. 3). This tree species is robust, adaptable and fast growing, which is the main population of *Ficus*[19].

Stone wall trees in the historic center of Macao. The historic center of Macao, covering an area of about 2.8 km^2, is the heartland of Macao's historical and cultural heritage, which plays a significant role in the cultural heritage around the world[18]. The historic center of Macao provides valuable historical and cultural resources that enable Macao to transform into a world tourism center[20].

A total of 14 plots were located in the historic Center of Macao (Fig. 4), with 45 stone wall trees, accounting for 47.9% of the total number of trees in the survey. Among them, Jardim Luís de Camões has the largest number of 9 stone wall trees. The park, built in the mid-eighteenth century, is one of the oldest gardens in Macao and has the largest number of old trees in Macao. The park had provided good time and environmental conditions for the growth of stone wall trees.

According to Decree No. 56/84/M of the Macao Special Administrative Region Government Printing Department, immovable property that represents the creation of man, or the development of nature or technology and has cultural significance is considered tangible cultural property. The occurrence of the stone wall tree was inextricably linked to ancient wall-building techniques of that time, which was of great significance for the study of the technological development and ecological landscape of the historic center of Macao. The concept of "historic urban landscape" was proposed by Zhang Song[20], who argued that cities were organisms in continuous evolution, emphasizing respect for the interrelationship between natural and man-made environments. The stone wall trees in the historic center of Macao have been associated with the local culture and ecology tightly and should be preserved as important urban landscape.

Symbiotic relationship between tree and stone walls. As shown in the table below (Table 2), it was found that most of the stone wall trees had root systems that were not only superficially attached to the wall but also extended to the top or bottom of the wall. In particular, *Ficus* spp. whose strong root system could closely mosaic with the wall, thus forming a strong symbiosis.

Stone walls can imitate the traditional nature-accommodating features to permit spontaneous establishment of a diverse plant assemblage. Besides vegetative diversities in terms of species composition, growth form and biomass structure, stone walls can support a mass collection of urban wildlife and provide various ecosystem service. It is highly recommended that modern urban design be created to embrace stone wall landscape as an integral part of naturalistic or ecological design.

Vision for the establishment of the stone wall tree trail system in the historic of Macao. The traditional street environment in the Macao Peninsula is a kind of distinctive urban landscape, which can high-

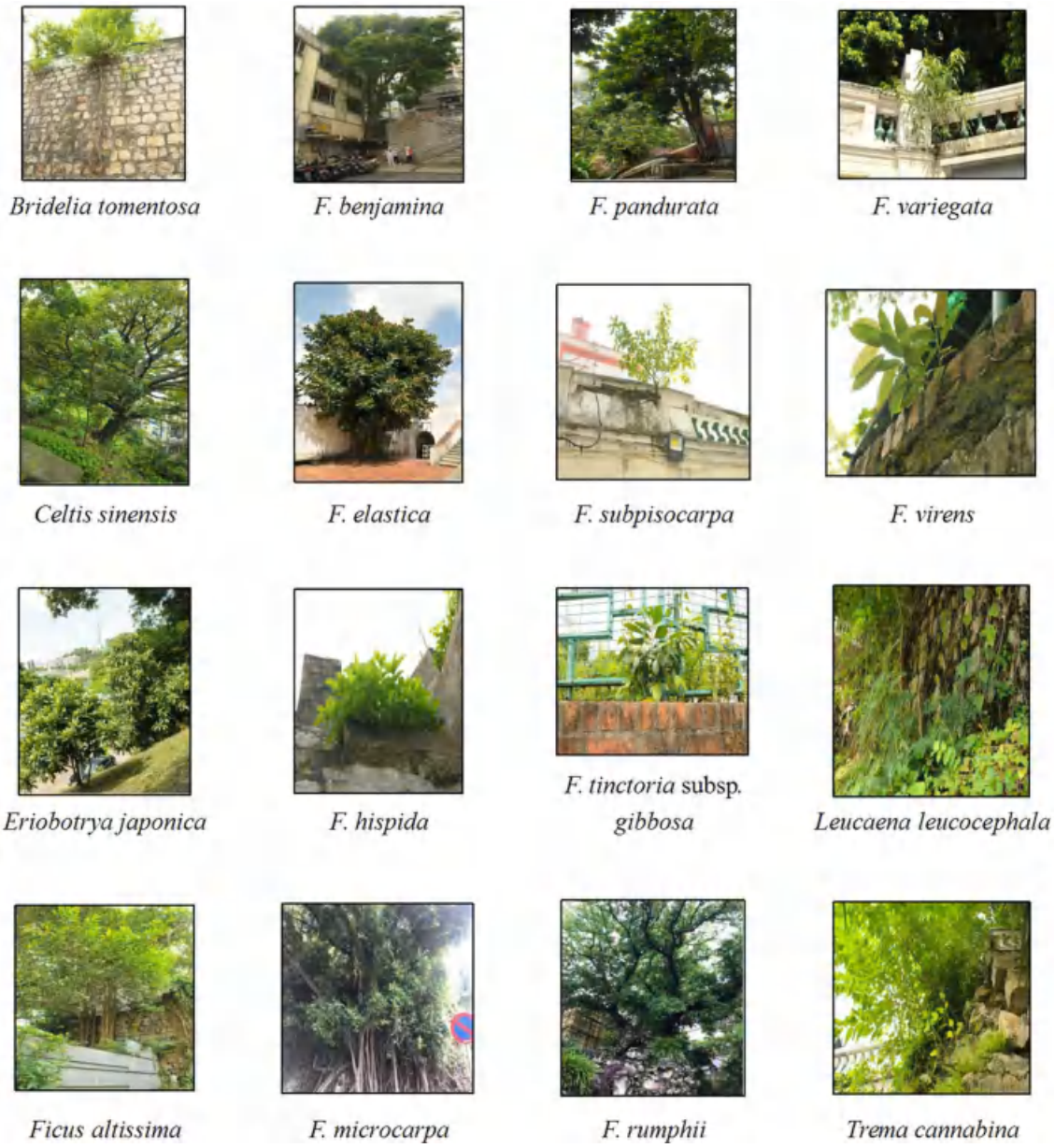


Figure 2. 16 species of stone wall trees in Macao (photo was taken by Professor Qin Xingsheng).

light the specificity and value of the urban context. The combination of the stone wall trees and walls, together with the traditional streets, form a spatial urban landscape. Starting from the location of the stone wall tree landscape, the dots and lines are prospective to promote the establishment of a comprehensive stone wall tree landscape trail system (Fig. 5), so that the public can make use of the existing biological resources to have a better understanding of the land on which they live.

Since 2012, the Macao Government has been implementing the "Strolling along Macao Street" project, which aims at studying and exploring the history and culture of the streets of Macao through an in-depth cultural tourism route and promoting it to different levels of society. The establishment of the stone wall tree trail system can rely on this project to raise the public's awareness of the protection and cultural identity of the stone wall tree landscape through a variety of ways. For example, route design competition, photography competition and exhibition, recruitment of "Stonewall Tree Protection Ambassadors" and other forms of participation, so that the public could complete the "role change" in the high degree of such participation—from "onlookers" to "bystanders".

Survey results of associated plant species. *Species composition and occurrence of frequency.* The survey showed that there were 101 species of stone wall tree associated plants in Macao, under 88 genera and 51 families. Most associated plants belonged to Euphorbiaceae, Compositae, and Araceae.

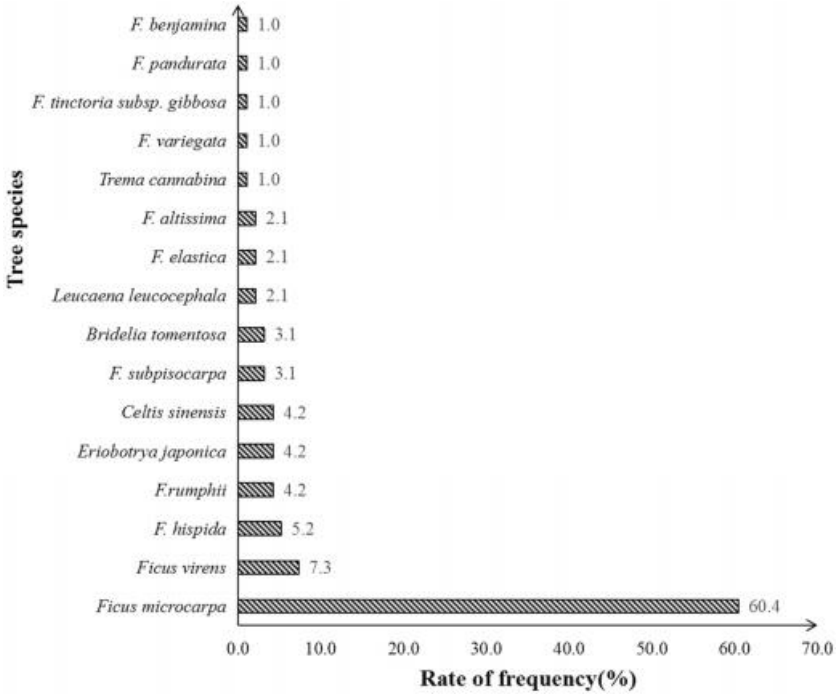


Figure 3. Frequency distribution of stone wall tree species in Macao.

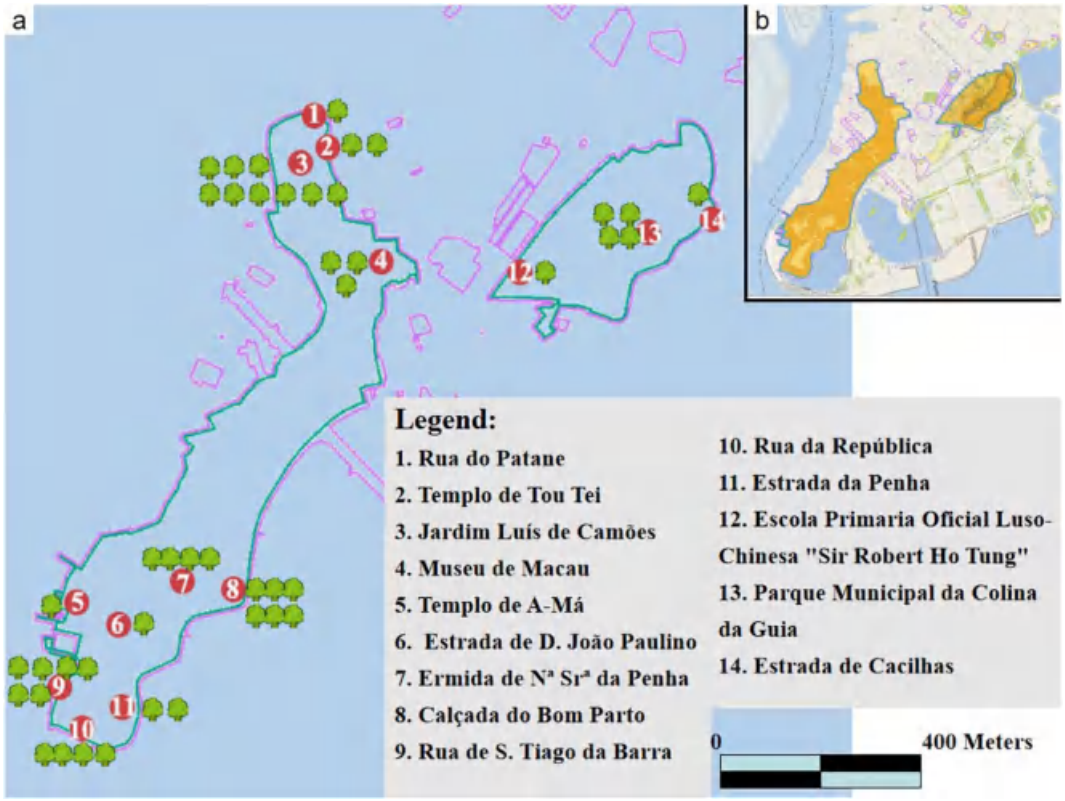


Figure 4. (**a**) Schematic diagram of distribution and number of stone wall trees in the historic Center of Macao. (**b**) Schematic diagram of historic center of Macao. (URL of the Macao map: https://www.d-maps.com/m/asia/china/macau/macau02.gif).

Location of root growing	count	Frequency (%)	Image
Only superficially attached	5	5.2	
Surface-attached and roots growing in the bottom of wall	42	43.8	
Surface-attached and roots growing in the top of wall	22	22.9	
Surface-attached, roots both growing in the top and bottom of wall	27	28.1	

Table 2. The relationship between the root system of the stone wall tree and the wall. (photo was taken by Professor Qin Xinsheng).

There were 85 species with a frequency of 1–5 times, accounting for 84.2% of total species. A total of 11 species appeared 11–15 times, accounting for 4.0% (Fig. 6). There were a total of 4 species that appeared more



Figure 5. Schematic diagram of the stone wall trees trail system on the Macao Peninsula (URL of the Macao map: https://www.d-maps.com/m/asia/china/macau/macau02.gif and the finished map is created by Meisi Chen through the Photoshop CS6 and Arc GIS 10.2).

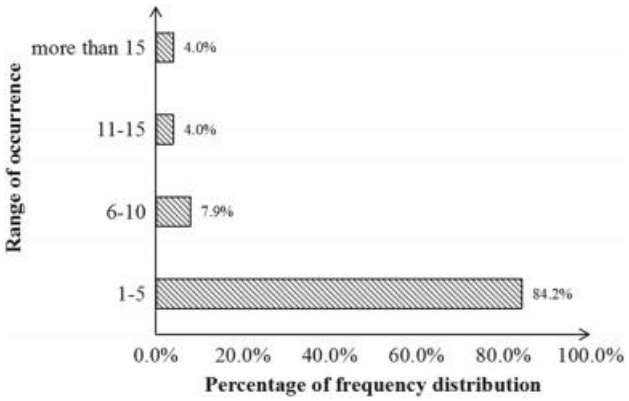


Figure 6. Occurrence frequency in various species of associated plants.

than 15 times. They were *Cocculus orbiculatus*, *Pteris cretica*, *Paederia scandens*, and *Pyrrosia adnascens*. Most of the associated species appeared only 1–5 times, indicating that most plants were selective and accidental for the growth conditions of stone wall sites.

Life form composition. Herbaceous plants with 37 species, accounting the percentage of 52.3% (Fig. 7), were dominant in the associated plant species because the seeds of herbaceous plants are lighter and can be propagated to the wall surface by wind force.

Similarity analysis of the associated plants in Macao. In order to compare the similarity of associated plant species in different environment, the surveyed sample sites for this study were divided into three categories: motorized lanes, non-motorized lanes, and park habitats (Table 3). According to Jaccard's similarity principle, S_j

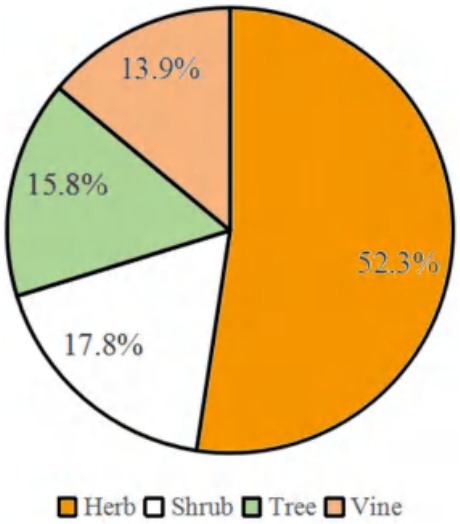


Figure 7. Life form of associated plants with stone wall trees in Macao.

Plots	Motorized lanes	Non-motorized lanes	Parks
Motorized lanes			
Non-motorized lanes	0.190		
Parks	0.130	0.042	

Table 3. Jaccard similarity index for companion plant species composition among three habitats.

is extremely dissimilar when it is 0.00–0.25, and the analysis showed that the similarity of companion plant species in all three habitats was extremely dissimilar. Therefore, it indicated that the companion plants in different habitats had obvious diversity and uniqueness.

Discussion

Differences in species composition of stone wall plants between Macao and cities in adjacent climate zones. The growth of stone wall trees was compared between several cities whose climate conditions are similar to Macao. The life form and species composition of the trees on the stone walls in Macao, Hong Kong, Nanjing and Chongqing show regular changes as the climate zone moves southward[21].

Hong Kong, similar to the climate and environment of the Macao region, also existed extensive stone wall trees. Similar to the survey of the stone wall trees in Macao, *Ficus microcarpa* was also the dominant species of stone wall trees[2]. The reason why it can become widespread group of stone wall trees was closely related to its root vitality. *Ficus microcarpa* could maintain the state of "dry death" in the environment of long-term water shortage[22]. When the rain falls, the aerial roots that seem to be dry and dead for a long time could grow new roots, reflecting a strong vitality. Therefore, compared with other plants, *Ficus microcarpa* may have better adaptability to the barren and dryness on the stone wall.

According to a survey of 289 stone walls in Chongqing[11], *Ficus virens* was dominant tree species of this city. *Ficus virens* has a long history of urban greening in Chongqing, which enables it to become an absolute dominant tree species in Chongqing. Compared with *Ficus microcarpa*, *Ficus virens* as a kind of deciduous tree is more adaptable to the climate conditions with less precipitation in Chongqing area and is more tolerant to the winter environmental stress in the area.

The dominant tree species in Nanjing was *Broussonetia papyrifera*, which was also the common tree species in Hong Kong, and Chongqing. *Broussonetia papyrifera* with fast-growing characteristics, whose fruits are succulent and large in quantity, are easy to spread seeds through birds[23].

The dominant stone wall tree species in various regions were closely related to local climate characteristics, natural species resources, characteristics of tree species, and human cultivation history[24]. The combination of different factors had created differences in the dominant stone wall tree species between cities.

Ecological benefits of stone wall trees in Macao. Most of the stone wall tree groups were *Ficus* species[25], which were tall in shape and dense in crown. The most frequent occurrence of *Ficus microcarpa* among the *Ficus* was 60.4%. It shows that *Ficus microcarpa* is well adapted to the special growing environment of the stone wall and can absorb the nutrients inside the stone wall through its strong root system, thus ensuring its growth in the difficult environment. *Ficus microcarpa* are excellent habitats for many birds and insects, giving

birth to relatively stable animal and plant habitat communities, so as to improve the local microclimate and environment.

Stone wall trees should be integrally protected together with the wall. The stone walls together with their vegetative companions constitute a unique urban ecology in Macao. The fortunate combination of abiotic and biotic factors, in an inordinately harsh compact city environment, on an apparently inhospitable habitat, has allowed abundant vegetative. Considering the stressful habitat conditions, the resulting of plant diversity is rare surprising, comprising a various range of species and life forms that range from lichen-moss to herbs, shrubs and trees.

The rich diversity and pleasant landscape quality of wall vegetation provide essential environmental and visual amenities. The mural vegetation has thrived spontaneously owing to a century or more of minimal human disturbance. Thus stone wall plants and walls are supposed to be protected as a combination to maximize their ecological benefit and aesthetic value. Measures could be taken to impede the decline in the natural supply of water-nutrient, seeds that could allow plant establishment.

Conclusions

In the twenty-first century, the development of new technology revolution has brought tremendous changes to the economic structure, people's living concepts, lifestyles and cultural practices. While enjoying the convenience and comfort brought by high technology, cities also impart people a sense of loneliness and depression. Many start to attach importance to the urban environment which is humane, historical and cultural. This research clarified in detail stone wall trees' important ecological and cultural value in Macao by analyzing their species characteristics and distribution locations. The combined landscape formed by the stone wall tree and walls is an important element in the study of Macao, as the landscape is closely connected with the adjacent space and the emotions of the residents through time, therefore it is necessary to explore rational and scientific conservation strategies for the stonewall landscape in order to optimize the urban ecosystem.

Guideline statement. This research strictly complies with the Regulations of the People's Republic of China on the Protection of Wild Plants, and we conducts legal research and utilization of the wild plants involved in the survey.

Received: 18 March 2021; Accepted: 10 January 2022
Published online: 28 January 2022

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Acknowledgements

This study was supported by Guangzhou Landscaping Company, Association for the Promotion of Landscaping and Greening in Macao, Brilliant Landscaping & Gardening Co., Ltd., the National Natural Science Foundation of China (31870699), project of Research on Urban Tree Protection and Its Strategy Based on the Ecological Environment Safety (GZLC-Z202006) and National Training Programs of Innovation and Entrepreneurship for Undergraduates (201910564048). Thanks to Ms. Xueqin Lu from Arizona State University for participating in the English revision work. Thanks SCAU Wushan Campus Teaching & Research Base for its provision.

Author contributions

M.C. put forward the idea of the thesis and completed the writing of the thesis. S.H. provided guidance on the writing. Z.C. and Y.X. was responsible for tree species survey in the field survey. F.X. adjusted the article structure. K.L. sorted some survey data. Y.Y. provided the necessary supplementary data. Y.Q. revised and improved the English writing of this article. X.Q. revised the article critically for important intellectual content and helped perform the analysis with constructive discussions.

Competing interests

The authors declare no competing interests.

Additional information

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中国自然科学核心期刊 全国中文核心期刊
全国优秀农业科技期刊 中国精品科技期刊

ISSN 1002-7351
CN 35-1136/S

福建林业科技

JOURNAL OF FUJIAN FORESTRY SCIENCE AND TECHNOLOGY

主管单位：福建省林业局
主办单位：福建省林学会 福建省林业科学研究院

2
2022
总第199期

ISSN 1002-7351
06>
9 771002 735221

第49卷第2期 Vol.49 No.2
2022年6月 Jun., 2022
FUJIAN LINYE KEJI

福建林业科技
Fujian Linye keji
季 刊
第49卷第2期
2022年6月

全国中文核心期刊
中国精品科技期刊
RCCSE中国核心学术期刊
全国优秀农业科技期刊

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期刊基本参数：CN35-1136/S • 1974 • q • A4 • 140 • zh • P • ¥15.00 • 2500 • 25 • 2022-06

福建林业科技
Fujian Linye keji
(季刊 1974年创刊)
主管单位：福建省林业局
主办单位：福建省林学会
福建省林业科学研究院
编辑出版：《福建林业科技》编辑部
本刊地址：福州市晋安区新店上赤桥35号
邮政编码：350012
联系电话：(0591)87911427
本刊网址：http://fjlk.chinajournal.net.cn
http://fjlykj.periodicals.net.cn
E-mail：linyekeji@vip.tom.com
或 linyekeji@163.net

主　　编：黄云鹏
副 主 编：叶功富　周新年
蒋家淡(常务)
责任编辑：许信玲
编　　辑：罗彩莲　刘　寒
排版印刷：福州雄胜彩印有限公司
邮发代号：34-34
订　　价：15.00元
订　　阅：全国各地邮政局(所)
海外总发行：中国国际图书贸易集团有限公司
国外发行代号：Q2621
国际标准连续出版物号：ISSN 1002-7351
国内统一连续出版物号：CN 35-1136/S
广告经营许可证：3500004000362

doi: 10.13428/j.cnki.fjlk.2022.02.021

广东陆丰市豆科野生药用植物资源调查分析

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摘要: 2021年8月,根据陆丰市药用植物资源普查数据和文献资料,探讨广东省陆丰市豆科野生药用植物资源的现状和利用情况,并分析该地区豆科野生植物地理成分特征。结果显示,陆丰市野生豆科植物32属53种,其中27属(占总属数的84.38%)37种(占总种数的69.81%)具有药用价值,以平性,苦、甘味药为主,具有清热解毒、凉血止血等功效;该市野生豆科植物以热带、亚热带成分为主,兼有少量温带成分,带有明显的过渡性质。研究结果可为广东陆丰市豆科药用植物资源的开发和利用提供参考。

关键词: 豆科;野生药用植物;植物地理成分;广东陆丰市
中图分类号: S757.2;Q949.95 **文献标识码:** A **文章编号:** 1002-7351(2022)02-0116-06

Investigation and Analysis of Wild Medicinal Plant Resources of Fabaceae in Lufeng City, Guangdong Province

YANG Jun, HUANG Junkai, QIN Xinsheng
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Abstract: In August 2021, according to the survey data and literature data of the medicinal plant resources in Lufeng City, the current situation and utilization of the wild medicinal plant resources of Fabaceae in Lufeng City, Guangdong Province were discussed, and geographical composition characteristics of Fabaceae wild plants in this area were analyzed. The results showed that there were 32 genera and 53 species of Fabaceae wild plants in Lufeng City, among which 27 genera (84.38% of the total number of genera) and 37 species (69.81% of the total number of species) had medicinal values. They were mainly flat, bitter and sweet medicines, and had the effects of clearing heat-toxic, cooling blood for hemostasis. The wild plants of Fabaceae were mainly tropical and subtropical components, with a small amount of temperate components, with obvious transitional properties. The study results can provide a reference for the development and utilization of leguminous medicinal plant resources in Lufeng, Guangdong.

Keywords: Fabaceae; wild medicinal plants; phytogeographic composition; Lufeng City Guangdong Province

豆科(Fabaceae)植物是人类食品中淀粉、蛋白质、油和蔬菜的重要来源之一,具有重要的经济意义,全世界约有748属,19700种,中国(包括栽培种)共有172属,1667种(亚种、变种、变型)[1-2]。广东省分布有豆科植物121属443种(亚种、变种、变型)[3],分别占全国豆科总属数的70.35%,总种数的26.57%,是豆科植物多样性较高的省份。豆科植物含有众多药用成分,如:三萜类、黄酮类、生物碱等抗肿瘤活性成分,具有很好的开发利用前景。在当前国家日益重视中医中药资源保护和利用以及乡村振兴的大背景下,对陆丰市豆科野生药用植物资源进行本底情况的整理和潜在价值的发掘具有重要的现实意义。

自新中国成立后,我国相继组织开展了三次全国中药资源普查。距第三次全国中药资源普查已过去30多年,国内药用植物的种类、资源分布、蕴藏量均发生了巨大变化。同时近些年野生药用植物滥采滥挖现象严重,生长环境遭到严重破坏;并且对中药资源保护和可持续利用的意识薄弱,导致中药种植栽培混

收稿日期: 2021-11-15; **修回日期:** 2022-01-13
基金项目: 2019年医疗服务与保障能力提升补助资金:中医药事业传承与发展部分(全国中药资源普查项目,财社[2019]39号);广东省林业科技创新项目(2018KJCX030)
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乱不均、药材质量参差不齐等问题层出不穷。基于以上背景，我国自 2011 年开始进行全国第四次中药资源普查[4]。依托此次普查，本文对陆丰市的豆科植物进行系统的调查分析，以期为今后更好的开发和利用豆科植物资源提供基础资料。

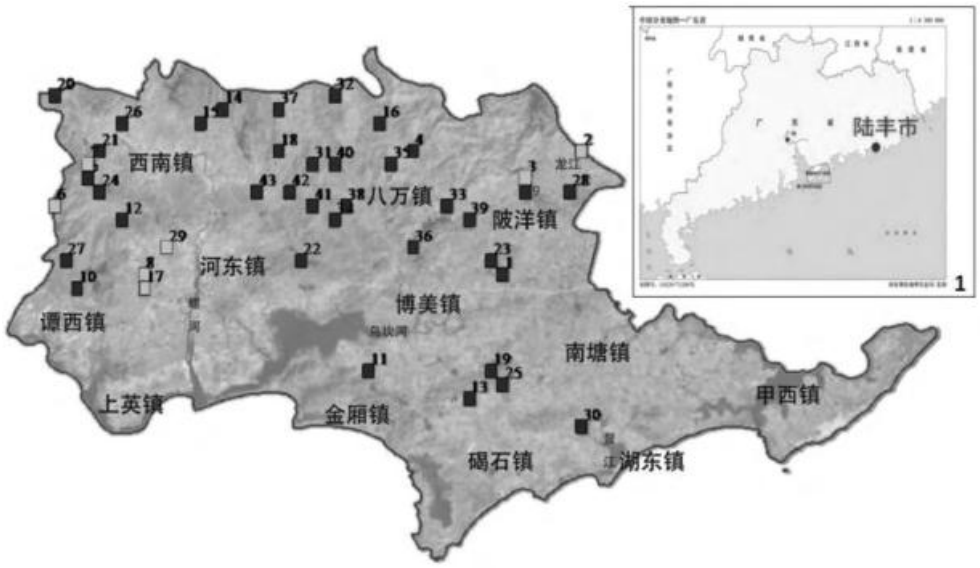
1　研究地概况

陆丰市隶属于广东省，由汕尾市代管，位于 115°15′—116°8′ E、22°27′—23°5′ N 之间，境内地势平坦，北部以山地为主，中部与南部多为丘陵、台地、平原与低洼地。陆丰市位于北回归线以南，属南亚热带季风气候，市中心城区年均气温大于 21.8 ℃，全年年均降水量为 1900 ~ 2500 mm，主要集中在 3—10 月[5]。

2　研究方法

广东省陆丰市中药资源普查队采用系统抽样法在陆丰市布设 43 个大小为 1 km × 1 km 的样地(图 1) ，按照完成 80% 以上样地的要求[6]，于 2021 年 8 月完成 36 个样地。每个样地范围内采用等距法均匀设置 5 个样方套，每个样方套内设置 6 个样方(1 个 10 m × 10 m 的乔木样方，1 个 5 m × 5 m 的灌木样方，4 个 1 m × 1 m 的草本样方) ，调查样方内野生药用植物资源的种类、数量、分布等，共计完成 36 个样地、180 个样方套、1080 个样方; 同时结合样线调查，对不同区域的典型植被进行调查和采集标本。样地和样线覆盖陆丰市全域范围。

在本次外业调查的基础上，通过查阅核对相关文献资料和有关标本馆(室) 标本，确定陆丰市豆科植物名录，再利用《中华人民共和国药典》[7]《全国中草药汇编》[8]《中药大辞典》[9]《潮汕中草药》[10] 等查证陆丰市豆科野生植物中富含药用价值的种类。



圆点为陆丰市在广东省的位置; 数字为系统生成的样地号，深色框为已调查样方，浅色框为未调查样地。

图 1　广东省陆丰市野生药用植物样地设置情况

3　结果与分析

3.1　药用植物资源分析

据本次调查统计，陆丰市豆科植物共有 32 属 53 种，其中野生药用植物 27 属 37 种，占总种数的 69.81%。对陆丰市的豆科植物的入药部位、中药性味、功效和分布情况进行系统的统计，汇总成陆丰市豆科药用植物资源情况表(表 1) 。

陆丰市 37 种豆科野生药用植物中，16 种以根入药，11 种以全草入药，10 种以叶入药，9 种以茎入药，

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以枝和种子入药各3种，以花入药仅1种。药性以平性居多，有17种，占45.95%；寒性最少，仅4种，占10.81%。药味以苦和甘为主，药味含苦和甘的植物分别有21种和19种，苦味药化学成分主要为生物碱、黄酮甙类等，有泻火、燥湿、降气的功效[11]；甘味药多含有糖类、皂苷、脂肪、维生素、蛋白质、甾醇、氨基酸等，具有调节机能，补其机体不足，增强机体抗病能力以及杀菌、解热、降血脂、降血压、降血糖、利尿等方面的作用[12]。

按照药用功效区别，可分为清热解毒、凉血止血类23种，包括丁癸草(*Zornia gibbosa*)、葫芦茶(*Tadehagi triquetrum*)、毛相思子(*Abrus pulchellus* subsp. *mollis*)等；补血活血、舒筋活络类13种，如亮叶鸡血藤(*Callerya nitida*)、白花油麻藤(*Mucuna birdwoodiana*)、香花鸡血藤(*Callerya dielsiana*)等；利尿滋养、消肿排脓类8种，如硬毛木蓝(*Indigofera hirsuta*)、千斤拔(*Flemingia prostrata*)、藤黄檀(*Dalbergia hancei*)等；祛痰、平喘类5种；如鸡头薯(*Eriosema chinense*)、猫尾草(*Uraria crinita*)等；健胃、健脾类4种，如龙须藤(*Bauhinia championii*)、灰毛豆(*Tephrosia purpurea*)、小叶三点金(*Desmodium microphyllum*)等；清肝明目类3种，如链荚豆(*Alysicarpus vaginalis*)、合萌(*Aeschynomene indica*)、望江南(*Senna occidentalis*)等[13-14]。其中，以清热解毒、凉血止血类(23种)的药用植物最多，而健胃、健脾类(4种)、清肝明目类(3种)最少。同种植物往往同时具有不同类型的功效，这是由豆科野生药用植物化学成分多样所决定的。

根据野外调查结果显示，这37种豆科野生药用植物主要分布在陆丰市的西南镇和八万镇，出现在3个样地以上的豆科植物有台湾相思、香港黄檀(*Dalbergia millettii*)、假地豆(*Desmodium heterocarpon*)、毛排钱树(*Phyllodium elegans*)、葛(*Pueraria montana*)、葫芦茶和猫尾草，其中又以假地豆、葛、葫芦茶分布最广，分布量最多。

表1 广东省陆丰市野生豆科药用植物资源情况表

种名	学名	入药部位	性味	药效	分布
毛相思子	*Abrus pulchellus* subsp. *mollis*	全草(种子有毒)	平；甘	清暑解表	兴田场
台湾相思	*Acacia confusa*	种子	平；辛、苦	祛风燥湿、解毒杀虫	黄泥溜、汕水塘水库、巷口水库、八万角、灯心湖、走马夫
合萌	*Aeschynomene indica*	根、茎、叶	寒；甘、苦	利尿解毒、清肝热、口腔溃烂	头肖乡
链荚豆	*Alysicarpus vaginalis*	全草	凉；甘	清肝热、治眼目赤痛、口腔溃烂肿胀	走马夫
猴耳环	*Archidendron clypearia*	枝、叶	凉；微苦、涩	清热解毒、祛湿敛疮、消炎	上官寮、高梓田
亮叶猴耳环	*Archidendron lucidum*	枝、叶	凉；涩、苦	凉血、消炎、生肌、消肿	陂角、灯心湖
龙须藤	*Bauhinia championii*	茎	平；苦、涩	祛风除湿、活血止痛、健脾理气	桥冲
香花鸡血藤	*Callerya dielsiana*	茎	温；苦、涩、微甘	补血止血、活血、通经活络	石门仔
亮叶鸡血藤	*Callerya nitida*	根	温；苦、甘	补血、活血、通络	罗经嶂
美丽鸡血藤	*Callerya speciosa*	根	平；甘	补虚润肺、强筋活络	陂角
猪屎豆	*Crotalaria pallida*	全草	平；苦、辛	清热利湿、解毒散结	五里排水库
藤黄檀	*Dalbergia hancei*	根、茎	温；辛	理气止痛	高梓田、灯心湖
香港黄檀	*Dalbergia millettii*	叶	温；辛	止血止痛	九斗凹村、芹洋村、山寨围、琼林村

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表 1(续)

种名	学名	入药部位	性味	药效	分布
假地豆	*Desmodium heterocarpon*	全草	寒; 苦、甘	清热解毒、消肿止痛	走马夫、上官寮、南新、天宝寺、秋冬村、汕水塘水库、黄泥溜
异叶山蚂蝗	*Desmodium heterophyllum*	全草	凉; 淡	利水通淋、散瘀消肿	金竹萍
小叶三点金	*Desmodium microphyllum*	根及全草	平; 甘	健脾利湿、止咳平喘、解毒消肿	头肖乡
三点金	*Desmodium triflorum*	全草	温; 苦、微辛	行气止痛、温经散寒、解毒	走马夫、菜坑
鸡头薯	*Eriosema chinense*	根	平; 甘	清热解毒、生津止渴、止咳化痰	塔仔行水库
千斤拔	*Flemingia prostrata*	根	微温、平; 甘	祛风利湿、消瘀解毒	石艮
硬毛木蓝	*Indigofera hirsuta*	枝、叶	寒; 微苦	解毒、散肿	洋口村
胡枝子	*Lespedeza bicolor*	根、茎、叶	凉、平; 辛、微苦、甘	解表	石艮
美丽胡枝子	*Lespedeza thunbergii* subsp. *formosa*	茎	平; 苦	清肺热、祛风湿、散瘀血	巷口水库
银合欢	*Leucaena leucocephala*	根皮	平; 甘、涩	收敛止血、解毒消肿	溪碧
含羞草	*Mimosa pudica*	全草	凉; 甘、微苦	清热、利尿、消炎、散淤	内岗、汕水塘水库、天宝寺
白花油麻藤	*Mucuna birdwoodiana*	根、茎、叶	平; 微苦、涩	补血、通经络、强筋骨	石门仔
毛排钱树	*Phyllodium elegans*	根	平; 苦、涩	祛湿解表、去瘀消滞	上官寮、八万角、菜坑、汕水塘水库、秋冬村、麻竹坑村
排钱树	*Phyllodium pulchellum*	根、叶	凉; 淡、涩	清热解毒、活血散瘀、利尿	秋冬村
水黄皮	*Pongamia pinnata*	种子	寒; 苦	祛风除湿、解毒杀虫	桥冲
葛	*Pueraria montana*	根、花	平; 甘、辛	清热解毒、生津止渴、透发麻疹	兴田场、内岗、黄泥溜、汕水塘水库、秋冬村、麻竹坑水库、天宝寺、上官寮、洋口村、灯心湖
三裂叶野葛	*Pueraria phaseoloides*	根	平; 甘	解热、驱虫	洋口村、安溪峡水库
鹿藿	*Rhynchosia volubilis*	根、叶	平; 甘	活血止痛、解毒、消积晕	王厝村、天宝寺
望江南	*Senna occidentalis*	荚果或种子	凉; 甘、苦	清肝明目、健胃、通便、解毒	麻竹坑村
密花豆	*Spatholobus suberectus*	茎	温; 苦、甘	补血、活血、通络	兴田场、芹洋村
葫芦茶	*Tadehagi triquetrum*	全草	凉; 微苦、涩	清热解毒、消积利湿	南新、山寨围、天宝寺、秋冬村、汕水塘水库、黄泥溜、第二村、上官寮

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表1(续)

种名	学名	入药部位	性味	药效	分布
灰毛豆	*Tephrosia purpurea*	根、茎、叶	平;微苦	解表、健脾燥湿、行气止痛	罗肖乡、甲子镇
猫尾草	*Uraria crinita*	全草	凉;淡	清热化痰、凉血止血	小场、长铺村、巷口水库、八子娘
丁癸草	*Zornia gibbosa*	全草	凉;甘、淡	清热解毒、凉血解毒	王厝村、鸟笼坑水库

3.2 地理成分分析

根据吴征镒对中国种子植物属的分布区类型划分原则[15-16],将陆丰市野生豆科植物32属53种分为6个分布区类型及2个变型(表2)。

泛热带分布:16属28种,占总属数的50%,分别为相思子属(*Abrus*)、金合欢属(*Acacia*)、羊蹄甲属(*Bauhinia*)、云实属(*Caesalpinia*)、鸡血藤属(*Callerya*)、猪屎豆属(*Crotalaria*)、黄檀属(*Dalbergia*)、鸡头薯属(*Eriosema*)、千斤拔属(*Flemingia*)、木蓝属(*Indigofera*)、银合欢属(*Leucaena*)、黧豆属(*Mucuna*)、鹿藿属(*Rhynchosia*)、决明属(*Senna*)、灰毛豆属(*Tephrosia*)、丁癸草属(*Zornia*)。该区系成分的豆科植物在海拔50~2500 m均有分布,在热带、亚热带广泛分布。热带亚洲、非洲和中、南美洲间断分布:1属2种,为含羞草属(*Mimosa*)。旧世界热带分布:3属3种,为合欢属(*Albizia*)、链荚豆属(*Alysicarpus*)、狸尾豆属(*Uraria*),皆为区域单种属,广布热带。热带亚洲至热带大洋洲分布:1属1种,为水黄皮属(*Pongamia*),单型属,分布在海岸林中。热带亚洲至热带非洲分布:2属2种,为大豆属(*Glycine*)、朱缨花属(*Calliandra*)。该区系成分豆科植物带有明显稀树草原(至季风林)的特性,或许是古南大陆中部的稀树草原生境在历史上较长期而稳定的反映[12]。热带亚洲(印度-马来西亚)分布:5属7种,分别为合萌属(*Aeschynomene*)、猴耳环属(*Archidendron*)、葛属(*Pueraria*)、密花豆属(*Spatholobus*)、葫芦茶属(*Tadehagi*);除猴耳环属、葛属含2种外,其余均为单种属。热带印度至华南(尤其云南南部)分布:1属2种,为排钱树属(*Phyllodium*),广布热带、亚热带。东亚和北美洲间断分布:3属8种,分别为两型豆属(*Amphicarpaea*)、山蚂蝗属(*Desmodium*)、胡枝子属(*Lespedeza*)。该分布区类型植物分布于温带及亚热带地区。

陆丰市野生豆科植物没有世界分布的属,以热带、亚热带成分为主,兼有少量温带成分,带有明显的过渡性质。而陆丰市在现代植物区系划分中隶属于东亚植物区南岭东段亚地区,且处于东亚植物区和古热带植物区的过渡地带[16-17],豆科植物的区划分析结果侧面印证了植物区划的合理性。此外,陆丰市豆科植物中单种属占总属数的59.37%,反映属的地理成分具有较强的多样性、分散性和复杂性,说明该区域古老残遗植物类群保存良好和适宜新建类群迁移定居。

表2 广东省陆丰市野生豆科植物的分布区类型和变型

分类区类型	属数	占总属数的百分比/%	种数	占总种数的百分比/%
2. 泛热带分布	16	50.00	28	52.83
2-3. 热带亚洲、非洲和中、南美洲间断分布	1	3.13	2	3.77
4. 旧世界热带分布	3	9.38	3	5.66
5. 热带亚洲至热带大洋洲分布	1	3.13	1	1.89
6. 热带亚洲至热带非洲分布	2	6.25	2	3.77
7. 热带亚洲(印度一马来西亚)分布	5	15.63	7	13.21
7-2. 热带印度至华南(尤其云南南部)分布	1	3.13	2	3.77
9. 东亚和北美洲间断分布	3	9.38	8	15.09
合计	32	100.00	53	100.00

4 豆科药用植物资源开发利用现状与建议

4.1 开发利用现状

人们对豆科植物的研究和利用历史悠久,其药用功效主要是清热解毒、消肿止痛、止血等[18]。近年

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来，国内外许多学者也对豆科植物的化学组成及药理活性做了大量研究，发现决明属植物具有抗菌、抗糖尿病、抗寄生虫等作用，陆丰常见的决明属植物望江南可作缓泻剂，种子炒后可治疟疾；云实属植物及其提取物具有抗炎、抗疟、抗病毒、抗肿瘤等方面的药理作用；密花豆（*Spatholobus suberectus*）中的儿茶素可促进造血和红系祖细胞的增殖和分化[19-21]。陆丰地区对于中医药十分重视，具有悠久的豆科药用植物利用历史，形成了一批具地方特色的药用植物材料和药方，如：当地人使用香花鸡血藤的鲜根以酒、水煎服，用于治疗关节风湿痛；美丽胡枝子（*Lespedeza thunbergii* subsp. *formosa*）的鲜根和酒精捣烂敷伤处，可用于治疗扭伤、脱臼、骨折。此外，葛的块状根可用于治疗早期突发性耳聋，炖服可用于治疗心热吐血不止；花有解毒止渴，治酒醉烦渴的功效。通过走访调查发现除美丽鸡血藤（*Callerya speciosa*）等少数植物实现了人工种植，其余都为野生分布，人们在利用这些药用植物时多是靠采挖野生植株，对生态造成了一定的破坏。此外部分药用植物尚处于书籍记载或是科学研究阶段，未得到有效开发，导致资源浪费。

4.2　开发利用建议

结合外业调查和内业分析，得知陆丰市豆科野生药用植物主要分布在西南地区，如西南镇、八万镇等，呈现种类丰富多样，分布范围广泛的特点，后续仍然需要加强对豆科植物的资源调查，细化调查内容，注重药用植物种类、分布、蓄积量等方面的调查，完善药用植物资源的本底资料，为开发利用提供科学资料和依据。

加强豆科药用植物的宣传工作，向人们普及其药效、开发价值和种群情况等；相关部门制定豆科药用植物的保护和利用方案，推进对豆科植物的传统药用经验、化学组成、药理活性、育种和栽培技术、基因多样性、制剂工艺等的研究，适当开展道地药材的引种驯化；在保护野生资源的同时推动当地的经济发展，为乡村振兴提供新思路。

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International Journal of
Environmental Research and Public Health

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Purification Efficiency of Three Combinations of Native Aquatic Macrophytes in Artificial Wastewater in Autumn

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Abstract: Water pollution caused by excessive nutrient and biological invasion is increasingly widespread in China, which can lead to problems with drinking water as well as serious damage to the ecosystem if not be properly treated. Aquatic plant restoration (phytoremediation) has become a promising and increasingly popular solution. In this study, eight native species of low-temperature-tolerant aquatic macrophytes were chosen to construct three combinations of aquatic macrophytes to study their purification efficiency on eutrophic water in large open tanks during autumn in Guangzhou City. The total nitrogen (TN) removal rates of group A (*Vallisneria natans* + *Ludwigia adscendens* + *Monochoria vaginalis* + *Saururus chinensis*), group B (*V. natans* + *Ipomoea aquatica* + *Acorus calamus* + *Typha orientalis*), and group C (*V. natans* + *L. adscendens* + *Schoenoplectus juncoides* + *T. orientalis*) were 79.10%, 46.39%, and 67.46%, respectively. The total phosphorus (TP) removal rates were 89.39%, 88.37%, and 91.96% in groups A, B, and C, respectively, while the chemical oxygen demand (COD) removal rates were 93.91%, 96.48%, and 92.78%, respectively. In the control group (CK), the removal rates of TN, TP, and COD were 70.42%, 86.59%, and 87.94%, respectively. The overall removal rates of TN, TP, and COD in the plant groups were only slightly higher than that in CK group, which did not show a significant advantage. This may be related to the leaf decay of some aquatic plants during the experiment, whereby the decay of *V. natans* was the most obvious. The results suggest that a proper amount of plant residue will not lead to a significant deterioration of water quality.

Keywords: aquatic plants; nitrogen and phosphorus; purification efficiency

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Citation: Xu, L.; Chen, S.; Zhuang, P.; Xie, D.; Yu, X.; Liu, D.; Li, Z.; Qin, X.; Wang, F.; Xing, F. Purification Efficiency of Three Combinations of Native Aquatic Macrophytes in Artificial Wastewater in Autumn. *Int. J. Environ. Res. Public Health* **2021**, *18*, 6162. https://doi.org/10.3390/ijerph18116162

Academic Editor: Daniela Varrica

Received: 18 May 2021
Accepted: 1 June 2021
Published: 7 June 2021

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1. Introduction

The pollution of water sources has been an issue of considerable public interest over the past few decades [1]. The wastewater pollution by excessive nitrogen (N) and phosphorus (P) has become a widespread global problem, leading to the degradation of aquatic ecosystems, a decline in biodiversity, the collapse of nutrient cycles, and the development of water blooms [2–4]. For example, eutrophication has caused negative effects on agricultural, industrial, and drinking water production [5]. To address these serious issues, various physical, chemical, and biological measures have been applied to remediate N and P pollution over the past several decades [6–8], including aeration, water diversion, sediment dredging, chemical flocculation, chemical algaecide addition, and in

situ chemical reaction techniques. Some of these approaches have high environmental costs because they can cause secondary pollution for the use of chemical agents, which can even destroy river ecosystems [9,10]. In recent years, phytoremediation using aquatic plants with high productivities and nutrient removal capabilities has received increasing public attention [11,12]. Phytoremediation uses plants to mitigate, transfer, stabilize, or degrade pollutants in soil, sediment, and water. This technique has been extensively applied in rivers [13], lakes [14], and constructed wetlands [15,16].

Vegetation is an important component that plays a key role in aquatic environments. As primary producers, plants supply food to the first consumers in trophic chains [17]. Vegetation also provides habitats and refuges for periphyton [18], zooplankton [19], and other invertebrate species [20]. Wastewater treatment in aquatic macrophyte systems occurs through several mechanisms, including solid settling, plant uptake of contaminants, biotransformation, and physicochemical reactions [12]. Previous studies on the phytoremediation of eutrophic waterbodies were usually carried out during warm seasons and mainly focused on the effect of individual plant species [21–23]. A study reported that water hyacinth achieved the highest removal efficiency for total N (TN) (89.4%) and ammonium N (NH_4^+-N) (99.0%) during a static experiment under a water temperature of 28~36 °C, while water lettuce exhibited the highest removal efficiency for total P (TP) (93.6%) [8]. However, fewer studies have reported on their efficacy in autumn and winter. There are insufficient systematic studies on the annual efficiency of water purification by aquatic plants. Therefore, it is meaningful to do some research on phytoremediation in low temperature season.

In fact, the nutrient absorption and water purification effects of different plants vary greatly, and the same plant may have a better removal effect on one index of water quality, while the effect on other indexes may be relatively poor. Single plant systems are temporally and spatially limited in their ability to assimilate N and P, thus potentially affecting the N and P removal rates. On the other hand, multi-species systems should deliver good performance by buffering against variations in weather and nutrient conditions as a result of their diversity and adaptability [24]. Some studies have shown that multiple plants can purify water quality better than a single plant owing to a more reasonable species diversity, which makes it easier to maintain the long-term stability of the ecological system [5,25]. Coleman et al. [26] found that the mixed planting of *Schoenoplectus tabernaemontani*, *Juncus effusus*, and *Typha latifolia* had a better purification effect on domestic sewage than a single species. However, some studies have pointed out that there is no significant difference between mixed and single planting [27]. The removal mechanisms and effects of water nutrients using combinations of different aquatic plants need to be explored more effectively.

Plant invaders can greatly diminish the abundance or survival of native species and can completely alter the native ecosystem in terrestrial and freshwater habitats [28]; however, exotic plants with strong reproduction are widely used in China [29]. For instance, *Eichhornia crassipes* may be the most important and commonly used species of aquatic macrophytes used to treat wastewater [30].

The aim of this study is to compare the potential of native aquatic plant combinations for the restoration of eutrophic waterbodies during autumn. In this study, various combinations of selected plant species were tested for their ability to remove nutrients from wastewater in open tanks over 54 days. The results provide a reference for engineering practice of water restoration in subtropical areas during autumn.

2. Materials and Methods

2.1. Plant Species

The plants used in this experiment were listed in Table 1 and were selected from the countryside in the Guangdong Province. All plants were grown in running water for a week before starting the experiment. The stem of *Saururus chinensis* was placed directly on the water surface to make it grow freely like a floating plant, while *Monochoria vaginalis*

was fixed on the water surface with a container like the plants in an ecological floating bed. The roots of other plants were anchored to the bottom with sand.

Table 1. Aquatic plant species selected in this study.

Scientific Name	Family	Type	Group Number
Vallisneria natans	Hydrocharitaceae	Submerged	A, B, C
Ludwigia adscendens	Onagraceae	Floating	A, C
Ipomoea aquatica	Convolvulaceae	Floating	B
Monochoria vaginalis	Pontederiaceae	Floating/emergent	A
Saururus chinensis	Saururaceae	Floating/emergent	A
Acorus calamus	Araceae	Emergent	B
Typha orientalis	Typhaceae	Emergent	B, C
Schoenoplectus juncoides	Cyperaceae	Emergent	C

2.2. Wastewater Preparation

Many previous studies have directly added nutrients to tap water or distilled water to produce artificial wastewater, thus ignoring the synergistic effect of microorganisms and plants in the water purification process [5,31]. In order to simulate natural eutrophic water as much as possible, the artificial wastewater in this experiment was prepared using $C_6H_{12}O_6 \cdot H_2O$ (207 mg/L), NH_4Cl (38 mg/L), and KH_2PO_4 (8.7 mg/L) dissolved in natural wastewater with a low nutrient content to prepare the designed average concentrations as follows: chemical oxygen demand (COD) of 207 mg/L, TN of 10 mg/L, and TP of 2 mg/L, respectively. In all cases, we used a trace mineral solution (1 mL/L) containing EDTA-Na (0.1 g/L), $FeSO_4 \cdot 7H_2O$ (0.1 g/L), $MnCl_2 \cdot 4H_2O$ (0.1 g/L), $CoCl_2 \cdot 6H_2O$ (0.184 g/L), $CaCl_2$ (0.05 g/L), $ZnCl_2$ (0.1 g/L), $CuCl_2 \cdot 2H_2O$ (0.015 g/L), $NiCl_2 \cdot 6H_2O$ (0.03 g/L), H_3BO_3 (0.01 g/L), $Na_2MoO_4 \cdot 2H_2O$ (0.01 g/L), and H_2SeO_3 (0.001 g/L) [5,16,32].

The initial water quality parameters are as follows: temperature (T, 23.26 ± 0.25 °C); pH (7.41 ± 0.14); dissolved oxygen (DO, 1.29 ± 0.95 mg/L); TN (9.70 ± 1.51 mg/L); TP (1.81 ± 0.23 mg/L); COD (343 ± 133 mg/L).

2.3. Experimental Design

A total of 12 rectangular open plastic tanks, measuring 150 cm in length, 150 cm in width, and 50 cm in height, were used for the experiments with 576 L of artificial wastewater and 800 g of aquatic plants. The tanks were divided into four groups: (A) *V. natans* + *L. adscendens* + *M. vaginalis* + *S. chinensis*; (B) *V. natans* + *I. aquatica* + *A. calamus* + *T. orientalis*; (C) *V. natans* + *L. adscendens* + *S. juncoides* + *T. orientalis*; and (CK) control (no plants). Each group contained three tanks.

Water samples were collected on days 0, 3, 8, 16, 27, and 54 by dipping a 300 mL graduated cylinder at three locations across the container surface during the mid-morning and then combining these. The aliquots of each sample were filtered, and both the filtered and unfiltered portions were immediately stored at 4 °C. The parameters measured included T, pH, DO, TN, TP, and COD. Losses in the culture volume due to evapotranspiration were countered by the addition of tap water to the original level every second day. Water sampling was performed on day 2 following the volume adjustment, such that tap water addition had a minimal impact on the measurements. After the experiments, the plants were removed completely from the solution, and the substrates entangled in the roots were cleaned. After being washed with deionized water and dried with absorbent paper, the plants were weighed with an electronic balance to obtain their fresh weight.

All experiments were conducted in a greenhouse located in the South China Botanical Garden, Guangzhou, China. The experiment was conducted from 14 November to 11 December 2018. The indoor air temperature was 14–23 °C.

2.4. Chemical Analysis

In this experiment, the values of T, pH, and DO were obtained using a portable multimeter (EXO2, YSI, Ohio, OH, USA); CODcr was measured using a closed reflux titrimetric method according to standard methods (GB 11914-1989); TP was determined using the ammonium molybdate spectrophotometric method (GB11893-1989); and TN was determined using a TOC analyzer (TOC-L, SHIMADZU (Hong Kong) Limited, Kyoto, Japan).

2.5. Statistical Analysis

All data were statistically analyzed via one-way analyses of variance using SPSS software (version 19.0; SPSS Inc., Chicago, IL, USA), and significant differences were tested using the least significant difference and Duncan multiple comparisons. Standard errors obtained from the triplicate experiments are graphically shown when they exceeded 5%.

3. Results

3.1. Variations in T, pH, and DO in Wastewater

The growth and absorption of aquatic plants are influenced by numerous environmental factors, such as solar radiation, rainfall, and temperature. The values of T, pH, and DO of the tested water with increasing hydraulic retention time (HRT) are illustrated in Figure 1.

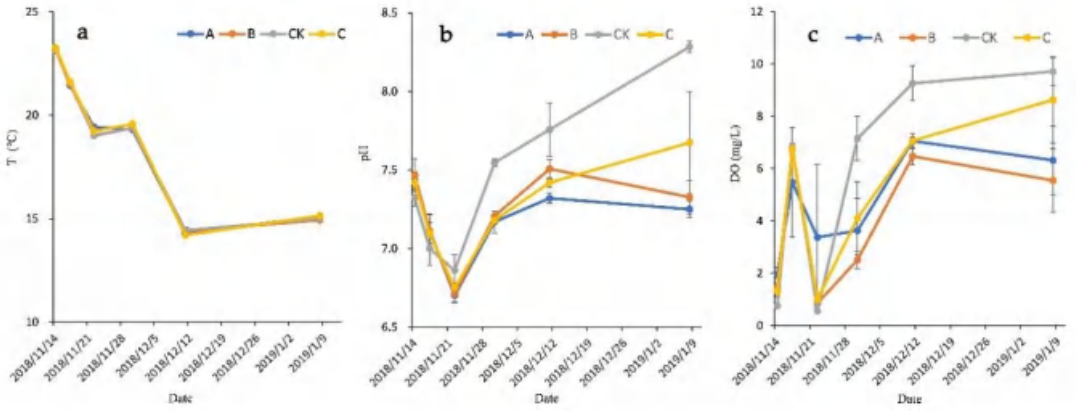


Figure 1. Variation in (**a**) T, (**b**) pH, and (**c**) DO of wastewater in groups: (A) *V. natans* + *L. adscendens* + *M. vaginalis* + *S. chinensis*; (B) *V. natans* + *I. aquatica* + *A. calamus* + *T. orientalis*; (C) *V. natans* + *L. adscendens* + *S. juncoides* + *T. orientalis*; (CK) control (no plants) (the same applies in the following figures).

During the experiment, the water temperature decreased significantly over time from 23 °C to 14 °C, except for a slight increase in the middle period. The pH values were between 6.5 and 8.0. The results of another study showed that no removal of the biological oxygen demand (BOD) or plant growth occurred at temperatures below 10 °C or at a pH of <5 and >10, and that the best conditions for the treatment of municipal sewage and aquatic plant growth were a temperature of 15–38 °C and pH of 7.5 [33]. Therefore, the water used in the present study was within the optimal temperature and pH ranges for macrophyte vegetative growth and aquatic microorganism development in wastewater, plant roots, and rhizomes.

In the first 8 days, the pH values of the plant groups and the control showed downward trends (Figure 1b), gradually changing from weakly alkaline conditions to weakly acidic conditions. From day 8 to day 32, the pH values of all groups kept increasing. Subsequently, the pH of group A and B went down. At the end of this experiment, the pH of group A, B, C and CK was 7.25 ± 0.05, 7.33 ± 0.11, 7.67 ± 0.33 and 8.28 ± 0.04, respectively, which of the control was significantly higher than the plant groups ($p < 0.05$). During the experiment, the pH values of each plant group first decreased and then gradually comes back up to the initial value, indicating that the water of plant groups had a certain buffering

capacity. These findings also suggest that the different types of aquatic plants had different responses to pH due to their different physiological characteristics, which agree with the results of Hu et al. [34].

The initial DO concentration of the wastewater was relatively low (1.29 ± 0.02 mg/L), and increased rapidly during the first 3 days. The DO concentrations of plant groups were significantly higher than that of the control ($p < 0.05$) on day 3, and subsequently decreased before increasing (Figure 1c). At the end of the experiment, the DO concentrations of all treatments were greatly improved with respect to the initial values, with the DO concentration of the control group being significantly higher than that of the plant groups ($p < 0.05$).

3.2. Comparison of TN Removal in Wastewater

As a major nutrient in aquatic ecological systems, excess N can lead to the eutrophication of surface waters. Figure 2 displays the TN concentration and removal rates with increasing HRT, and shows that the initial TN concentration was 9.70 ± 1.51 mg/L. During the first 8 days, the TN concentration of each group showed a decreasing trend; the removal rates of groups A, B, C, and CK were 21.81%, 13.38%, 11.52%, and 21.36%, respectively. From day 8 to day 16, the variation trend of TN concentration in each group was not consistent. On day 27, the TN concentration of group B became higher than the initial and the removal rate reached −0.18%, which may have been related to the decay of *V. natans*. During the experiment, the TN removal rates of group B were significantly lower than those of the other groups ($p < 0.05$). At the end of the experiment, the TN removal rates of groups A, B, C, and CK were 79.10%, 46.39%, 67.46%, and 70.42%, respectively. There were no significant differences between groups A, C, and CK; however, the TN removal rate of the CK group was significantly higher than that of group B ($p < 0.05$). The average TN concentrations of groups A, B, C, and CK were 1.82 ± 0.91 mg/L, 5.03 ± 0.53 mg/L, 3.03 ± 0.16 mg/L, 2.88 ± 1.34 mg/L, respectively.

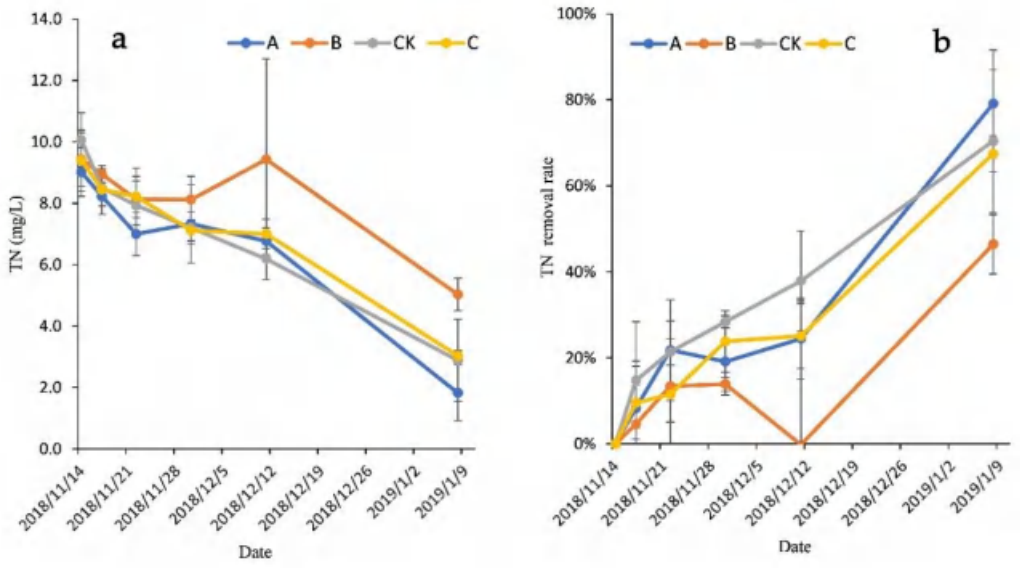


Figure 2. Variation in the (**a**) TN concentration and (**b**) removal rate of each treatment.

3.3. Comparison of TP Removal in Wastewater

The assimilation and removal of nutrients from water by aquatic plants is an efficient phytoremediation approach. Phosphorus is an important nutrient in the composition of biological life and is a highly significant limiting factor for water eutrophication.

In this experiment, the initial TP concentration was 1.81 ± 0.23 mg/L. Figure 3 shows the variation in the TP concentration and removal rate of each treatment. During the first 3 days, the TP concentration of group A decreased rapidly, and the TP removal rate reached

24.86%, which was slightly higher than that of the other groups ($p < 0.05$). At the end of the experiment, the TP removal rates increased to 89.39%, 88.37%, 91.96%, and 86.59% in groups A, B, C, and CK respectively, with no significant differences between plant groups and the CK group.

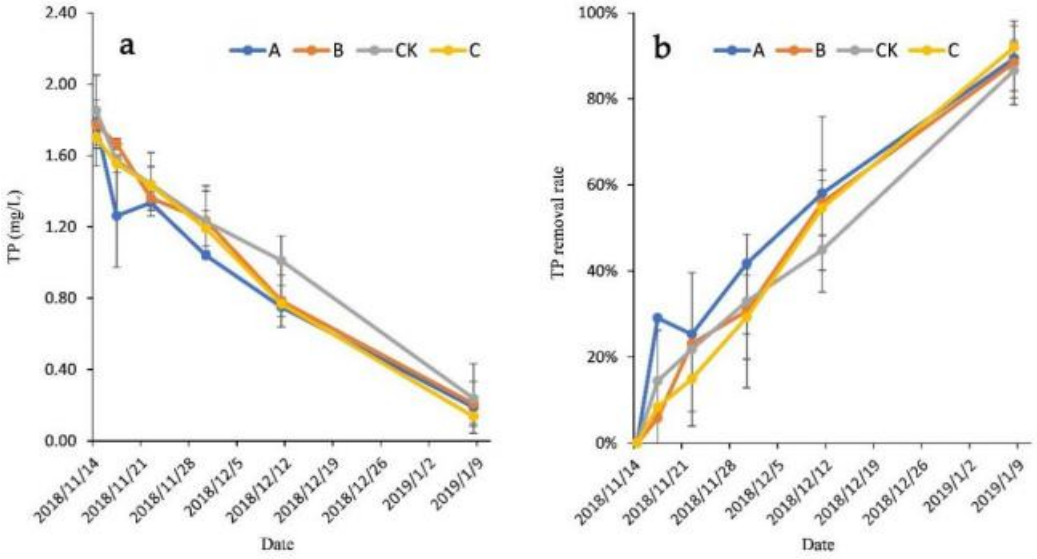


Figure 3. Variation in the (**a**) TP concentration and (**b**) removal rate of each treatment.

3.4. Comparison of COD_{cr} Removal in Wastewater

The initial COD concentration was 407.7 ± 55.0 mg/L. As shown in Figure 4, during the first 3 days, the COD concentrations of groups A and CK increased slightly, and the COD removal rates of groups A, B, C, and CK were −5.45%, 4.69%, 2.08%, and −2.5%, respectively. Subsequently, the COD concentration of all groups exhibited rapid downward trends. At the end of the experiment, the COD removal rates of groups A, B, C, and CK were 93.91%, 96.48%, 92.78%, and 87.94%, respectively, which were slightly higher than that of the CK group ($p > 0.05$). The average COD concentrations of groups A, B, C, and CK were 21.3 ± 7.0 mg/L, 15.53 ± 8.1 mg/L, 28.9 ± 6.16 mg/L, 52.8 ± 4.4 mg/L, respectively.

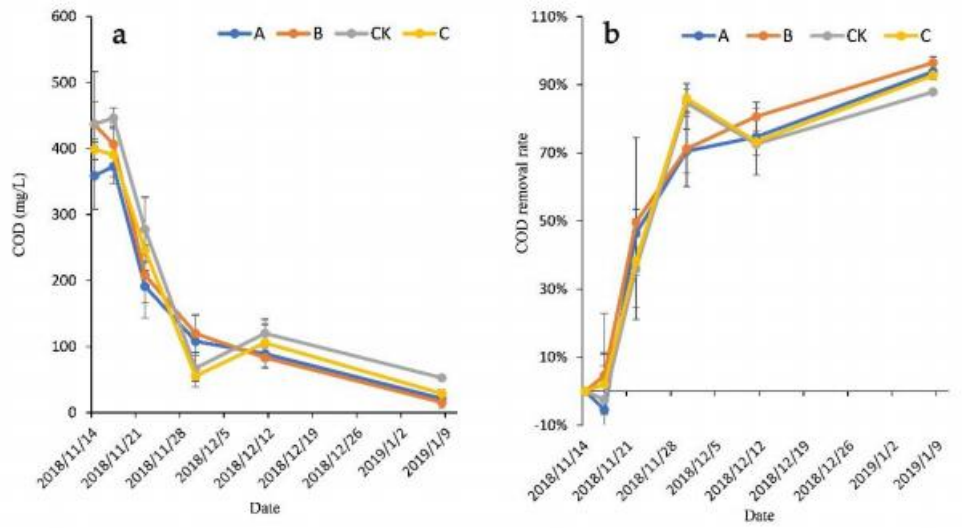


Figure 4. Variation in the (**a**) COD concentration and (**b**) removal rate of each treatment.

3.5. Visual Observations and Biomass Production

Figure 5 showed the growth status of the plants in each treatment. During the first 15 days, the biomass of the floating plants (*L. adscendens* and *I. aquatica*) increased rapidly due to the rich nutrient contents of the water. Their floating stems grew rapidly with numerous branches and roots (Figure 5b), and there were white spindle-shaped pneumatophores in clusters at the nodes of *L. adscendens*. The emergent plants (*S. chinensis* and *M. vaginalis*) floating on the water surface (Figure 5a) also developed new leaves and many roots. The height of the submerged plant *V. natans* increased, and more adventitious roots were grown for reproduction. The stems and leaves of the emergent plants *S. juncoides*, *A. calamus*, and *T. orientalis* did not grow above the ground layer, possibly because their roots were directly buried in the sand and the underground roots of the plants needed time to adapt to the new environment.



Figure 5. Growth status of plant combinations in wastewater: (**a**) day 0 and (**b**) day 27 of group A; (**c**) day 8 and (**d**) day 27 of *M. vaginalis*; (**e**) day 35 of group B; (**f**) day 35 of the CK group.

On day 16 of the experiment, considerable decay was observed in the upper leaves of *V. natans* under the floating plants. Therefore, the floating plants that blocked the light of *V. natans* were moved to other places. Over time, the decayed *V. natans* gradually decomposed in the water, and its adventitious roots grew new shoots. In the middle and late periods of the experiment, after a period of prosperous growth, the leaves of *M. vaginalis*

in group A also began to wither gradually (Figure 5c,d), and some litter entered the water; the green leaves of *I. aquatica* gradually turned yellow, as the weather became colder and the nutrient content of the water decreased (Figure 5e). Figure 5e,f reveals that the water transparency of the plant groups was improved and was significantly better than that of the CK group. The net biomass growth rates of each plant in groups A, B, and C at the end of the experiment are presented in Table 2, which shows that the net biomass growth rates were not high, and were even negative in some cases. This may have been related to the growth stages of the plants in this experiment, which went from a bloom phase to a declining phase.

Table 2. Biomasses of aquatic macrophytes after 54 days of treatment in artificial wastewater (g/pot, fresh weight).

Plants	Group A				Group B				Group C			
	Vn	**La**	**Mv**	**Sc**	**Vn**	**Ia**	**Ac**	**To**	**Vn**	**La**	**Sj**	**To**
NBG	−84.3	141	8.88	101	−13.3	40.3	−41.9	152.5	141.2	101.2	106.7	34.5
	8.86	225	−15.2	166	−86.8	181	−11.2	101.1	83.3	68.8	73.7	−26.4
	−123	114	65.0	142	−63.7	178.9	−10.3	−27.7	54.4	−51.8	106.2	−15.6
ANBG	−66.2	160	19.6	136.6	−54.6	133.4	−21.1	75.3	93.0	39.4	95.6	−2.5
NBGR	−33.1%	80.0%	9.8%	68.3%	−27.3%	66.7%	−10.6%	37.7%	46.5%	19.7%	47.8%	−1.3%

Note: NBG: net biomass growth of each plant; ANBG: average net biomass growth; NBGR: net biomass growth rate; Vn: *V. natans*; La: *L. adscendens*; Mv: *M. vaginalis*; Sc: *S. chinensis*; Ia: *I. aquatica*; Ac: *A. calamus*; To: *T. orientalis*; Sj: *S. juncoides*.

The amount of nitrogen absorbed by the plants and plant groups, the total removal rates of nutrients in water and absorption contribution rates of plants after 54 days treatment are shown in Table 3. In the removal of TN in water, the absorption contribution rates of plants in groups A, B, and C were 15.29%, 14.63%, and 18.24%, respectively, which were 2.05%, −2.71%, and −4.71%, respectively, in the removal of TP from water. In this experiment, all plant groups showed the phenomenon of decreasing plant biomass and releasing nitrogen or phosphorus into water. In group A, the biomass of *V. natans* decreased most obviously, by which the nitrogen and phosphorus released into the water were 95.84 mg and 15.71 mg, respectively. Although the biomass of some plants increased, it also increased the pollution load of the water body to some extent; in group A, the net biomass growth rate of *M. vaginalis* was 9.8%, but the nitrogen and phosphorus absorbed by it were −33.82 mg and −8.08 mg, respectively; in group B, the net biomass growth rate of *T. orientalis* was 37.7%, and the total phosphorus absorbed by it was −8.93 mg; in group C, the net biomass growth rate of *L. adscendens* was 19.7%, and the total phosphorus absorbed by it was −53.74 mg, which was related to the decrease of N or P concentration in plants.

Table 3. The amount of nitrogen absorbed by plants and plant groups, the total removal rates of nutrients in water and absorption contribution rates of plants after 54 days' treatment.

Combinations	Species	NBGR	MNAP (mg)	MPAP (mg)	MNAPG (mg)	MPAPG (mg)	Removal Rate of Nutrients		Absorption Contribution Rate	
							TN	TP	TN	TP
Group A	Vn	−33.1%	−95.84	−15.71	633.87	18.84	79.10%	89.39%	15.29%	2.05%
	La	80.0%	331.50	−9.28						
	Mv	9.8%	−33.82	−8.08						
	Sc	68.3%	432.03	51.90						
Group B	Vn	−27.3%	−24.12	−6.54	370.80	−24.49	46.39%	88.37%	14.63%	−2.71%
	Ia	66.7%	166.51	18.08						
	Ac	−10.6%	54.03	−27.10						
	To	37.7%	174.38	−8.93						
Group C	Vn	46.5%	101.93	11.66	668.50	−42.42	67.46%	91.96%	18.24%	−4.71%
	La	19.7%	19.87	−53.74						
	Sj	47.8%	381.90	0.96						
	To	−1.3%	164.81	−1.31						

Note: NBGR: net biomass growth of each plant; MNAP: the mean amount of nitrogen absorbed by each plant; MPAP: the mean amount of phosphorus absorbed by each plant; MNAPG: the mean amount of nitrogen absorbed by plant groups; MPAPG: the mean amount of phosphorus absorbed by plant groups; Vn: *V. natans*; La: *L. adscendens*; Mv: *M. vaginalis*; Sc: *S. chinensis*; Ia: *I. aquatica*; Ac: *A. calamus*; To: *T. orientalis*; Sj: *S. juncoides*.

4. Discussion

In the present study, the TN removal rates of groups A, B, C, and CK were 79.10%, 46.39%, 67.46%, and 70.42%, respectively, while the TP removal rates were 89.39%, 88.37%, 91.96%, and 86.59%, respectively. The COD removal rates of groups A, B, C, and CK were 93.91%, 96.48%, 92.78%, and 87.94%, respectively. The TN removal rate of group B was significantly lower than that of other groups ($p < 0.05$). Apart from this, there were no significant differences in the TN, TP, and COD removal rates in the wastewater of each group, which may be related to the metabolism of microorganisms in wastewater and seasonal changes of aquatic plants. In order to simulate natural eutrophic water as much as possible, the artificial wastewater in this experiment was prepared using $C_6H_{12}O_6 \cdot H_2O$, NH_4Cl, and KH_2PO_4 dissolved in natural wastewater with abundant microorganisms. It was reported that the most important removal process in most treatment wetland systems were based on physical and microbial processes [35]. Vymazal [36] found that processes that affect removal and retention of nitrogen during wastewater treatment are manifold and include NH_3 volatilization, nitrification, denitrification, nitrogen fixation, plant and microbial uptake, mineralization (ammonification), nitrate reduction to ammonium (nitrate-ammonification), anaerobic ammonia oxidation (ANAMMOX), fragmentation, sorption, desorption, burial, and leaching. Phosphorus transformations during wastewater treatment in CWs include adsorption, desorption, precipitation, dissolution, plant and microbial uptake, fragmentation, leaching, mineralization, sedimentation (peat accretion), and burial. The major phosphorus removal processes are sorption, precipitation, plant uptake (with subsequent harvest), and peat/soil accretion [11,36,37]. Many studies found that the coupling effects of microorganisms and plants play important roles in nutrient removal from wastewater [1,5,36]. However, in this experiment, the purification effect of TN, TP, and COD of the plant groups was not significantly better than that of the blank control group, which was related to the decline of plants in the cold season and the abundance of microorganisms in water.

Here, we cannot deny the ecological restoration effect of aquatic plants on the water body in the low temperature season. The most important effects of aquatic plants in relation to the wastewater treatment processes are the physical effects the plant tissues give rise to (e.g., erosion control, filtration effect, provision of surface area for attached

microorganisms). The metabolism of the macrophytes (plant uptake, oxygen release, etc.) affect the treatment processes to different extents depending on the design. The macrophytes have other site-specific valuable functions, such as providing a suitable habitat for wildlife, and giving systems an aesthetic appearance [35]. The richest root system of aquatic macrophytes provided a suitable environment for aerobic microorganisms to degrade organic matter and nutrients into inorganic compounds, which were then utilized by the plants. Rhizospheric microorganisms in aquatic plants can participate in various activities, such as COD degradation and N removal and fixation.

In this experiment, the absorption contribution rates of plants in groups A, B, and C with regard to the removal of TN in water were 15.29%, 14.63%, and 18.24%, respectively, and were 2.05%, −2.71%, and −4.71%, respectively, with regard to the removal of TP from water. The absorption contribution rate of plants is affected by plant species and nitrogen and phosphorus loads in water bodies. It was reported that plant uptake of nutrients was only of quantitative importance in low-loaded systems (surface flow systems) [31,35]. Jiang [38] found that plant uptake played a major role in nitrogen and phosphorus removal in the constructed wetland treating low eutrophic water, of which the contribution rates were 46.8% and 51.0%, respectively. Due to the artificial wastewater with high nutrient load and seasonal decline of aquatic plants, the absorption contribution rates of TN in this experiment were not very high, but that of TP were very low or even negative. The result shows that the absorption of plant group has a certain effect on the removal of total nitrogen from water, while the decay of some plants increases the total phosphorus load in water.

The decay of aquatic plants has complex environmental effects on waterbodies [39]. Plant decomposition includes all the physical and chemical changes that occur after tissue senescence and death, starting with complex organic molecules and ending in simple inorganic elements [40]. The processes involved include: (1) Mechanical fragmentation by animal grazers, weathering, or other mechanisms; (2) leaching and/or autolytic production of dissolved organic matter; and (3) digestion of labile and recalcitrant materials by bacteria and fungi [41–43].

On day 16 of the experiment in this study, the leaves of *V. natans*, which were covered by floating plants, were fractured from the upper middle part and rotated to some extent. The net biomass growth rate of V. *natans* in groups A, B, and C was −33.1%, −27.3%, and 46.5%, respectively. By studying the decay process of six aquatic plants, Zhou et al. [44] found that floating plants and submerged plants were the most susceptible to decay, with submerged plants rotting and decomposing the most thoroughly, while emergent plants decomposing relatively slowly. Pan et al. [45] reported that *Vallisneria spiralis*—a plant of the same genus to *V. natans*—gradually began to wither and turned yellow when the water temperature was 3–10 °C in November. During that process, the authors added some nutrition to the water, which was mostly held in the plant remains. When the weather became warmer in the following year, the plants decayed more rapidly, releasing N and P to the water and sediment. It is accepted that the summer decomposition rates of plants are generally higher than those of other seasons [39]. Therefore, the present experiment was carried out during autumn in South China, when the water temperature was between 14 °C and 24 °C. Hence, the decomposed residue of *V. natans* would have been more likely to decompose even though the rate may not have been as fast as that during summer. In the first period of this experiment, the floating plants, *L. adscendens* and *I. aquatica*, both grew well due to the rich nutrient contents of the water, and their biomasses were nearly 2.5 times greater than their initial biomasses; however, at the end of the experiment, the net biomass growth rates of *L. adscendens* in groups A and C were just 80.0% and 19.7%, respectively, while that of *I. aquatica* in group B was 66.7%. These results suggest that the two floating plants were decomposed to some extent, but that decomposition started after *V. natans* began to decompose.

Plant decay may cause secondary pollution in waterbodies. The decay process and water quality effects vary depending on the plant species and the amount of residue decomposition [46]. Tang et al. [47] performed a 64-day decomposition experiment, and found

that the COD and TN concentrations of water increased during the late decomposition period of *Zizania latifolia*, resulting in the deterioration of water quality. On the other hand, some studies have suggested that the existence of moderate plant residues could effectively promote the N and P cycles in waterbodies, thus reducing the N concentration to some extent and decreasing the N load [45]. In the present experiment, the tested plants absorbed nutrients from the wastewater during their growth, and their presence also improved the water environment to some extent, promoting the removal of N and P by other factors. At the same time, some plant residues entered the water and released nutrients to increase the nutrient load; hence, the N and P released by plant decay and absorption by plant growth were offset to some extent. The results indicate that a proper amount of plant residue will not lead to a significant deterioration of water quality. However, the residual biomass of aquatic plants must be controlled, fully utilized, and harvested at appropriate times to avoid excessive plant residues that can degrade water quality as temperature rises.

It has been suggested that maintaining a certain amount of aquatic plants during autumn and winter can improve the cycling process of nutrient elements such as N and P in water and prevent the deterioration of water quality [47]. In the present experiment, the litter, decay, and decomposition of plants did not cause any significant increase in nutrient concentrations of the water in the various treatments. This was related to the relatively slow decomposition rate of litter in autumn, and to the increased stability of the water due to the combination of multiple plants. Although the purification effects of the plant groups were not significantly superior to those of the CK group, there was a good purification effect on the TN, TP, and COD under the condition of plant decomposition. Hence, the introduction of appropriate aquatic plants into eutrophic waterbodies may facilitate long-term improvements in water quality.

5. Conclusions

In this study, all the groups had a good purification effect; the water transparency was improved in the plant groups (A, B, and C), and was significantly better than that of the CK group. The TN removal rates of groups A, B, C, and CK were 79.10%, 46.39%, 67.46%, and 70.42%, respectively, while the TP removal rates were 89.39%, 88.37%, 91.96%, and 86.59%, respectively. The COD removal rates of groups A, B, C, and CK were 93.91%, 96.48%, 92.78%, and 87.94%, respectively. Overall, the removal rates of the plant groups were slightly higher than those of the CK group, and the combination of multiple plants increased the stability of the water in groups A, B, and C. The conclusions of this study are important for the phytoremediation of wastewater in the area of south China and similar climatic zones throughout the year. However, this study was only an experiment in a relatively stable environment, and further observations of practical applications of such phytoremediation treatments are required.

Author Contributions: Conceptualization, L.X., S.C. and F.W.; methodology, P.Z. and Z.L.; software, D.X.; validation, X.Q., F.X. and L.X.; formal analysis, L.X. and S.C.; investigation, D.X., X.Y. and D.L.; resources, X.Q., F.W. and F.X.; data curation, L.X. and S.C.; writing—original draft preparation, L.X.; writing—review and editing, L.X. and F.W.; visualization, L.X.; supervision, F.W.; project administration, F.W.; funding acquisition, F.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Major Basic Research and Cultivation Project of Guangdong Natural Science Foundation (grant number 2015A030308015), Key Special Project for Introduced Talents Team of Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) (grant number GML2019ZD0408), and the Strategic Priority Research Program of the Chinese Academy of Sciences (grant number XDA13020500).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author (F.W.). The data are not publicly available due to privacy concerns.

Conflicts of Interest: The authors declare no conflict of interest.

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Guangdong
Landscape
Architecture

1979 年创刊
Vol.43 总第 203 期
广东园林学会主办

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4
2021
双月刊



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投稿网址：http://gdylzz.gdylxh1962.com

电子邮箱：1146724404@qq.com

国内统一连续出版物号：CN44—1219/S

国际标准连续出版物号：ISSN 1671—2641

广告发布登记通知书：440100190032

国内发行：广东省报刊发行局

国内邮发代号：46-331

订　　阅：全国各地邮局

国外发行：中国出版对外贸易总公司

国外邮发代号：BM7470

发行范围：国内外发行

制版印刷：广州市人杰彩印厂

排　　版：广州百彤文化传播有限公司

出版日期：2021年8月

定　　价：25.00元

廣東園林

Guangdong yuanlin

双月刊

Vol.43/203
2021年第4期

主管单位：
广东省科学技术协会
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广东园林学会

JOURNAL OF GUANGDONG LANDSCAPE ARCHITECTURE
CN44—1219/S, ISSN 1671—2641

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Edited by:
EDITORIAL DEPARTMENT OF GUANGDONG LANDSCAPE ARCHITECTURE

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(Mail Code 46-331)

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DOI：10.12233/j.gdyl.2021.04.016

澳门地被植物资源 *

Resources of Ground Cover Plants in Macao

侯庆纯　高淑真　秦新生*
HOU Qing-chun，GAO Shu-zhen，QIN Xin-sheng *

摘要：地被植物是城市园林绿化的重要组成部分。通过野外实地调查和文献查阅，现统计到澳门地被植物共有134科529属1009种，其中禾本科（61属112种）、菊科（55属90种）和蕨类植物（46属83种）所含数量位列前三，草本类、灌木类和藤蔓类占比分别是72%（731种）、12%（117种）和16%（161种）。澳门的地被植物与广州、深圳、珠海相比，所含科和种的数量接近，物种密度最高。4个城市均主要应用爵床科、龙舌兰科、百合科、茜草科、天南星科、大戟科、马鞭草科以及蝶形花科等所含地被植物。针对澳门现有地被植物存在乡土植物开发利用程度小、外来物种运用过多、特色不鲜明等问题，提出因地制宜、应景而异、重视利用乡土植物和科学管养等建议。

关键词：澳门；地被；绿化；乡土植物
中图分类号：S688
文献标志码：A
文章编号：1671-2641（2021）04-0079-06
收稿日期：2020-12-22
修回日期：2021-04-07

Abstract: Ground cover plants are an indispensable part of urban landscaping. Through field research and literature review, 1009 species belonging to 529 genera and 134 families of ground cover plants are recorded in Macao. Among them, the species number of Gramineae (61 genera and 112 species), Compositae (55 genera and 90 species) and Pteridophytes (46 genera and 83 species) ranks among the top three. Herbs, shrubs, and vines account for 72% (731 species), 12% (117 species), and 16% (161 species) respectively. The number of families and species in Macao is close to that in Guangzhou, Shenzhen and Zhuhai, and the species density in Macao is the highest among the four cities. The ground cover plants mainly used in the 4 cities belong to Acanthaceae, Agavaceae, Liliaceae, Rubiaceae, Araceae, Euphorbiaceae, Verbenaceae, and Fabaceae, et al. According to the problems of the existing ground cover plants in Macao, such as the low degree of exploitation and utilization of local plants, excessive use of alien species, and lack of regional features, this article proposes that planting should be adapted to local conditions, and the utilization of local plants and scientific management should be emphasized.

Key words: Macao; Ground cover plant; Landscape greening; Local plant

地被植物是指自然界中低矮的覆盖在地面上的植物，较为常见的有草坪、蕨类植物、矮生灌木、短期花卉和蔓藤植物等[1]。地被植物通常相对矮小，枝叶层紧密且与地面相接，成群生长，覆盖地表，对地面兼具保护和装饰作用[2]。

地被植物作为园林植物中较大面积的覆盖层，能有效利用阳光进行光合作用，对周围环境起到净化空气的作用[3]。其姿态万千，色彩丰富，在实际应用过程中，通过与花、草、灌木等植物综合搭配，可以实现园林景观立体结构的构建，进而大幅度提升园林整体的观赏效果[4]。在现阶段园林建设中，地被植物起到烘托景观的作用，通常作为配景应用在花坛边缘、绿地林缘，或是用于实现对硬质景观的柔化[5]。

在高密度城市中构筑可持续发展的生态人居环境，已成为我国城市建设亟待解决的问题。澳门是亚洲高密度城市的典型，未来发展定位为“世界旅游休闲中心”，必须打造生态健全、景观优美的城市环境。澳门城市特色鲜明，最为突出的是其中西文化混合的城市气质和高密度发展的城市形态。高密度的特性决定了澳门有限的土地供给力与市民对绿色空间的大量需求之间必将存在矛盾。为了解澳门绿地中地被植物的应用现状，充分发掘可用于澳门绿化的地被植物资源，笔者结合近年来在澳门的实践和相关资料，对澳门的地被植物资源进行了初步梳理，期待研究结果可为后续资源开发利用、科学管养提供基础数据。

1 澳门绿色空间和城市绿化现状

1.1 绿化覆盖率低

澳门目前拥有约5 930 km^2绿地，绿化覆盖率保持在21%~22%，人均占有绿地为12~13 m^2[6~7]，而同样高密度的华南地区国家级中心城市广州的人均绿地面积为16.8 m^2。近年来，尽管澳门的填海工程使得绿化面积有所增加，但增长速度远远低于土地面积的增长，导致绿化覆盖率不升反降。绿地面积的不足将带来一系列的影

* 基金项目：国家自然科学基金项目（31870699）；广东省林业科技创新项目（2018KJCX030）；大学生创新创业训练计划项目（201910564048）

响，如降低城市对自然灾害的适应性及灾后系统恢复的能力等。地被植物作为绿地覆盖主要的材料之一，其增长速率也备受人们的关注。利用地被植物与乔木合理配置，进而构成和谐、稳定、能长期共存的植物群落[8]，从点、线、面等方面提炼绿色空间的构成要素，对绿色空间的功能、绿色空间与用地的关系及用地需求进行分析，梳理出澳门绿色空间营造的原则和策略[9]，是当前提高绿化覆盖率的重要措施之一。

1.2 人口高密度化

据澳门统计年鉴的数据，截至2018年，澳门总用地面积32.90 km^2，人口66.74万人，人口密度达2.03万人/km^2，其中人口密度最高的街区达5.1万人/km^2[10~11]。尽管现代化的技术发展为城市的高密度开发提供了一定的技术保障，但是在人口密集且流动性大的情况下，随着城市化加剧，越来越多的绿地逐渐被高楼大厦所替代，如何兼顾绿色空间的数量与质量正越来越为人们所关注。

2 澳门地被植物资源分析

2.1 澳门地被植物资源基本概况

通过2004—2019年笔者在澳门半岛、氹仔以及路环城市绿地和郊野公园的实地调查及相关文献资料查阅[12~17]，按照J·Hutchinson 1973年的分类系统，统计出澳门现有地被植物1 009种，隶属于134科529属（表1），

表1　澳门地被植物概况

序号	科名	属数	种数	序号	科名	属数	种数	序号	科名	属数	种数
1	禾本科	61属	112种	46	姜科	1属	5种	91	露兜树科	1属	2种
2	菊科	55属	90种	47	葫芦科	4属	4种	92	灯心草科	1属	2种
3	莎草科	18属	65种	48	蹄盖蕨科	3属	4种	93	美人蕉科	1属	2种
4	蝶形花科	32属	54种	49	马齿苋科	2属	4种	94	松叶蕨科	1属	1种
5	茜草科	11属	33种	50	粟米草科	2属	4种	95	石松科	1属	1种
6	百合科	17属	32种	51	白花菜科	2属	4种	96	木贼科	1属	1种
7	天南星科	19属	28种	52	苏木科	2属	4种	97	箭蕨科	1属	1种
8	大戟科	8属	27种	53	千屈菜科	2属	4种	98	莲座蕨科	1属	1种
9	唇形科	17属	24种	54	野牡丹科	2属	4种	99	紫萁科	1属	1种
10	兰科	17属	20种	55	肾蕨科	1属	4种	100	碗蕨科	1属	1种
11	爵床科	14属	20种	56	堇菜科	1属	4种	101	卤蕨科	1属	1种
12	旋花科	10属	19种	57	秋海棠科	1属	4种	102	铁角蕨科	1属	1种
13	苋 科	5属	18种	58	柳叶菜科	1属	4种	103	实蕨科	1属	1种
14	马鞭草科	9属	17种	59	忍冬科	1属	4种	104	金粟兰科	1属	1种
15	蓼科	6属	17种	60	膜蕨科	3属	3种	105	莲科	1属	1种
16	玄参科	12属	17种	61	乌毛蕨科	3属	3种	106	金鱼藻科	1属	1种
17	十字花科	6属	16种	62	仙人掌科	3属	3种	107	毛茛科	1属	1种
18	鸭跖草科	8属	15种	63	五加科	3属	3种	108	罂粟科	1属	1种
19	茄科	5属	14种	64	紫草科	3属	3种	109	商陆科	1属	1种
20	锦葵科	6属	13种	65	凤梨科	3属	3种	110	紫茉莉科	1属	1种
21	龙舌兰科	5属	13种	66	海金沙科	1属	3种	111	番杏科	1属	1种
22	蔷薇科	6属	10种	67	鳞毛蕨科	1属	3种	112	五桠果科	1属	1种
23	葡萄科	5属	10种	68	牻牛儿苗科	1属	3种	113	猪笼草科	1属	1种
24	金星蕨科	4属	9种	69	凤仙花科	1属	3种	114	绣球花科	1属	1种
25	伞形科	7属	8种	70	里白科	2属	2种	115	虎耳草科	1属	1种
26	萝摩科	7属	8种	71	裸子蕨科	2属	2种	116	含羞草科	1属	1种
27	水龙骨科	6属	8种	72	叉蕨科	2属	2种	117	瑞香科	1属	1种
28	防己科	6属	8种	73	三白草科	2属	2种	118	使君子科	1属	1种
29	夹竹桃科	6属	8种	74	桑科	2属	2种	119	卫茅科	1属	1种
30	石竹科	4属	8种	75	落葵科	2属	2种	120	无患子科	1属	1种
31	景天科	3属	8种	76	小二仙草科	2属	2种	121	芸香科	1属	1种
32	胡椒科	2属	8种	77	桃金娘科	2属	2种	122	旱金莲科	1属	1种
33	凤尾蕨科	1属	8种	78	金虎尾科	2属	2种	123	菟丝子科	1属	1种
34	薯蓣科	1属	7种	79	苦苣苔科	2属	2种	124	车前草科	1属	1种
35	鸢尾科	5属	6种	80	蕨科	1属	2种	125	胡麻科	1属	1种
36	藜科	4属	6种	81	中国蕨科	1属	2种	126	紫葳科	1属	1种
37	菝葜科	2属	6种	82	骨碎补科	1属	2种	127	桔梗科	1属	1种
38	铁线蕨科	1属	6种	83	睡莲科	1属	2种	128	草海桐科	1属	1种
39	谷精草科	1属	6种	84	白花丹科	1属	2种	129	香蒲科	1属	1种
40	梧桐科	5属	5种	85	茅膏菜科	1属	2种	130	旅人蕉科	1属	1种
41	闭鞘姜科	4属	5种	86	西番莲科	1属	2种	131	芭蕉科	1属	1种
42	鳞始蕨科	2属	5种	87	紫金牛科	1属	2种	132	芦荟科	1属	1种
43	竹芋科	2属	5种	88	远志科	1属	2种	133	水玉簪科	1属	1种
44	卷柏科	1属	5种	89	酢浆草科	1属	2种	134	透骨草科	1属	1种
45	木犀科	1属	5种	90	狸藻科	1属	2种				

注：按照各科所含种类数量倒序排列

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种数占澳门维管束植物总种数的66.91%，数量较为丰富。从科属分布情况来看，数量排前十位的类群分别是禾本科（61属112种）、菊科（55属90种）、蕨类植物（46属83种）、莎草科（18属65种）、蝶形花科（32属54种）、茜草科（11属33种）、百合科（17属32种）、天南星科（19属28种）、大戟科（8属27种）和唇形科（17属24种）。

2.2 澳门地被植物的物种组成

根据植物的生活型，澳门地被植物可分为多年生草本、一二年生草本、灌木和藤蔓4类，其中草本类种类占比72%（731种），灌木类占比12%（117种），藤蔓类占比16%（161种），三类地被植物分别有76种、1种和6种属于蕨类植物。

根据植物观赏部位特点，一般植株具有以下特征被认为观赏性或观赏价值较高：花朵色彩艳丽且纯度高、花形奇特、花径大、花序集中，花量多且显著度高，花叶对比度强烈；果实颜色鲜艳、数量多且果实显著度高；叶色有季相变化，且颜色艳丽或叶形奇特[18]。以下分类介绍具有观赏价值的地被植物及其园林应用形式。

2.2.1 草本类地被植物

草本类地被植物在园林实际应用的范围最广，种数占比最大，是组成园林色块的重要部分，主要包括一二年生草本和多年生草本（表2）。这类植物植株低矮，枝叶稠密，分枝能力强，生长迅速，短期内能覆盖地面，如巴西莲子草（红龙草）、竹节蓼等；同时具有色彩鲜艳、形态优美的特点，以观花为主，如鸡冠花、三色堇和旱金莲等，可用于花境、花带、花坛、缀花草坪等，或与乔灌木等搭配种植。

2.2.2 灌木类地被植物

灌木类地被植物是园林植物构成中的主要类型之一（表3）。这类植物通常用作低矮覆盖层，具有形态色彩各异、季相变化丰富，同时枝叶繁茂、萌枝力强、耐修剪的特点，如草珊瑚、石斑木、基及树（福建茶）和龙船花等。其中绣球、月季花和长春花等具有较高的观赏性，在园林应用中可用于城市道路绿化带，或孤植、丛植于庭院、草坪等。

2.2.3 藤蔓类地被植物

藤蔓类地被植物是园林垂直绿化的重要组成部分，包括木质藤本、草质藤本和匍匐生长的草本植物（表4）。这类植物单株覆盖面积大、附着力强、生长迅速，可以有效防止水土流失，是良好的护坡绿化地被植物，如牛筋藤、龙须藤和扭肚藤等；五爪金龙、玉叶金花和炮仗花等花朵艳丽，观赏性高，主要用于垂直绿化，扩展绿化空间，或林下片植。但需注意五爪金龙等外来植物具有一定入侵性，大面积种植时需评估其对周边环境的影响。

表2　澳门20种观赏性较高的草本类地被植物

序号	植物学名	科名	生活型	观赏部位	应用形式
1	艳山姜 *Alpinia zerumbet*	姜科	多年生草本	花、叶	溪水丛植
2	巴西莲子草 *Alternanthera dentata*	苋科	多年生草本	叶	大面积栽培
3	鹤顶兰 *Phaius tancarvilleae*	兰科	多年生草本	花	室内盆栽
4	虾衣花 *Justicia brandegeeana*	爵床科	多年生草本	花、苞叶	盆栽、花坛
5	鸡冠花 *Celosia cristata*	苋科	一二年生草本	花	花镜花坛
6	醉蝶花 *Cleome hassleriana*	白花菜科	一二年生草本	花	花镜花坛、盆栽
7	风车草 *Cyperus involucratus*	莎草科	多年生草本	叶	水培、插花材料
8	石竹 *Dianthus chinensis*	石竹科	多年生草本	花	花坛花镜
9	蛇莓 *Duchesnea indica*	蔷薇科	多年生草本	花、果	片植
10	小苍兰 *Freesia refracta*	鸢尾科	多年生草本	花	室内盆栽
11	竹节蓼 *Homalocladium platycladum*	蓼科	多年生草本	茎	室内摆设
12	长寿花 *Kalanchoe blossfeldiana*	景天科	多年生草本	花	盆栽
13	半边莲 *Lobelia chinensis*	桔梗科	多年生草本	花、叶	片植
14	花叶冷水花 *Pilea cadierei*	荨麻科	多年生草本	叶	林下、花镜
15	虎耳草 *Saxifraga stolonifera*	虎耳草科	多年生草本	花、叶	林下、花镜
16	绶草 *Spiranthes sinensis*	兰科	多年生草本	花	室内盆栽
17	孔雀草 *Tagetes patula*	菊科	一二年生草本	花、叶	花坛
18	紫竹梅 *Tradescantia pallida*	鸭跖草科	多年生草本	花、叶	盆栽、丛植
19	旱金莲 *Tropaeolum majus*	旱金莲科	多年生草本	花、叶	室内盆栽
20	三色堇 *Viola tricolor*	堇菜科	多年生草本	花	花坛、盆栽

表3　澳门20种观赏性较高的灌木类地被植物

序号	植物学名	科名	观赏部位	应用形式
1	红穗铁苋菜 *Acalypha hispida*	大戟科	叶、花	片植、群植
2	鸳鸯茉莉 *Brunfelsia brasiliensis*	茄科	花	花坛、花境
3	基及树 *Carmona microphylla*	紫草科	叶	绿篱
4	长春花 *Catharanthus roseus*	夹竹桃科	花	群植、花境
5	白花灯笼 *Clerodendrum fortunatum*	马鞭草科	花、叶	盆栽、片植
6	变叶木 *Codiaeum variegatum*	大戟科	叶	绿篱、丛植
7	朱蕉 *Cordyline fruticosa*	龙舌兰科	叶	片植、群植
8	翠芦莉（蓝花草）*Ruellia simplex*	爵床科	花	片植、花境
9	绣球 *Hydrangea macrophylla*	绣球花科	花	丛植、花镜
10	龙船花 *Ixora chinensis*	茜草科	花	群植、片植
11	马缨丹 *Lantana camara*	马鞭草科	花	绿篱、丛植
12	金苞花 *Pachystachys lutea*	爵床科	花、叶	花境、丛植
13	蓝丹花 *Plumbago auriculata*	白花丹科	花	丛植、花境
14	石斑木 *Rhaphiolepis indica*	蔷薇科	花、果	绿篱、群植
15	月季花 *Rosa chinensis*	蔷薇科	花	片植、群植
16	草珊瑚 *Sarcandra glabra*	金粟兰科	叶、果	群植、花境
17	草海桐 *Scaevola taccada*	草海桐科	花、叶	散植、片植
18	白马骨 *Serissa serissoides*	茜草科	花、叶	片植、盆栽
19	珊瑚樱 *Solanum pseudocapsicum*	茄科	果、叶	盆栽、片植
20	巴西光荣树 *Pleroma semidecandrum*	野牡丹科	叶、花	群植、花境

2.2.4 蕨类地被植物

蕨类是园林绿化中优良的耐阴地被植物，具有很好的发展前景（表5）。这类植物虽然没有娇美的花朵与鲜艳的果实，但其叶姿优美，四季常青，如翠云草、海金沙和巢蕨等，可与其他地被植物配置，打造出清幽、富有野趣的自然景观效果；还可与山石相配，丰富整体景观。澳门地被植物中蕨类总共有83种，绝大部分的生活型属于草本类，只有很小部分属于灌木类和藤蔓类。

3 澳门与周边城市地被植物资源与应用比较

澳门地处珠江西岸，属于南亚热带季风气候区，是粤港澳大湾区的核心城市之一，经济发达。本文特选取经济、社会和自然资源相近的珠海、深圳、广州3个城市，与澳门进行地被植物资源与应用的比较。因珠海、深圳、广州目前仍未见有完整的地被植物数据，故此处仅能作种类和应用方式的粗略分析。

澳门面积相对较小，仅约为珠海的1.8%、深圳的1.6%和广州的0.4%。澳门、深圳和广州均有植物志书出版，分别完成于2007、2017和1956年，各自记载了维管束植物206科1 508种[12~15]、237科2 862种[19]和198科1 651种[20]；珠海尚未有植物志书统计数据，根据已发表的论文记载，珠海有野生维管植物202科1 448种[21]。由以上数据比较可以看出，虽然澳门相比其他3个城市面积极小，但其所含科和种的数量却很接近，是物种密度最高的城市。

有关4个城市地被植物的研究主要关注城市公园地被植物的应用，均缺少全面性总结，仅见在广州6个公园统计到常见地被植物87种[22~23]，在深圳21个公园统计到地被植物108种[24]，而珠海缺少地被植物的统计数据。4个城市地被植物应用的共同特点是爵床科、龙舌兰科、百合科、茜草科、天南星科、大戟科、马鞭草科以及蝶形花科等所含植物占绝大多数，常用的种类包括红背桂*Excoecaria cochinchinensis*、香港斑叶鹅掌藤*Heptapleurum arboricola*、金叶假连翘*Duranta erecta* 'Golden Leaves'、金边龙舌兰*Agave americana* 'Variegata'、黄脉爵床*Sanchezia oblonga*和长隔木（希茉莉）*Hamelia patens*等，主要是用作布置花坛、花境，或在草坪上片植。4个城市地被植物种类和应用的相似性，与其处于同一地理气候区域、广府文化圈、植被苗木同源等因素密切相关。2017年起国家全力推进建设粤港澳大湾区世界级城市群，宜居宜业的自然人文环境显得尤为重要。地被植物在城市环境的改善方面有着不可替代的重要作用，建议今后在其种类发掘、新品种培育和管养技术等方面，

表4　澳门20种观赏性较高的藤蔓类地被植物

序号	植物学名	科名	观赏部位	应用形式
1	珊瑚藤 *Antigonon leptopus*	蓼科	花	花架
2	龙须藤 *Phanera championii*	苏木科	叶	护坡、墙垣绿化
3	蝶豆 *Clitoria ternatea*	蝶形花科	花、果	构架绿化
4	木防己 *Cocculus orbiculatus*	防己科	果	花架
5	球兰 *Hoya carnosa*	萝摩科	花	花架
6	五爪金龙 *Ipomoea cairica*	旋花科	花、叶	垂直、花架绿化
7	扭肚藤 *Jasminum elongatum*	木犀科	花、果	构架绿化
8	清香藤 *Jasminum lanceolaria*	木犀科	叶、花	林缘、树池
9	华南忍冬 *Lonicera confusa*	忍冬科	叶、花	构架、地面绿化
10	牛筋藤 *Malaisia scandens*	桑科	叶	地面绿化
11	玉叶金花 *Mussaenda pubescens*	茜草科	花、叶	地面绿化
12	鸡矢藤 *Paederia foetida*	茜草科	叶、花	地面绿化
13	鸡蛋果 *Passiflora edulis*	西番莲科	果、花	构架绿化
14	牵牛 *Ipomoea nil*	旋花科	花、叶	垂直绿化
15	山蒟 *Piper hancei*	胡椒科	叶	构架、高架桥绿化
16	百足藤 *Pothos repens*	天南星科	叶	林下，树池绿化
17	炮仗花 *Pyrostegia venusta*	紫葳科	花	花架、高架桥绿化
18	绿萝 *Epipremnum aureum*	天南星科	叶	墙面、林下绿化
19	菝葜 *Smilax china*	菝葜科	叶、果	地面、棚架绿化
20	山牵牛 *Thunbergia grandiflora*	爵床科	花	高架桥、棚架绿化

表5　澳门20种观赏性较高的蕨类地被植物

序号	植物学名	科名	属名	应用形式
1	铁线蕨 *Adiantum capillus-veneris*	铁线蕨科	铁线蕨属	盆栽、岩石景观
2	华南实蕨 *Bolbitis subcordata*	实蕨科	实蕨属	林下、石上
3	华南毛蕨 *Cyclosorus parasiticus*	金星蕨科	毛蕨属	林下、水边
4	粤里白 *Diplopterygium cantonense*	里白科	里白属	护坡、丛植
5	团扇蕨 *Crepidomanes minutum*	膜蕨科	团扇蕨属	水边、假山
6	杯盖骨碎补 *Trogostolon griffithianus*	骨碎补科	阴石蕨属	树干、石上
7	伏石蕨 *Lemmaphyllum microphyllum*	水龙骨科	伏石蕨属	岩石景观
8	海金沙 *Lygodium japonicum*	海金沙科	海金沙属	林下、路边
9	华南鳞盖蕨 *Microlepia hancei*	碗蕨科	鳞盖蕨属	路边
10	巢蕨 *Asplenium nidus*	铁角蕨科	巢蕨属	吊盆观赏
11	肾蕨 *Nephrolepis cordifolia*	肾蕨科	肾蕨属	花镜、水边
12	华南羽节紫萁 *Plenasium vachellii*	紫萁科	紫萁属	丛植
13	粉叶蕨 *Pityrogramma calomelanos*	裸子蕨科	粉叶蕨属	林下、路边
14	毛轴蕨 *Pteridium revolutum*	蕨科	蕨属	林下、护坡
15	井栏边草 *Pteris multifida*	凤尾蕨科	凤尾蕨属	岩石景观
16	半边旗 *Pteris semipinnata*	凤尾蕨科	凤尾蕨属	假山、水边
17	蜈蚣凤尾蕨 *Pteris vittata*	凤尾蕨科	凤尾蕨属	岩石景观
18	石韦 *Pyrrosia lingua*	水龙骨科	石韦属	丛植
19	翠云草 *Selaginella uncinata*	卷柏科	卷柏属	岩石景观
20	狗脊 *Woodwardia japonica*	乌毛蕨科	狗脊属	水边

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4 澳门绿地系统不同场景地被植物应用建议

澳门地被植物资源丰富，物种多样，占澳门维管束植物总种数的66.91%。然而，澳门城市园林绿化对现有地被植物资源的开发利用较少，常用的地被植物100余种，仅占澳门维管束植物总种数约6.6%。为了能适应澳门世界级休闲城市丰富的园林景观需求，需根据植物的生长习性、观赏特性等，打造适应不同环境的植物配置方式，使其达到生态与景观效益的最大化[25]。特提出以下建议供参考。

4.1 因地制宜，满足生态原则

适地适树是园林和林业绿化种植设计的基本原则。在园林植物配置方面，光因子常作为主导因子，根据地被植物对光线的适应性，可把其分为耐阴地被、喜阳地被和半耐阴地被3类[26]。耐阴地被一般以观叶为主，大部分为蕨类地被植物，少数为草本类，这类植物常配置于林下或庇荫处，如华南毛蕨、翠云草和巴西莲子草等；喜阳地被植物一般都具有艳丽的花朵，多为草本类和藤蔓类，可配置于林缘、岩石园或天台花园等地，如鸡冠花、三色堇和山牵牛等；半耐阴地被植物多为灌木类，部分为藤蔓类和蕨类，该类植物对光线适应性强，在全日照或半阴的环境下都能生长良好，应用范围较广，可以在阴暗的高架桥下，也可以在露天广场花坛，如龙船花、长春花、玉叶金花和海金沙等。

4.2 应景而异，满足观赏需求原则

不同绿地类型有不同的景观和功能要求，需根据不同绿地的自然和人文特点，选择不同的地被植物。将场地划分为公园、道路、滨水、坡地与垂直建筑5类，下面针对各类场地的地被植物配置提出建议：

1）公园绿地

公园和花园是澳门市民休闲、聚集的主要活动场所，虽然面积不大，但人流量较大，故对景观观赏性要求较高。应选择观赏性地被植物，以阳性植物为主，如一串红*Salvia splendens*、四季秋海棠*Begonia cucullata*、石竹和艳山姜等，配置形成花境、花坛、花丛，能够与常绿乔木、草坪等相对比，形成色彩丰富的植物景观。

2）道路绿化

澳门道路绿化形式以列植为主，景观较为单一，所以在选取生性强健、抗逆性强、自我更新能力强的地被植物[27]，如巴西莲子草、天门冬、龙船花、山菅兰*Dianella ensifolia*和小蚌兰*Tradescantia spathacea* ‘Compacta’等的同时，加以时花和彩叶植物，形成相对多元化的道路绿化种植方式，并且将乔木、灌木和地被植物有机结合，形成一种稳定的、能够体现当地特色的自然景观。

3）滨水造景

在水边栽植地被植物不仅可以保护水岸、固坡和建设生态环境，还能巧妙利用水面倒影，与蓝天、白云、绿树共同构成色彩斑斓的景观[28]。滨水场地的植物一般选择以下两种：一是下垂的植物，如肾蕨和水鬼蕉*Hymenocallis littoralis*等，此类植物可起遮挡作用，从而柔化岸线；二是观花或色叶植物，如朱蕉和美人蕉*Canna indica*等，此类植物能吸引人的眼光，从而弱化岸线，达到柔化岸线的目的。

4）坡地绿化

地被植物植株低矮，根系固土能力强，不仅能美化边坡，还具有良好的护岸固坡、防止水土流失的作用，如棕叶狗尾草*Setaria palmifolia*、大叶仙茅*Curculigo capitulata*、花叶竹芋*Maranta arundinacea* ‘Variegata’、朱蕉和华南毛蕨等。坡地的地被植物配置常用形式有片状种植、斑点状种植和点片混种，片状和点片种植的防护效果较为明显，斑点状种植显得更为灵活有趣，要根据坡地具体情况进行安排，合理配置，才能达到良好的景观效果和生态效果[22]。

5）垂直绿化

澳门半岛内的一般居住区以及医疗卫生、行政机关等单位，除个别外，普遍专用绿地面积极小，甚至没有绿地，且大部分地区立体绿化欠缺。建议利用单株覆盖面积大、附着力强、生长迅速，抗污染及病虫害的能力强且管理粗放的藤蔓类地被植物，如异叶地锦*Parthenocissus dalzielii*、使君子*Quisqualis indica*等，进行立体绿化，来提升高密度城市的绿化覆盖率。

4.3 丰富种类和形式，科学养护管理

澳门地被植物资源因为乡土种类多而呈现物种丰富度较高的特点，但仍然迫切需要加强对乡土地被植物的种质资源收集、保存、繁育与栽培等基础研究。虽然将乡土地被植物应用于园林景观配置有着广阔的开发前景，但是实现量产并投入使用的种类不多，大部分仍处于野生状态，尚未得到开发。建议开辟澳门园林种质资源主题公园，引种驯化并推广乡土地被植物，从而做到保护和利用相结合，进一步探索野生地被植物的繁殖技术，筛选出更多适合观赏的种类，增加澳门城市植物的多样性。

由于澳门受西方文化影响长达数百年，其园林中完全采用自然式种植的情况较为少见，大多是采用规则式种植，把植物修剪成各种抽象的几何形，或以行列式对称种植，刻意追求一种艺术的形式美感，却少了东方园林的意境自然美。建议采用规则式的地被植物与自然式的中上层植物景观搭配，并增加地被植物的种类，避免单一种类数量过多，体现出人工结合自然的精致[28]。

俗语“三分种、七分养”，地被植物需要根据其生物学和生理学特性进行有针对性的科学养护管理，除了做好日常的浇灌、除草、施肥、修剪

等工作外，还需结合现代监测设备，做到精细化和智慧化管理，营建有岭南特色的地被景观。

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ISSN 1671-2641

RCCSE 中国核心学术期刊
中国科学引文数据库 (CSCD) 来源期刊
中文科技期刊数据库来源期刊

中国核心期刊（遴选）数据库来源期刊
中国学术期刊综合评价数据库来源期刊

ISSN 1006-9690

第40卷 第12期
Vol.40 No.12

中国野生植物资源
Chinese Wild Plant Resources

12
2021

主管：中华全国供销合作总社
主办：南京野生植物综合利用研究院

ISSN 1006-9690

中国野生植物资源

第 40 卷 12 期(卷终) 2021 年 12 月 总第 213 期

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中国野生植物资源
ZHONGGUO YESHENG ZHIWU ZIYUAN
（月刊，1982年创刊）
2021年12月　第40卷第12期（总第213期）

Chinese Wild Plant Resources
(Monthly, Started in 1982)
Vol. 40 No. 12 December 2021 (Tot. No. 213)

主　　管　中华全国供销合作总社
主　　办　南京野生植物综合利用研究院
主　　编　张卫明
编辑出版　《中国野生植物资源》编辑部
　　（南京江宁区江云路7号，邮政编码：211111）
　　（E-mail：ysrw2009@vip.163.com）
　　（电话：025－85471187）
官　　网　http://zysw.cbpt.cnki.net
印　　刷　南京百花彩色印刷广告制作有限责任公司
总 发 行　江苏省邮政局

Administration All China Federation of Supply & Marketing Cooperatives
Sponsor Nanjing Institute for Comprehensive Utilization of Wild Plants
Editing & Publishing Editorial Board of *Chinese Wild Plant Resources*
(No. 7, Jiangyun Road, Jiangning District, Nanjing 211111, China,
E-mail: ysrw2009@vip.163.com; Tel: 025－85471187)
Chief Editor Zhang Weiming
Official website http://zysw.cbpt.cnki.net
Printing Nanjing Baihua Print Advertising Limited Liability Company
Distributor Jiangsu Post Office

中国标准连续出版物号：ISSN 1006－9690 / CN 32－1381/Q　广告发布登记通知书号：广字32000000023　邮发代号：28－245　定价：20.00元

doi:10.3969/j.issn.1006-9690.2021.12.015

广东汕尾城区捷胜镇野生药用植物资源初步研究

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摘 要 为摸清广东汕尾城区捷胜镇野生药用植物资源家底,采用野外样地和样线调查,结合文献收集与分析,获取捷胜镇野生药用植物的种类、数量等指标,分析其物种组成、生活型、药用部位和资源储量等基础信息。结果表明,捷胜镇野生药用植物共统计到52科122属138种;生活型多样,以草本占明显优势;不同药用植物的药用部位不同,以根及根茎入药的植物最多(41.30%);药用植物中重点药用植物17种(12.32%)、入侵植物18种(13.04%)。捷胜镇野生药用植物资源种类总体上较少,重点药用植物储量不多,野生植物资源亟待保护和合理开发利用。

关键词 药用植物;植物资源;捷胜镇

中图分类号:Q949.95 **文献标识码**:A **文章编号**:1006-9690(2021)12-0080-05

A Preliminary Study on Wild Medicinal Plant Resources in Jiesheng of Shanwei City, Guangdong Province

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Abstract In order to map out the resource base of wild medicinal plants in Jiesheng Town, Shanwei City, Guangdong Province, the survey of field samples and sample lines, combined with literature collection and analysis, were used to obtain the species and quantity of wild medicinal plants in Jiesheng Town, and analyzed the basic information of their species composition, life forms, medicinal parts and resource reserves. Results: There were 138 species of wild medicinal plants in Jiesheng Town, including 52 families and 122 genera; The life forms were diverse, with herbs taking the lead; The medicinal parts of different medicinal plants were different, with the most plants using roots and rhizomes for medicine (41.30%); There were 17 species of key medicinal plants (12.32%) and 18 species of invasive plants (13.04%). Jiesheng Town had fewer kinds of wild medicinal plant resources in general, not many key medicinal plant reserves, and wild plant resources were in urgent need of protection and reasonable development and utilization.

Key words Medicinal plants; Plant resources; Jiesheng Town

随着经济社会的迅猛发展,我国已全面建成小康社会,人们的健康意识日益增强,认识到药用植物具有取材自然、毒副作用小、价格便宜、疗效好等优点,也越来越重视药用植物的使用。自1987年开展的第三次全国中药资源普查表明我国药用植物达到11 116种[1],但是距今已经30多年,各地野生

收稿日期:2021-04-27,录用日期:2021-12-13
基金项目:2019年医疗服务与保障能力提升补助资金(中医药事业传承与发展部分)"全国中药资源普查项目"(财社〔2019〕39号);广东省林业科技创新项目(2018KJCX030);华南农业大学创新训练项目(S202010564031)。
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药用植物资源均发生了极大的变化，而且有关文献指出调查研究局部地区的药用植物资源，可以了解当地药用植物的种类组成与资源利用现状[2]。此外，广东省作为中国光、热和水资源最丰富的地区之一，有着丰富的药用植物资源。因此，本研究者依托全国第四次中药资源普查，于2020年6月至2020年9月，对广东省汕尾市城区捷胜镇14个行政村进行了野外考察、民间走访和资料整理，以期掌握当地野生药用植物资源分布情况，为中药产业的发展提供科学依据。

1　材料与方法

1.1　研究地概况

捷胜镇（22°43′～22°44′ N，115°23′～115°24′ E）位于广东省汕尾市城区东南部的红海湾畔，总面积52 km^2，下辖14个行政村和4个居民社区。捷胜镇地理位置上背山面海，境内西北有大伯山、虎洞山，西南有烟墩山，中有云山，陆上被九伯岭分隔为两部分，中部地势略高，且自东向西错落分布有石狗湖、双石湖、沙坑湖、东坑湖等四个天然湖泊。气候上属亚热带季风气候，年均气温22.8℃，年均降水量为2 107.1 mm[3]，独特的自然条件孕育了丰富的药用植物资源。

1.2　研究内容与方法

1.2.1　研究内容

对捷胜镇野生药用植物进行实地样地调查，以《中华人民共和国药典》[4]、《中国药用植物志》[5]、《广东植物志》[6]、《中华本草》（2-8册）[7]，《现代本草纲目》（上、下册）[8]以及相关文献资料[9-10]为依据，整理出捷胜镇野生药用植物名录，并根据调查所记录的数据，分析当地药用植物资源的物种组成、生活型、不同药用植物的药用部位、重点药用植物资源储量和入侵植物的具体情况，从而为中药资源开发应用以及防治入侵植物提供科学依据。

1.2.2　调查方法

本研究依据全国第四次中药资源普查技术规范，属于区域性药用植物多样性本底调查。以《全国中药资源普查技术规范》为技术指导，进行样地、样线调查和走访调查，沿途拍摄植物照片作调查凭证，采集植物标本并请专家鉴定。样地调查采用随机抽样法和分层抽样法生成7个1 km × 1 km的样地，每个样地设置5个10 m × 10 m的样方套，样方套之间间隔直线距离200 m以上。每个样方套中包括1个10 m × 10 m的乔木样方，编号为1；1个5 m × 5 m的灌木样方，编号为2；4个2 m × 2 m的草本样方，编号为3、4、5、6（图1）。捷胜镇共完成7个样地，35个样方套，210个样方。

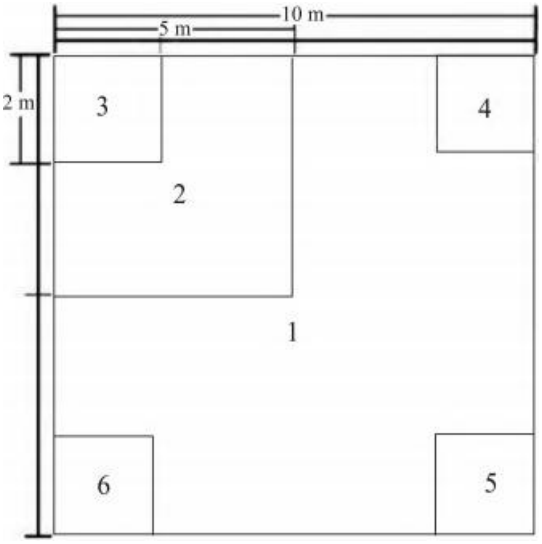


图1　样方套示意图

Fig. 1　Schematic diagram of sample square

2　结果与分析

2.1　捷胜镇野生药用植物物种组成多样性分析

根据初步调查结果显示，广东省汕尾市城区捷胜镇野生药用植物共有52科122属138种，占该地区维管束植物（156种）的88.46%，其中蕨类植物有5科5属5种，裸子植物1科1属2种，被子植物中单子叶植物有6科21属23种，双子叶植物有40科95属108种（表1）。可见捷胜镇野生药用植物种类组成以双子叶被子植物为主，其科、属和种占药用植物总科、属和种的比例为76.92%、77.87%、78.26%，而蕨类植物和裸子植物相对较少，占比均在4%以下。

表1　汕尾城区捷胜镇药用植物的物种组成

Table 1　Species composition of medicinal plants in Jiesheng Town, Shanwei City

类别		科数	占总科数比例（%）	属数	占总属数比例（%）	种数	占总种数比例（%）
蕨类植物		5	9.62	5	4.10	5	3.62
裸子植物		1	1.92	1	0.82	2	1.45
被子植物	单子叶植物	6	11.54	21	17.21	23	16.67
	双子叶植物	40	76.92	95	77.87	108	78.26
总数		52	100.00	122	100.00	138	100.00

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2.2 捷胜镇野生药用植物生活型统计与分析

生活型是植物在其发展历史过程中，对一定生活环境长期适应形成的各种基本形式[11]，常用来描述成熟的高等植物。生活型可以反映一定地区的自然环境，主要按照植物的外貌特征及生命周期来区分，如高矮、大小、形状、分枝及年度周期等[12]。参考Drude的生活型系统划分标准划分捷胜镇药用植物的生活型[13]（表2）。

表2 汕尾城区捷胜镇野生药用植物生活型统计

Table 2 Statistics on life forms of wild medicinal plants in Jiesheng Town, Shanwei City

生活型	科数	占总科数比例(%)	属数	占总属数比例(%)	种数	占总种数比例(%)
一、二年生草本	9	11.54	21	16.28	21	15.22
多年生草本	10	20.51	30	23.26	31	22.46
藤本	11	20.51	20	15.50	22	15.94
灌木	12	24.36	28	21.70	30	21.74
乔木	13	23.08	30	23.26	34	24.64
总计	55	100.00	129	100.00	138	100.00

根据生活型的分类，捷胜镇的野生药用植物中草本植物较多，占当地药用植物总数的37.68%，灌木和乔木植物的物种数量相差不大，均在20%～25%，藤本植物较少，为15.94%，乔灌草分配较为均衡，这可能与捷胜镇的亚热带季风气候有关，植被层次较分明，符合汕尾市城区整体植被分布的特点。

2.3 捷胜镇野生药用植物科的多样性分析

按照科内所含药用植物物种数目多寡为依据，可将该科分为单种科（仅含1种）、寡种科（含2～5种）、中等科（6～10种）和大科（含＞10种）。由表3统计结果看，野生药用植物中单种科最多有25个，占总科数的48.08%；其次是寡种科，有21个，占总科数的40.38%；而中等科和大科的科数占总科数的比例低，分别为7.69%和3.85%。大科按所含种数由多到少的顺序排列，依次为禾本科（Poaceae）16种、豆科（Fabaceae）12种，中等科按所含种数由多到少的顺序排列，依次为大戟科（Euphorbiaceae）9种、菊科（Asteraceae）9种、茜草科（Rubiaceae）9种、芸香科（Rutaceae）7种。

表3 汕尾城区捷胜镇野生药用植物科的多样性统计

Table 3 Diversity statistics of wild medicinal plant families in Jiesheng Town, Shanwei City

类别		科数	占总科数比例(%)	种数	占总种数比例(%)
单种科	1	25	48.08	25	18.12
寡种科	2～5	21	40.38	51	36.96
中等科	6～10	4	7.69	34	24.64
大科	＞10	2	3.85	28	20.28
总数		52	100.00	138	100.00

2.4 捷胜镇野生药用植物的药用部位分析

不同的药用植物入药的部位是不同的，各部位成熟季节的差异也很大，明确的划分捷胜镇药用植物资源的药用部位，有利于当地居民根据药用部位的成熟期，确定合理的采摘时间。本研究参考相关文献资料[4-8]，对捷胜镇野生药用植物药用部位的类型进行了划分与归类统计分析。将该镇野生药用植物划分成9大类，分别是全草类、根及根茎类、叶类、花类、果实和种子类、皮类、茎木类、树脂类、其他类。统计中，若一种植物有多个药用部位，则分别记录名称与频次。由表4可知，以根及根状茎入药的最多，有白背叶（*Mallotus apelta*）、黑面神（*Breynia fruticosa*）、鸡骨香（*Croton crassifolius*）等，总物种数的41.30%；其次分别是以全草入药，有白子菜（*Gynura divaricata*）、一点红（*Emilia sonchifolia*）、苘麻（*Abutilon theophrasti*）等，占总种数的34.78%；以叶入药的有秋枫（*Bischofia javanica*）、木薯（*Manihot esculenta*）、桃金娘（*Rhodomyrtus tomentosa*）等，占总种数的24.64%；以果实和种子入药的有血桐（*Macaranga tanarius* var. *tomentosa*）、余甘子（*Phyllanthus emblica*）、柚（*Citrus maxima*）等，占总种数的18.78%；以皮入药的有阔荚合欢（*Albizia lebbeck*）、朴树（*Celtis sinensis*）、潺槁木姜子（*Litsea glutinosa*）等，占总种数的10.14%；以茎木入药的有山香（*Hyptis suaveolens*）、紫苏（*Perilla frutescens*）、两面针（*Zanthoxy-*

表4 汕尾城区捷胜镇不同药用部位的植物种数

Table 4 Number of plant species with different medicinal parts in Jiesheng Town, Shanwei City

药用部位	科数	占总科数比例(%)	属数	占总属数比例(%)	种数	占总种数比例(%)
全草类	26	50.00	43	35.25	48	34.78
根及根茎类	30	57.69	49	40.16	57	41.30
叶类	20	38.46	34	27.87	34	24.64
花类	9	17.31	10	8.2	10	7.25
果实和种子类	17	32.69	23	18.85	23	16.67
皮类	12	23.08	14	11.48	14	10.14
茎木类	13	25.00	14	11.48	14	10.14
树脂类	1	1.92	1	0.82	1	0.72
其它类	15	30.77	22	18.03	25	18.12

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lum nitidum）、海金沙（*Lygodium japonicum*）等，占总种数的 10.14%；以花入药的有青葙（*Celosia argentea*）、马尾松（*Pinus massoniana*）、白茅（*Imperata cylindrica*）等，占总数的 7.25%；以树脂入药的野漆（*Toxicodendron succedaneum*）和以其他类入药的地茶（*Melastoma dodecandrum*）、苘麻（*Abutilon theophrasti*）等，各占总种数的 0.72% 和 18.12%。在调查范围内，有将近半数（41.30%）的药用植物以根及根状茎作为入药部位，使用这些药用植物是以全株死亡为代价。因此，在开发利用时，应适度采挖，如果植物濒临灭绝，应停止开采并保护濒危药用植物的生境。

2.5　捷胜镇重点药用植物资源分析

依据全国中药资源普查重点调查中药资源（中药材）目录[9]，本次捷胜镇共调查到重点植物药材 19 种（表 5），涉及基原植物 17 种，占捷胜镇野生药用植物总种数的 12.32%，隶属于 14 科 17 属，其中高达 19 种重点植物药材被 2020 年版《中国药典》（一部）[4] 收载，说明捷胜镇中草药资源有保护意义和开发利用价值。我们通过整理得出重点调查药用植物名录，并将其多少用“+”符号表示在样方中出现的频次，统计结果见表 5。

表 5　汕尾城区捷胜镇重点调查药用植物资源储量一览表

Table 5　Statistics on the reserves of key medicinal plant resources in Jiesheng Town，Shanwei City

序号	基源植物	中药材名称	植物学名	科名	储量评价
1	菝葜	菝葜	*Smilax china*	菝葜科	++
2	紫苏	紫苏叶、紫苏梗、紫苏子	*Perilla frutescens*	唇形科	+
3	飞扬草	飞扬草	*Euphorbia hirta*	大戟科	++
4	海金沙	海金沙	*Lygodium japonicum*	海金沙科	++++
5	白茅	白茅根	*Imperata cylindrica*	禾本科	++++
6	鸦胆子	鸦胆子	*Brucea javanica*	苦木科	+++
7	楝	苦楝皮	*Melia azedarach*	楝科	++
8	盐肤木	五倍子	*Rhus chinensis*	漆树科	+
9	栀子	栀子	*Gardenia jasminoides*	茜草科	++
10	枇杷	枇杷叶	*Eriobotrya japonica*	蔷薇科	+
11	马尾松	松花粉	*Pinus massoniana*	松科	+++
12	荔枝	荔枝核	*Litchi chinensis*	无患子科	+
13	龙眼	龙眼肉	*Dimocarpus longan*	无患子科	+
14	青葙	青葙子	*Celosia argentea*	苋科	+
15	两面针	两面针	*Zanthoxylum nitidum*	芸香科	+
16	九里香	九里香	*Murraya exotica*	芸香科	+
17	柚	化橘红	*Citrus maxima*	芸香科	+

注：++++表示随处可见；+++表示中等、经常可见；++表示少、少见；+表示很少、个别、偶遇。

统计结果表明，海金沙、鸦胆子（*Brucea javanica*）、白茅与马尾松出现频次多；菝葜（*Smilax china*）、飞扬草（*Euphorbia hirta*）、楝（*Melia azedarach*）、栀子（*Gardenia jasminoides*）出现频次较多；紫苏、盐肤木（*Rhus chinensis*）、枇杷（*Eriobotrya japonica*）等出现少（如表 5）。说明中草药资源的储量各不相同，总体上偏少，在开发利用时需注意资源保护。

2.6　捷胜镇外来入侵植物分析

本研究所界定的捷胜镇的外来入侵植物，是指那些原产地不在中国，但通过人为或自然传播进入捷胜镇并已逸为野生或归化的植物[10]。通过对捷胜镇的外来植物进行较全面的调查研究，以期在处理当地外来植物问题时提供一定的依据。根据野外实地调查及查阅相关文献资料[14-16]，总结出捷胜镇的外来植物名录（如表 6）。捷胜镇共有 18 种入侵植物，其中 6 种植物的危害较为严重，包括山香、光荚含羞草（*Mimosa bimucronata*）、假马鞭（*Stachytarpheta jamaicensis*）、红毛草（*Rhynchelytrum repens*）、马缨丹（*Lantana camara*）和阔叶丰花草（*Borreria latifolia*），其生长、繁殖和扩散非常迅速，对当地的自然生态系统产生了较大的影响。

3　结论与讨论

3.1　捷胜镇野生药用植物基本特点

此次样地的选取采用随机法，几乎可以代表捷胜镇所有的植被类型。调研记录到捷胜镇野生药用植物共 52 科 122 属 138 种，主要为双子叶被子植物，所占比例高达 76.92%；生活型多样，以草本占明显优势，占总种数的 37.68%；不同药用植物的药用部位不同，以根及根茎入药的植物最多，占 41.30%；药用植物中重点药用植物共计 17 种，占总种数的 12.32%；入侵植物以山香、光荚含羞草、假马鞭、红毛草、马缨丹和阔叶丰花草危害最为严重。

3.2　捷胜镇野生药用植物保护与利用建议

捷胜镇野生药用植物资源相对较少，大部分还处于野生或半野生状态，为进一步研究、保护和利用当地的野生药用植物资源，提出以资源保护为前提，合理开发利用的建议：

（1）捷胜镇野生药用植物在科属构成、药用部位、重点中草药储量方面呈现一定的多样性，但野生药用植物的分布较为分散，未形成规模。如需发展中草药产业，建议加强人工干预，先做好种植种类与区域规划，逐步建立人工种植示范区，取得成效后再规模化种植推广。

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表6 汕尾城区捷胜镇外来入侵植物统计

Table 6 Statistics on alien mvasive plants in Jiesheng Town, Shanwei City

序号	种名	学名	科名	生活型	生境	危害程度
1	山香	*Hyptis suaveolens*	唇形科	草本	路边、荒地或农田	严重
2	飞扬草	*Euphorbia hirta*	大戟科	草本	路边、荒地或农田	中等
3	光荚含羞草	*Mimosa bimucronata*	含羞草科	小乔木	各地栽培或逸生	严重
4	含羞草	*Mimosa pudica.*	含羞草科	草本	路边或荒地	中等
5	银合欢	*Leucaena leucocephala*	含羞草科	灌木或小乔木	山坡、路旁或河旁	中等
6	阔荚合欢	*Albizia lebbeck*	含羞草科	落叶乔木	多为栽培、荒地有野生	暂无危害
7	红毛草	*Rhynchelytrum repens*	禾本科	草本	路边或次生灌木林	严重
8	狗尾草	*Setaria viridis*	禾本科	草本	田边、草地或路旁	中等
9	牛筋草	*Eleusine indica*	禾本科	草本	路边、荒地、农田等	中等
10	赛葵	*Malv astrum coromandelianum*	锦葵科	草本	路边或荒地	中等
11	羽芒菊	*Tridax procumbens*	菊科	草本	路边或荒地	中等
12	一年蓬	*Erigeron annuus*	菊科	草本	旷野、路边、沟边	轻微
13	飞机草	*Eupatorium odoratum*	菊科	草本	路边、荒地、农田、林地	轻微
14	假马鞭	*Stachytarpheta jamaicensis*	马鞭草科	草本或亚灌木	路边或荒地	严重
15	马缨丹	*Lantana camara*	马鞭草科	灌木	路边、荒地、林地	严重
16	阔叶丰花草	*Borreria latifolia*	茜草科	草本	荒地、农田、林地	严重
17	墨苜蓿	*Richardia scabra*	茜草科	草本	旷野或耕地杂生	暂无危害
18	龙珠果	*Passiflora foetida*	西番莲科	草质藤本	公园花圃常有栽培	暂无

(2)药用植物隶属科的多样性较为明显,以禾本科、豆科、大戟科、茜草科和菊科为优势科,但属则以单种属和寡种属为主,这与曾宪峰等[17]所做的粤东药用种子植物多样性调查的结果一致。根据实地调查,大部分捷胜镇近自然植被为次生林,林分年龄小,且多有经历过火烧的痕迹,建议加强当地居民的自然保护意识,禁止乱砍滥发,全面杜绝火灾,尤其是人为火灾,促进植被的自然演替。

(3)重点调查药用植物资源统计结果显示,鸦胆子、白茅、栀子、海金沙出现的频次相当高,说明当地的环境适宜该植物的自然生长。建议当地秉承"适地适树"的原则,充分利用该地自然环境特性,开发利用这4种药用植物,带动当地经济发展。

(4)入侵植物较大程度上影响了原有的生物多样性和生态环境。因此,建议加强人们对入侵植物的认识,及时对恶性入侵和严重入侵植物进行防治,保护当地的物种多样性和生态系统的平衡。

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Guangdong
Landscape
Architecture

1979 年创刊
Vol.43 总第 200 期
广东园林学会主办

廣東園林

1
2021
双月刊



本期要文：

自然灾害风险评估下广东江门台山海宴镇海岸线生态修复景观策略初探
广东三水云东海国家级湿地公园秋冬季鸟类多样性研究
中山公园和人民公园的历史渊源

本期专题：滨水景观　野生动物及栖息地保护



ISSN 1671-2641
02
9 771671 264213

国内邮发代码 46-331　CN44-1219/S　定价：25.00 元

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DOI：10.12233/j.gdyl.2021.01.013

澳门药用植物资源*

Resources of Medicinal Plant in Macao

方惠婷　刘康　秦新生*
FANG Hui-ting，LIU Kang，QIN Xin-sheng*

摘要：药用植物对人类健康起着至关重要的作用。以澳门为例，通过野外实地调查和查阅文献，统计到澳门药用植物共152科506属725种，占澳门维管束植物总种数的40.08%。其中菊科、大戟科、蝶形花科所含种类数量位列前三；乔木类、灌木类、草本类、藤本类种数占比分别为25%、18%、47%、10%；药用部位以全草或者全株、根、叶为主。针对目前澳门药用植物应用的主要问题提出了相应建议：加强乡土药用植物资源基础研究，充分挖掘其保健康养作用，增加其在绿色公共空间中的种类与数量。

关键词：澳门；药用植物；绿化；资源
中图分类号：S688
文献标志码：A
文章编号：1671-2641（2021）01-0060-04
收稿日期：2020-07-27
修回日期：2020-08-28

Abstract: Medicinal plants play an important role in human health. Through field research and literature review, 725 species belonging to 152 families and 506 genera of medicinal plants were recorded in Macao, accounting for 40.08% of the total vascular plant species in Macao. Among them, the number of species in Asteraceae, Euphorbiaceae, and Papilionaceae ranked the top three, and the number of species of trees, shrubs, herbs and vines accounted for 25%, 18%, 47% and 10%, respectively. In addition, whole grasses or whole plants, roots and leaves were the main medicinal parts. Some suggestions on the main problems of the medicinal plant application in Macao are put forward: strengthening the basic research of native medicinal plants resources, giving full play to their health and medicinal effects, and enriching their species and quantities in public green spaces.

Key words: Macao; Medicinal plant; Landscape greening; Resource

2020庚子年春，新型冠状病毒疫情的爆发，再次让社会公共安全健康走入人们的视野。药用植物既有医学价值，又有观赏性价值，将其作为园林植物，对维护与促进公共安全健康有着独特的作用。药用植物是指根、茎、叶、花、果实等含有特殊成分，可供人类用于防病、治病的植物[1]。有些药用植物能挥发出有益的化学物质，通过人的呼吸系统及皮肤进入人体，起到防病、抗病、强身保健，提高人体免疫能力等作用[2]。多数药用植物的花、果、叶片或形态等也具观赏价值[3]。在公共绿色场所中，灌木类、藤蔓类的药用植物可作为绿篱及绿墙植物使用，具有良好的观赏价值，同时药用植物的有效成分主要通过空气传播，或者通过枝叶、果实与肌肤接触，利于公众健康。

澳门地处高密度、自由开放的粤港澳大湾区，在这次疫情的公共安全健康方面也面临着巨大的风险。寻求以适用于园林绿化的药用植物，来提高公共安全健康水平的方法，必将引起风景园林工作者的关注和深度思考。

1 澳门药用植物资源分析

1.1 基本概况

经实地调查及查阅澳门植物研究的相关文献资料[4-7]，统计出澳门药用维管束植物共725种，隶属于152科506属，种数占澳门维管束植物总种数的40.08%。其中蕨类植物有10科13属14种，裸子植物有6科9属10种，被子植物有136科484属701种（表1）。

澳门药用植物种类数量排列前十位的科分别是菊科（41属54种）、大戟科（22属41种）、蝶形花科（26属31种）、禾本科（27属30种）、茜草科（15属25种）、百合科（14属22种）、桑科（5属20种）、芸香科（10属20种）、苏木科（5属16种）和锦葵科（6属14种），所含种类累计达到273种（表2）。目前澳门城市园林绿化中应用较多的类群包括菊科、蝶形花科、桑科、芸香科与禾本科等。

1.2 种类组成

按照植物的习性，澳门药用植物分为乔木、灌木、草本与藤本植物，其中乔木类占比25%（179种），灌木类占比18%（128种），草本类占比47%（340种）和藤本类占比10%（78种）。

1.2.1 药用草本植物资源

澳门药用草本植物的资源丰富，可以形成良好的地被景观层。常见的草本植物（表3）如肾蕨，在园林中

*基金项目：国家自然科学基金项目（31870699）；第四次全国中药资源普查项目（2019502001）；大学生创新创业训练计划项目（201910564048）；广东省林业科技创新项目（2018KJCX030）

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可作背景、衬景植物，其根茎、叶皆可为药用，具有清热利湿、通淋止咳、消肿解毒的功效。一年生草本植物鸡冠花因其艳丽的颜色受到城市居民的喜爱，其花及全株有凉血、清湿热之功效。常见的水生草本植物莲是十大传统名花之一，全株皆可入药：莲叶有清热解暑的功效；荷蒂可和胃安胎；莲蓬则可化瘀止血、清心益脾、止泻；以莲子作为主要用料的莲子羹，也有清心顺气的功效[8]。莲还可以和其他药用水生植物如鼠尾草、野慈姑等形成专类展示区。因此，具有药用价值的草本植物除美化环境外，还可开发利用为药材，继续为人所用。

1.2.2 **药用乔木资源**

乔木可作为园林植物景观的“骨架”，起到遮荫、屏障等作用。澳门的常用乔木种类（表 4）如白兰有淡淡的幽香，可使人身心愉悦，消除精神疲劳，提高人体的免疫力。木棉除具有较高观赏价值外，还是岭南传统的清热祛湿食材，其花蕾经过处理后对治疗痢疾、肠炎等有一定的帮助，可促进人的生理健康。鸡蛋花盛放时同样具有较高的观赏价值，晾晒后是广东传统凉茶——五花茶中的一味，具有清热解暑、润肺、润喉等功效。阴香、樟等散发出的特殊气味可以起到驱散蚊虫的作用[8]，能降低公共空间传染性疾病发生的几率，为城市居民创造一个健康、舒适的公共空间。

1.2.3 **药用灌木资源**

灌木构成园林植物中下层景观，可起到分割空间、特色造景的作用。澳门常用的灌木（包括乔木修剪为灌木状树种）（表 5）如含笑花、海桐是清秀淡雅的赏花对象，且兼具康养功能，其散发出的淡淡香味沁人心脾，可以缓解生活压力，减轻心理负担。使君子是藤状灌木，花色艳丽，初夏时盛放枝头，其种子具有健脾胃、消积杀虫功效，叶则有促进人体的肠胃消化的功能。红桑叶具有清热消肿的功效[8]，其红色的枝叶可与绿色的植物景观大面积映衬，丰富园林景观的色彩层次。

表 1　澳门药用植物科的类型组成

科的类型	科数	占总科数比例（%）	各类型列举	所含种数	占总种数比例（%）
单种科（ 种）	60	39.47	肾蕨科、松科、商陆科	60	8.27
寡种科（ ~ 5 种）	55	36.18	千屈菜科、榆科、景天科	169	23.31
中等科（ ~ 10 种）	23	15.13	兰科、樟科、含羞草科	175	24.14
较大科（ ~ 20 种）	8	5.26	桑科、苏木科、芸香科	118	16.28
大科（ 种以上）	6	3.96	大戟科、菊科、禾本科	203	28.00

表 2　澳门药用植物所含种数排前五的科及其代表物种

科名	所含种数	占总种数比例（%）	代表物种
菊科	54	7.44	五月艾 *Artemisia indica*、茼蒿 *Glebionis coronaria*、莴苣 *Lactuca sativa*、万寿菊 *Tagetes erecta*、苍耳 *Xanthium strumarium*
大戟科	41	5.65	铁苋菜 *Acalypha australis*、红桑 *Acalypha wilkesiana*、算盘子 *Glochidion puberum*
蝶形花科	31	4.28	三点金 *Desmodium triflorum*、豆薯（沙葛）*Pachyrhizus erosus*、紫藤 *Wisteria sinensis*、亮叶鸡血藤 *Callerya nitida*
禾本科	30	4.14	薏苡 *Coix lacryma-jobi*、白茅 *Imperata cylindrica*、芦苇 *Phragmites australis*、狗牙根 *Cynodon dactylon*
茜草科	25	3.25	栀子 *Gardenia jasminoides*、鸡矢藤 *Paederia foetida*、玉叶金花 *Mussaenda pubescens*、香港大沙叶 *Pavetta hongkongensis*

表 3　澳门园林绿地中常用的药用草本

植物	药用部位	药用功能
肾蕨 *Nephrolepis cordifolia*	块茎及叶	清热解毒，生津止渴，润肺止咳，治肺热咳嗽、腹泻
鸡冠花 *Celosia cristata*	花及全株	凉血，清湿热，治痔漏下血、赤白痢、赤白带下
莲 *Nelumbo nucifera*	全株	清热解暑，和胃安胎，凉血止血，化瘀止血，清心益脾，止泻
鼠尾草 *Salvia japonica*	根	治风湿痛、神经痛、产后流血过多
野慈姑 *Sagittaria trifolia*	球茎或全草	清热解毒，凉血消肿，治咳血、难产、狂犬咬伤；全株治黄疸、蛇伤、水肿

注：“药用功能”参考自文献 [8]，表 4~6 同。

表 4　澳门绿地中常用的药用乔木

植物	药用部位	药用功能
白兰 *Michelia × alba*	花	行气化浊，止咳，治咳嗽、白浊、白带
阴香 *Cinnamomum burmannii*	树皮	祛风散寒，温中止痛，接骨，止血，治风湿骨痛、胃寒痛、腹泻外伤出血
樟 *Cinnamomum camphora*	根、树皮、叶	祛风散寒，消肿止痛，治风湿腰腿痛、扭挫伤、感冒头痛、胃寒腹痛，驱蚊
榕树 *Ficus microcarpa*	气根、叶、树汁	化痰止咳，消肿止痛，治支气管炎、流感、扁桃腺炎、白带、风湿、肠炎
桉 *Eucalyptus robusta*	叶	消炎杀菌，防腐止痒，治流感、流脑、肠炎、痢疾、乳腺炎、创伤感染、神经性皮炎等
木棉 *Bombax ceiba*	花、根皮	治痢疾、肠炎、慢性胃炎、胃及十二指肠溃疡、风湿关节炎；树脂为滋事补药
鸡蛋花 *Plumeria rubra*‘Acutifolia’	花、树皮	清热解毒，治痢，润肺，止咳，平喘

表 5　澳门绿地中常用的药用灌木

植物	药用部位	药用功能
含笑花 *Michelia figo*	花	去瘀生新，治月经不调
海桐 *Pittosporum tobira*	枝、叶	煎水外洗治疥疮
使君子 *Quisqualis indica*	种子、叶	祛健脾胃，消积杀虫，治虫积、虚热、泻痢、牙痛；叶助消化
翅荚决明 *Senna alata*	叶	杀虫，止痒，治神经性皮炎、牛皮癣、湿疹、皮肤瘙痒、疮疖肿疡
红桑 *Acalypha wilkesiana*	叶	清热消肿

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1.2.4 药用藤本植物资源

姿态婀娜的藤本植物是园林造景中常用的材料。澳门常见的藤本植物（表 6）如木防己，叶色翠绿，可用于垂直绿化，其根、茎可入药，有祛风除湿、通经活络、解毒消肿的作用。龙珠果是岭南常见的植物，其果可食，全株能清热解毒，果实有润燥除痰、生津止渴功效。鸡矢藤开淡蓝色的小花，常攀于其他植物或岩石上，其根、藤、叶皆可入药，有祛风活血、止痛解毒作用，对治疗痢疾、咽喉炎、风湿痛等具有一定效用。作为广东五花茶原材料之一的忍冬（金银花）也是常用的园林造景植物，其花色黄白相间，开花时簇拥为一串，高挂枝头，颇为美观，具有清热解毒、治感冒发热等功效 [8]。

1.3 药用部位

药用部位主要包括全株或全草、根、茎、叶、花、皮、果实及种子八类。澳门可全草或者全株入药的植物资源最多，占药用植物总种数的 41.93%；其次为利用根及叶入药的植物，分别占总种数的 26.90% 和 25.10%；以茎入药的植物占总种数 11.17%；以果实、花、皮入药的植物种数相近，分别占总种数的 8.83%、8.69% 和 8.14%；利用种子入药的植物资源最少，仅占总种数 6.34%（表 7）。

2 本地药用植物资源利用的评价与建议

2.1 优点

澳门地处亚热带，其湿润温暖的气候适宜大部分植物的生长繁殖。据本次调查统计，澳门药用植物共 152 科 506 属 725 种，种类数量占澳门维管束植物总种数的比例高达 40.08%。可见澳门本地拥有的药用植物种类较多，开发利用潜力大。

2.2 存在的不足

虽然澳门在园林绿化方面的重视程度较高，但对药用植物在园林绿化方面的应用仍存在不足之处。

2.2.1 应用种类单一，搭配不协调

我国园林植物应用种类超过 1 000 种的城市较少，大多数城市绿化应用的植物种类为 200~400 种 [9]。在大部分城市中，对药用植物的应用主要体现在数量的增加，而非种类的增加，因而没能达到真正意义上园林植物多样性的效果。澳门园林绿化应用目前以菊科、大戟科、蝶形花科的植物为主，其他科的植物使用偏少。

2.2.2 乡土植物应用的重视程度不够

乡土植物一般具有食用、药用、观赏、文化等应用价值。尽管以乡土树种绿化、美化城市的观念日渐深入人心，但其推广应用仍受到苗木短缺、价格偏高、技术薄弱等因素限制。澳门拥有较为丰富的本土药用植物资源，但目前城市绿地中使用种类数量较少，仍有较大开发利用空间。

2.3 建议

针对目前澳门药用植物资源运用存在的有关问题，从城市园林绿化角度初步提出以下建议。

2.3.1 加强乡土药用植物资源基础研究

乡土植物适应性强，多数具有易种、易活、易管、抗旱等优势，种植养护成本与风险较低。澳门水热资源丰富，适宜南方大多数植物生长，建议全面深入调查当地具有药用价值的乡土植物，同时开展种源收集与驯化

表 6　澳门绿地中常用的药用藤本植物

植物	药用部位	药用功能
木防己 *Cocculus orbiculatus*	根	行水利湿，消肿止痛，治肾炎水肿、尿路感染、风湿性关节炎、神经痛
龙珠果 *Passiflora foetida*	果、叶	果润燥除痰、生津止渴；叶敷治痈疮
忍冬 *Lonicera japonica*	花蕾、花、藤	治感冒发热、流行性脑膜炎、痢疾、眼发炎、湿疹、白痢；藤治风湿骨痛
鸡矢藤 *Paederia foetida*	根、藤、叶	气管炎、痔疮出血、痢疾、热滞腹痛、咽喉炎、扁桃体炎、牙龈肿痛、赤眼、风湿痛

表 7　澳门药用植物药用部位统计

药用部位	种数	占总种数比例（%）	代表植物
全株或全草	304	41.93	假蒟 *Piper sarmentosum*、马齿苋 *Portulaca oleracea*、何首乌 *Fallopia multiflora*、火炭母 *Persicaria chinensis*、天胡荽 *Hydrocotyle sibthorpioides*、龙葵 *Solanum nigrum*
根	195	26.90	粗叶榕（五指毛桃）*Ficus hirta*、秤星树（岗梅）*Ilex asprella*、深山含笑 *Michelia maudiae*、樟 *Cinnamomum camphora*、山黄麻 *Trema tomentosa*
叶	182	25.10	薄荷 *Mentha canadensis*、土牛膝 *Achyranthes aspera*、落地生根 *Bryophyllum pinnatum*、三叉蕨 *Tectaria subtriphylla*
茎	81	11.17	仙人掌 *Opuntia dillenii*、买麻藤 *Gnetum montanum*、马松子 *Melochia corchorifolia*、相思子 *Abrus precatorius*、乌蕨 *Odontosoria chinensis*
果实	64	8.83	艳山姜 *Alpinia zerumbet*、桂花 *Osmanthus fragrans*、栀子 *Gardenia jasminoides*、苍耳 *Xanthium strumarium*
皮	63	8.69	阴香 *Cinnamomum burmannii*、木蝴蝶 *Oroxylum indicum*、幌伞枫 *Heteropanax fragrans*、两面针 *Zanthoxylum nitidum*
花	59	8.14	木棉 *Bombax ceiba*、夜来香 *Telosma cordata*、鸡蛋花 *Plumeria rubra* ‘Acutifolia’、万寿菊 *Tagetes erecta*
种子	46	6.34	芝麻 *Sesamum indicum*、龙眼 *Dimocarpus longan*、杧果 *Mangifera indica*、绿豆 *Vigna radiata*、蚕豆 *Vicia faba*

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繁育工作，选育出具有观赏价值和药用价值、适合城市绿化应用的乡土植物种类[10]。

2.3.2 充分挖掘药用植物的保健康养作用

除了观赏价值，药用植物还具有调节人的心理、生理机能，改善精神状态，抑制细菌等保健康养作用[11~12]，且其药用部位也十分多样。可以充分发挥药用植物不同部位的功效，交叉种植有相互促进作用的药用植物，发挥其更大的药用价值。建议在资源调查的基础上全面梳理适用于澳门城市绿化种植的药用植物，发挥利用好植物的生物学特性。

2.3.3 增加绿色公共空间中乡土药用植物的种类和数量

澳门的公园重视保护原有山体，园中保留较多野生乡土的乔木和灌木[13]，但是在小区绿地、附属绿地以及行道树的植物选择上，乡土植物的应用仍较少。在高密度的人居环境下，建议在增加绿色公共空间的基础上，充分发挥乡土植物的药用价值。如可以根据地势营造窗台绿化、灯柱花饰等垂直绿化[14]；在小区绿地中，草地可利用药用草本植物狗肝菜 *Dicliptera chinensis*、大车前 *Plantago major* 和黄鹤菜 *Youngia japonica* 等，而灯柱、架棚或者天桥的绿化可以运用忍冬和两面针等来丰富形式，乔灌树种则可用无患子 *Sapindus saponaria*、粗叶榕和毛稔 *Melastoma sanguineum* 等，辅助芳香植物如樟、薄荷和假鹰爪 *Desmos chinensis* 等。

3 结语

新型冠状病毒疫情仍未消散，其给人类社会带来的损失不可计量，影响重大而深远。在公共健康日益被重视的背景下，人类应该反思在设计和构建城市绿地中所存在的弊端，不断总结经验，提出长时间、大范围、持久的绿化建设改革思路和措施。在疫情爆发后的园艺疗养中，应重视药用植物资源的发掘与应用，科学筛选并合理运用于城市园林绿化建设，服务于公共健康。

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海南夹竹桃科植物园林应用分析与评价

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摘要： 夹竹桃科植物在热带、亚热带地区广布，生活形式多样，在城市绿化中被广泛应用。通过实地调查海南省海口市和三亚市的公园绿地、居住区绿地、道路广场绿地及企事业单位绿地 4 类绿地 28 个地点，共 80 个样点中夹竹桃科植物的应用状况，并运用植物群落生态学的调查方法和植物配置理论，对海南 4 类绿地中实地调查的夹竹桃科植物的数量、频率以及景观配置进行了分析。通过建立视觉质量、生态质量、服务功能、心理功能 4 层面 16 个指标的 AHP 模糊评价模型，对上述 4 类绿地类中各抽取 20 处植物景观品质进行了综合评价和分级，各筛选出 2 个Ⅰ级、Ⅳ级配置典例进行对比分析和总价。最后，从观赏性角度推介了 13 种海南分布的夹竹桃科野生观花植物，乔木类有止泻木、蕊木、红花蕊木、倒吊笔；灌木类有萝芙木、红酒杯花、纽子花；藤本有紫蝉花、球兰、吊灯花、海南鹿角藤、眼树莲；草本有马利筋。

关键词： 海南；园林植物；夹竹桃科；植物景观配置
中图分类号： X173；TU986　　**文献标识码：** A　　**文章编号：** 2096-6830（2019）05-0047-10

Landscape application analysis and landscape evaluation of apocynaceae plant in Hainan province. XU Zhi-qiang，QIN Xin-sheng*（College of Forestry and landscape Architecture，South China Agricultural University，Guangzhou 510642，China）. *Environmental Ecology*，2019，1（5），47～56.

Abstract: Apocynaceae plants are widely distributed in tropical and subtropical regions with a living diversity and extensive use.Through investigating and recording the landscape application of Apocynaceae plant eighty samples of twenty-eighty places including four kinds of green spaces of park，residential area，road and square，and enterprises in Haikou and Sanya city in Hainan Province；the Apocynaceae plants' quantity，frequencyand the configuration of the landscape in four types of green spaces of Hainan are analysed by applying plant community ecology survey methods and plant allocation theory；eighty plant landscape sample's quality in the above four kinds of green spaces are made a comprehensive evaluation and graded by making an AHP fuzzy evaluation model from four aspects including visual quality，ecological quality，service function and psychological function and sixteen factors，and then twoplant landscape samples of grade Ⅰ and two ones of grade Ⅱ will be analyzed and summarized；from the perspective of aesthetics，thirteen wild ornamental flowering plants of Apocynaceae distributed in Hainan are recommended，including trees species such as *Holarrhena pubescens*，*Kopsia arborea*，*K. fruticosa*，*Wrightia pubescens*，shrubs species such as *Rauwolfia verticillata*，*Thevetia peruviana* 'Aurantiac'，*Vallaris solanacea*，vines species such as *Allamanda blanchettii*，*Hoya carnosa*，*Ceropegia trichantha*，*Chonemorpha splendens*，*Dischidia chinensis*，herbs species such as *Asclepias curassavica*.

Key words: Hainan Province；garden plant；Apocynaceae；plant landscape arrangement

1　研究背景

夹竹桃科（Apocynaceae）植物在热带、亚热带地区分布广，部分种类已在城市绿化中得到广泛应用。目前有关该科植物的种类构成在城市园林配置应用中报道较少。海南岛地处热带地区，植被类型和热带植物丰富[1]，夹竹桃科种类多，共 56 属，108 种，36 个栽培种[2]。但目前有关夹竹桃科植物在海南园林应用中研究较少，本研究以调查海南城市中夹竹桃科植物应用状况为切入点，分析其应用特点与方式并对其参与构成的植物景观效益进行评价，以此来归纳总结同类型植物的景观营造方式以及在应用中存在的问题，并且提出合理性的修复策略，对改善海南城市绿化、加快国际旅游岛建设、谱写美丽中国海南篇章具有重要意义。

2　研究地概况和方法

2.1　研究地概况

根据 2011 年《海南统计年鉴》显示，海南岛总

收稿日期：2019-09-02
基金项目：广东省林业科技创新项目（编号：2018KJCX030）资助。
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面积约为3.5万 km^2，地处热带北缘。气候变化很大，独特的地形使气候要素也具有环状结构。海南省海口市和三亚市近十年城市绿化发展速度较快，城市绿化植物种类多样，记录有838种绿化植物，隶属145科，475属，但藤本植物与耐阴植物运用较少，分别为46种和74种，影响了空中和立体绿化建设的发展，此外海口市与三亚市在绿化树种选择方面，表现出过高的相似性[3]。

2.2 调查方法与数据分析

2.2.1 调查样地筛选

本次调查选取了城市绿地景观重要构成中的公园绿地、道路广场绿地、居住区绿地及企事业单位绿地4个类型，每个类型在海口和三亚又各调查了4个以上的样点，共80个样点。

2.2.2 调查方法及数据分析

在调查地调查夹竹桃科植物种类、数量、频率、生长状况等，然后确定科内不同植物应用状况，确定方法是：统计植物的总株数、该植物在城市绿地中出现的频数、频率，公式为：

$$P = M_i/M$$

式中，P 为应用频率值；M_i 为种 i 在单位绿地中出现的频数；M 为单位绿地总的调查样点数。

2.3 评价材料、方法与模型建立

2.3.1 评价材料

在本次研究调查的海口和三亚样地进行本项评价工作。公园绿地、道路广场绿地、居住区绿地及企事业单位绿地类型各随机选择20个样点植物景观，通过幻灯片播放的方法评分，根据视觉停留效应，每张幻灯片播放2~3 s后暂停，留出8~9 s的时间评分，之后继续下一景观的评分。

2.3.2 评价方法

2.3.2.1 建立绿地景观评价AHP递阶层次结构

在目前绿地景观的评价研究成果的基础上，结合海口和三亚城市绿地实际情况，分析评价系统各因素关系，将目标分为元素，按照属性把元素分成若干组，每一组构成一个层次，层次之间互不相交，构成自上而下多层关系的绿地植物景观评价AHP递阶层次结构模型[4-6]。建立完全相关的综合评价指标体系：最高层是综合评价的最终目标层(A)；第二层为确定综合评价值分的主要原则，即评价的主要构成要素层(B)；第三层为隶属各主要构成要素的评价因子层(C)(表1)。为了方便得出公园各植物群落的综合评价值，对各评价因子采用评分的办法，拟定了评价因子由好到差分为3级评分等级标准：10~15分、5~10分、0~5分(表2)。这样就构成了由总目标、主要评价要素、评价指标因子、评分标准等组成的多层次评价系统。其中，生态效能和服务功能是根据样点的现场实际状况评价；视觉质量和心理功能则是根据调查测试者获得评价，并且测试者分为硕士生专业组10人，本科生专业组10人，非专业组10人。

表1 海南夹竹桃科植物配置环境AHP评价层次结构体系

Table 1 Hierarchical structure system of AHP evaluation for plant configuration environment of Apocynaceae in Hainan

目标层(A)	准则层(B)	因子层(C)
海南夹竹桃植物配置环境景观(A)	视觉质量(B1)	植物形态美(C1)
		色彩与联想(C2)
		空间感受(C3)
		景观季相性(C4)
	生态质量(B2)	物种多样性(C5)
		群落乡土性(C6)
		植物生长势(C7)
		郁闭度(C8)
	服务功能(B3)	可停留度(C9)
		绿地可达性(C10)
		抗干扰能力(C11)
		标志性(C12)
	心理功能(B4)	安全感(C13)
		喜悦感(C14)
		新奇感(C15)
		认同感(C16)

表2 指标因子评价标准

Table 2 Indicator factor evaluation criteria

指标因子	评价标准(0~15任意分，5分为一等级)
植物形态美(C1)	1.植物形态多样与统一，变化又协调，高低大小变化富有节奏性、韵律性，使人产生舒适感与轻松感(10~15分)； 2.植物形态整体上有变化，但因形态过多显得杂乱不统一，或因大小搭配不合理显得不均衡，或因高低起伏没有节奏韵律感显得不舒适，使人产生美中不足(5~10分)； 3.形态无变化差异，大小、高低搭配严重失衡，单调乏味，看起来不舒适(0~5分)。

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续表

指标因子	评价标准(0~15 任意分,5 分为一等级)
色彩与联想(C2)	1.色彩种类变化丰富并且协调,色块布局均衡; 能使人产生积极的生命与生活联想(10~15 分) ; 2.色彩种类较丰富,变化稍微杂乱,过渡不佳; 美感效果欠缺,画面平淡,视觉上不能产生积极的联想(5~10 分) ; 3.色彩单调,没有变化,枯燥乏味,或是色彩过多而杂乱,厌恶感强(0~5 分) 。
空间感受(C3)	1.空间具有渗透与流通功能,层次感丰富,具有远、中、近景; 并有夹景、对景、借景等艺术手法; 具有人性化情感空间,或是恬静思考,或是休闲解压,或是驻足休憩,或具有浓浓的人文精神"桃李送春" "蒲香荷馨" "苍松作揖"等(10~15 分) ; 2.空间通透感不强,空间艺术手法不明显,可以在其中活动,但是空间情感与精神不浓烈(5~10 分) ; 3.空间之间没有什么渗透流通联系,缺乏艺术感和层次感,不能满足一定的休闲活动功能(0~5 分) 。
景观季相性(C4)	1.季相特征明显,变化自然而协调,观叶、观花、观果四季交替,富有规律性变化(10~15 分) ; 2.季相特征欠缺,不能保证四季均有花可赏、有果可看,但绿视率符合心理需求(5~10 分) ; 3.没有季相变化特征,零乱的观赏性树种随意搭配,甚至没有应用显著的特色观赏植物(0~5 分) 。
物种多样性(C5)	1.高等植物物种丰富,种数达 10 种 10 分,每加 1 种加 1 分,最高 15 分(10~15 分) ; 2.高等植物物种一般,物种数为 6~10 种,分值为种数值(6~10 分) ; 3.高等植物物种较少,种数在 5 种以下,分值为种数值(0~5 分) 。
群落乡土性(C6)	1.乡土植物数量占群落总数的 70%以上,并且表现出明显的地域特色(10~15 分) ; 2.乡土植物数量占群落总数的 50%~70%,地域特征稍微显著,50%为 6 分,60%为 8 分,70%为 10 分,比例位于区间取中间分值(6~10 分) ; 3.乡土植物数量占群落总数的 50%以下,地域特征不明显,每减少 10%便减 1 分(0~5 分) 。
植物生长势(C7)	1.植株生长速度普遍适中; 健康度良好,没有病虫害发生(10~15 分) ; 2.速生树种占有少量; 部分植株出现病虫害(6~10 分) ; 3.速生树种数量占有比例在 50%以上,有大量植株出现病虫害现象(0~5 分) 。
郁闭度(C8)	1.乔木丛植、列植、群植郁闭度应大于 0. 5,灌木带植郁闭度应大于 0. 6(10~15 分) ; 2.乔木丛植、列植、群植的郁闭度 0. 3~0. 5,灌木带植郁闭度 0. 3~0. 6(5~10 分) ; 3.乔木丛植、列植、群植群植的郁闭度在 0. 3 以下(0~5 分) 。
可停留度(C9)	1.绿化的活动空间可吸引游人驻足休闲,人气度高(10~15 分) ; 2.绿化空间虽可以供人休憩,人气度不高(5~10 分) ; 3.绿化空间没有吸引性,人气度差(0~5 分) 。
绿地可达性(C10)	1.有多级别不同园路引导至植物景观区,或是有低矮灌木未形成阻隔(0~15 分) ; 2.有单一的园路可引至植物景观区,灌木过高过密,难以穿越(5~10 分) ; 3.没有园路引至植物景观区,灌木高大密集(0~5 分) 。
抗干扰能力(C11)	1.绿地内植物围合可以很好地抗噪音; 满足需要的阻隔作用,有良好的舒适休闲活动需求(10~15 分) ; 2.绿地内植物围合的空间可以进行活动,但是不能很好地满足活动环境需求(5~10 分) ; 3.绿地与交通要道相邻,植物围合后依旧遭受噪音影响以及游人打扰(0~5 分) 。
标志性(C12)	1.植物配置具有显著特色,选用层次感丰富优美、高观赏性植物,可以显著发现(10~15 分) ; 2.植物配置中选用有一定程度的标志性植物或特色景观,但不能很容易发现(5~10 分) ; 3.植物配置中没有显著标志性植物和特色景观(0~5 分) 。
安全感(C13)	1.不存在任何安全隐患,无枯枝悬挂、剧毒植物、棘刺植物使用等(10~15 分) ; 2.安全感没有太大问题,使用少量轻微有毒植物、棘刺植物(5~10 分) ; 3.有残枝、枯枝植株,使用剧毒植物、棘刺植物并且栽种在容易靠近的地方(0~5 分) 。
喜悦感(C14)	1.植物景观易使人心情舒畅,产生轻松、愉悦、快乐之感(10~15 分) ; 2.植物景观中规中矩,不能让人立马感受到轻松愉悦感,停留较长时间后有心情舒畅变化(5~10 分) ; 3.植物景观使人感觉平淡,甚至有些许不适感(0~5 分) 。

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续表

指标因子	评价标准(0~15任意分,5分为一等级)
新奇感(C15)	1.植物配置选用新奇树种或是一种新的风格造型手法,并有良好的视觉、心理效应(10~15分); 2.植物配置存在少量的新奇树种或是手法应用(5~10分); 3.植物配置中不存在任何新奇树种、造景手法或是独特的风格(0~5分)。
认同感(C16)	1.植物景观具有地域特色,能够获得普遍在视觉上的满意和心理上的赞赏(10~15分); 2.植物景观可以得到大家的认可,但很难发现其显著地域特色(5~10分); 3.植物景观使人感觉平淡,甚至有些许不适感(0~5分)。

2.3.2.2 构造两两比较判断矩阵

通过专家针对A的两元素Ci,Cj(i,j指的是C1~C16中的两个不同因子)的重要性进行数量化比较(表3),分别构成A-B、B1-C、B2-C、B3-C、B4-C两两比较判断矩阵。在建立递阶层次结构和两两比较判断矩阵后,分别向10位专家调研咨询填写A-B、B1-C、B2-C、B3-C、B4-C两两比较判断矩阵表。

表3 AHP比较判断矩阵元素比较度含义

Table 3 AHP comparison judgment matrix element comparison meaning

分值	1	3	5	7	9
含义	同等重要	稍微重要	明显重要	强烈重要	极端重要
备注	2,4,6,8为上述判断相邻中间值				

2.3.2.3 层次单排序及一致性检验

运用和积法求解各判断矩阵进行层次单排序一致性检验,RI平均随机一致性指标(表4)。

表4 平均随机一致性指标

Table 4 Average random consistency indicator

阶数	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45

2.3.2.4 层次总排序及一致性检验

层次总排序就是计算最后一层对于第一层的相对重要性排序,实际上是层次单排序的加权组合,得到植物景观综合评价的各个因子的权重值,并进行一致性检验,当一致性比例值<0.10时,认为层次总排序结果具有满意一致性,否则需要重新调整判断矩阵的元素取值。最后利用群决策分析加权几何平均法计算上述10个专家构造的权重矩阵,得出最终各指标因子的权重值。

2.3.2.5 视觉质量与心理功能指标因子评分值显著性分析

用SPSS19.0将调查获取的评价数值进行植物形态美、色彩与联想、空间感、景观季相性、安全感、喜悦感、新奇感及认同感8因子的评价类群与照片编号在Duncan模式下的双因素方差分析。

2.3.2.6 综合评价分值的确定

通过景观综合评价指数法得出综合评价分值。景观综合评价指数法,即:$V=\sum Fi\times Ci$,式中,V为某植物景观综合评价指数,Fi为某评价因子的权重值,Ci为某植物景观在某指标因子下的得分值。利用公式$CEI=V/V_0\times 100\%$,确定公园植物景观的等级,其中CEI为综合评价指数,V为评价得分值,V_0为理想值(取每一个因子的最高级别与权重相乘叠加而得),CEI作为分级的依据,并以差值百分比分级法划分为Ⅰ、Ⅱ、Ⅲ、Ⅳ级(见表5)。划分标准以调查样地实际打分情况和前人研究成果综合设定。

表5 景观效果登记表

Table 5 Landscape effect registration form

M%	>75	75~65	65~60	<60
景观质量等级	Ⅰ	Ⅱ	Ⅲ	Ⅳ

2.4 问卷调查法

为了更好地建造出更多更加科学、生态的美丽的植物景观,采用网上问卷(http://www.sojump.com/jq/2268064.aspx,问卷见附录F)对海南、广东、广西、福建、四川等地共30名园林设计人员进行了关于夹竹桃科植物认知应用和植物景观设计理论方法的调查。

3 结果与分析

3.1 海南城市园林应用的夹竹桃科植物资源的种类组成

3.1.1 属种与习性构成分析

经调查统计,海南城市绿化及园林应用出现的夹竹桃科植物鸡蛋花属(*Plumeria*)、鸡骨常山属(*Alstonia*)、海芒果属(*Cerbera*)、夹竹桃属(*Nerium*)、黄花夹竹桃属(*Thevetia*)、黄蝉属(*Allamand*)、狗牙花属(*Ervatamia*)、眼树莲属(*Dischidia*)、络石属(*Trachelospermum*)、长春花属(*Catharanthus*)、马利筋属(*Asclepias*)共11属,有鸡蛋花*Plumeria rubra*

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'Acutifolia'、红花鸡蛋花 *Plumeria rubra*、盆架树 *Alstonia rostrata*、糖胶树 *A. scholaris*、海芒果 *Cerbera manghas*、夹竹桃 *Nerium indicum*、白花夹竹桃 *Nerium indicum* 'Paihua'、红酒杯花 *Thevetia peruviana* 'Aurantiaca'、黄花夹竹桃 *T. peruviana*、紫蝉 *Allamanda blanchetii*、软枝黄蝉 *Allamanda cathartica*、黄蝉 *A. schottii*、狗牙花 *Tabernaemontana divaricata*、眼树莲 *Dischidia chinensis*、络石 *Trachelospermum jasminoides*、长春花 *Catharanthus roseus*、马利筋 *Asclepias curassavica* 共 17 种。应用的属数占海南总属数的 19.6%,总种数的 15.7%。

调查出现的夹竹桃科植物都具备良好的抗逆性,大多数具有喜光、喜湿、喜高温的特性,这一点使其适应海南的气候环境。其中,鸡蛋花、红花鸡蛋花、海芒果、夹竹桃、白花夹竹桃、黄花夹竹桃、络石等具有耐干旱性,使其能适应干旱的城市土壤。黄蝉、软枝黄蝉、紫蝉和狗牙花不耐旱,土壤需要一定的湿润度。盆架树、糖胶树、夹竹桃、白花夹竹桃、黄花夹竹桃和红酒杯花具有抗污染特性,适宜用于工业区环境绿化与治理。此外,海芒果、夹竹桃、白花夹竹桃、黄花夹竹桃和红酒杯花具有抗风性,可适用于防风林带[7]。

3.1.2　观赏习性统计分析

经调查统计并查阅文献得出,海南城市绿化与园林应用的夹竹桃科植物都具有观花特性,花色多样,有白、红、橙、紫、粉、黄白、红黄等色彩,并且花季有全年型、春夏型、夏秋型、秋冬型。花期全年的有白花夹竹桃、马利筋、长春花、夹竹桃共 4 种,8—11 个月长的有海芒果、黄花夹竹桃、红酒杯花共 3 种,4—7 个月长的有糖胶树、狗牙花、鸡蛋花、红花鸡蛋花等共 9 种,4 个月以下长的有眼树莲 1 种。其中,5—10 月开花的种类最多,12 月至翌年 3 月较少。观果类树种有海芒果,圆溜溜地挂于树梢,果期为 7—12 月份。此外,乔木类龙枝形观形树种有鸡蛋花和红花鸡蛋花,塔形观形树种有糖胶树和盆架树。

3.1.3　常绿与落叶、乡土与外来树种分析

经调查统计并查阅文献得出,海南城市绿化与园林应用的夹竹桃科植物以常绿型树种有 15 种,落叶树种只有鸡蛋花和红花鸡蛋花,这两种也是海南城市绿化应用中的极少数落叶植物之一,凸显出季节的变化性。并且,乡土树种有糖胶树、盆架树、海芒果、眼树莲、络石和狗牙花共 6 种,外来树种有 11 种,其原产地主要是中、南美洲,应用的夹竹桃科乡土树种只占据少数。

3.2　海南城市绿化的夹竹桃科植物应用数量、频率与方式

从应用的夹竹桃科物种数来看,公园绿地类型最多为 14 种,居住区绿地最少为 8 种。在 4 类绿地当中应用广的乔木类植物有鸡蛋花、盆架树和糖胶树,灌木类有软枝黄蝉、黄花夹竹桃、夹竹桃、黄蝉,草本类有长春花。从应用的夹竹桃科植物数量来看,乔木、灌木、草本类最多的均为道路广场绿地,乔木 1 038 株,灌木 24 324 株,草本 1 061 株,乔木类、灌木类企事业单位绿地中最少,分别为 275、2 536 株,草本类在居住区绿地最少为 470 株,远远小于道路广场绿地的用量。从应用夹竹桃科植物应用方式来看,公园、道路广场、企事业单位绿地以自然群落式配置居多,居住区绿地以混合式配置居多,而规则式配置在企事业单位绿地中应用占据比例最大为 35%。总体来看,夹竹桃科植物在 4 类绿地应用物种类似、数量不同、应用方式稍微有差异。

乔木类均在 4 类绿地的自然式及混合式植物景观中多次出现,以糖胶树和盆架树与其他乔木组合搭配形成自然式或混合式中的乔木层为主,这两种树树形笔直,树枝层次轮生,与椭球形、圆球形、棕榈形、塔形树种易搭配出优美景观,构造主景或配景。鸡蛋花、夹竹桃、黄花夹竹桃小乔木或大灌木,鸡蛋花龙枝形,苍遒有力,树形优美,可群植、丛植、孤植形成主景或配景。规则式配置较少,主要出现于道路广场绿地中,以糖胶树、盆架树作为行道树等距列植规则式应用。更少的以单层乔木群落为主,如鸡蛋花林、盆架树林,主要应用于公园绿地、企事业单位附属绿地中。灌木类在 4 类绿地应用方式类似,夹竹桃与黄花夹竹桃有很好的观花特性,花期较长,丛植搭配,形成植物群落的配景,或是种植在园林建筑旁软化建筑边角,衬托建筑; 或是与景石搭配,起软化与美化作用,或是种植在水边,构成观赏的主角。黄蝉与软枝黄蝉或是片植成的林下花藤灌,或垂落于水边,驳岸美化,或边坡绿化。少部分灌木作为规则式植物景观应用,表现为修建的灌木球,如狗牙花球、紫蝉球; 曲线形、直线型及面型绿篱或花篱,如黄蝉、软枝黄蝉单一或两两组成的花篱,狗牙花绿篱,夹竹桃扦插形成的花篱; 或与柱状造型、动物造型绿雕搭配。混合式中,以绿雕形式与其他乔木、草本花卉搭配。草本在 4 类绿地应用最多的是长春花,构成地被层,丰富整个配置群落。此外,在一些老公园自然野生植被保护良好的区域会有眼树莲和

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络石附生于树干，立体绿化效果良好。

3.3 海南夹竹桃科植物景观评价

根据上述的评价原理与方法，得出 4 个绿地类型中 80 个调查样点夹竹桃科城市绿地植物景观的综合品质得分分布如图 1 所示，调查抽选的 28 个地点编号见表 6。

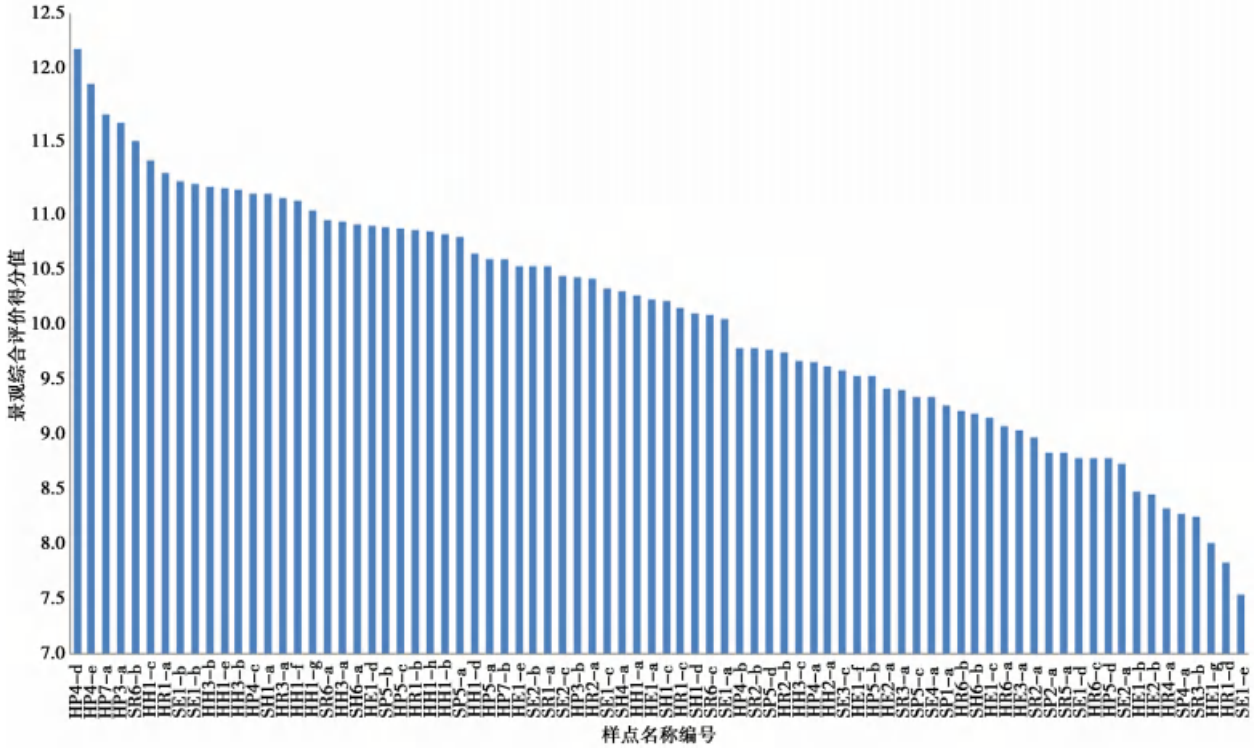


图 1 海南 4 个绿地类型中 80 个样点夹竹桃科植物景观综合评分值分布图

Fig.1 Distribution map of comprehensive scores of 80 species of Apocynaceae in 4 green land types in Hainan

表 6 调查抽选的 28 个地点编号

Table 6 28 locations number table for survey selection

绿地类型	样点名称	编号
公园绿地	海口万绿园	HP3
	海口金牛岭公园	HP4
	白沙门公园	HP5
	海口西秀海滩公园	HP7
	三亚滨海公园	SP1
	三亚白鹭公园	SP2
	三亚红树林公园	SP4
	三亚亚龙湾度假公园绿地	SP5
道路广场绿地	海口滨海大道	HR1
	海口国兴大道	HR2
	海口人民大道	HR4
	海口海南广场	HR6
	三亚三湾路	SR2
	三亚凤凰路	SR3
	三亚鹿回头广场	SR6
居住区绿地	海口荣誉花园	HH1
	海口棕榈园	HH2
	海口奥林匹克花园	HH3
	三亚山水国际	SH1
	三亚擎天半岛	SH4
	三亚鸿洲花园	SH6
企事业单位绿地	海口海南大学	HE1
	海口海南职业技术学院	HE2
	海口省人民医院	HE3
	三亚一中	SE1
	三亚学院	SE2
	三亚 405 医院	SE3
	三亚市人民医院	SE4

Ⅰ级、Ⅳ级的植物景观点评价结果如表 7，对比公园绿地类型评价结果中排名前、末两位的样点植物景观可发现：Ⅰ级的金牛岭公园 d、e 两处比同样滨水类型的白沙门公园 d 处、红树林公园 a 处植物景观植物种类多，层次丰富，植物天际线高低起伏跌宕，驳岸利用软枝黄蝉、黄蝉片植软化硬石，分割空间，并且花期较长，花色亮丽，起到了很好的美化作用。但是Ⅳ级的红树林公园 a 处只利用软枝黄蝉修剪成大面积的圆形绿篱，形式单一，并且软质黄蝉藤状灌木不适宜修建成形；白沙门公园 d 处的夹竹桃与无瓣海桑、狄草配置零乱。

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表 7　4 个绿地类型的Ⅰ级、Ⅳ级评价结果表

Table 7　Grade Ⅰ and Ⅳ evaluation results of four green land types

绿地类型	Ⅰ级	Ⅳ级
公园绿地类型	 海口金牛岭公园 d 点	 海口白沙门公园 d 点
	 海口金牛岭公园 e 点	 三亚红树林公园 a 点
道路广场绿地	 三亚鹿回头广场 b 点	 海口滨海大道 d 点
	 海口滨海大道 a 点	 三亚凤凰路 c 点

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续表

绿地类型	Ⅰ级	Ⅳ级
居住区绿地	 海口荣誉花园 c 点	 海口棕榈园 a 点植物景观
	 三亚山水国际 b 点	 三亚擎天半岛 a 点
企事业单位绿地	 三亚第一中学 b 点	 三亚第一中学 e 点
	 海口海南大学 d 点	 海口海南大学 g 点

对比道路广场绿地类型评价结果中排名前、末两位的样点植物景观可发现：Ⅰ级的三亚鹿回头广场 b 点、海口滨海大道 a 点比Ⅳ级的海口滨海大道 d 点及三亚凤凰路 c 点的植物景观结构层次多，郁

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闭度大,应用的植物种类多,配置形式美观,空间开闭变化丰富,而且多色彩观花植物使观赏者产生积极的心理感受。粉花夹竹桃花期较长,花、枝、叶密集,植株质感细腻,与硬邦邦的建筑外墙、粗大的大王椰子、蒲葵叶形成对比,构成整个植物景观的一个焦点。道路旁绿地带状软质黄蝉与红色金凤花、蝎尾蕉构成艳丽的三色带。

对比居住区绿地类型评价结果中排名前、末两位的样点植物景观可发现: Ⅰ级的海口荣誉花园 c 点与三亚山水国际 b 点,比Ⅳ级的海口棕榈园 a 点、三亚擎天半岛 a 点的植物景观能够更好地依照生境、地形、道路设计植物郁闭度与多样性,空间感舒适。并且利用鸡蛋花、黄花夹竹桃在水边以及重要节点处种植,树形可观、亮丽的黄花夹竹桃形成水边观赏的焦点,提升了植物景观的层次,形成水景特色。

对比企事业单位绿地类型评价结果中排名前、末两位的样点植物景观可发现: Ⅰ级的三亚第一中学 b 点、海南大学 d 点比Ⅳ级的三亚第一中学 e 点、海南大学 g 点植物景观种类丰富,更好地利用了乔灌草结构搭配,以多种形式围合及分割出视线大小不一的空间。并且利用鸡蛋花、夹竹桃、软枝黄蝉种植于水边美化驳岸、限制空间,提升整体景观,但软枝黄蝉在草坪上大面积种植时没有优美的平面形式,很难创造美景; 个别不健康、外形丑陋的糖胶树会影响整体的景观效果。

从 4 个绿地类型中Ⅰ级样点植物景观可看出配置特点有: 营造规则式植物景观时,在树种选择上,选用树形笔挺、枝条层次感强的盆架树,龙枝形的鸡蛋花、红花鸡蛋花,枝叶细密、花色鲜亮的黄花夹竹桃列植,增强了空间感; 选用长春花作为绿雕的下层图案装饰,层次丰富; 海南独特的气候条件,使棕榈科椰子树和大王椰子地域特色显著植物共同搭配,在观形、观叶、观花多种观赏角度下,给观察者带来心理安全感、愉悦感,有积极影响。

自然式植物景观营造中,可在水体旁选用黄花夹竹桃、鸡蛋花丛植,驳岸上用软枝黄蝉、黄蝉藤灌美化,在园建、假山旁丛植夹竹桃软化硬质景观,衬托主景,在林下列植、丛植花期长的黄花夹竹桃、软枝黄蝉,这些植物组合成整体后再与其他植物的搭配获取了良好的景观效果。

混合式植物景观营造中,大面积图案花篱、绿篱、球状大灌木、造型盆景具有很强的吸引力,景观停留度高。

4　结论与讨论

4.1　结论

4.1.1　海南夹竹桃科植物园林应用资源种类

在本次海南城市绿化及园林应用调查到的只有 11 属 17 种,应用的树种比例低,可开发利用的观赏植物资源具有很高的前景。其中,落叶类乔木有红花鸡蛋花和鸡蛋花 2 种,常绿类乔木有糖胶树、盆架树 2 种,观花类灌木有夹竹桃、白花夹竹桃、红酒杯花、黄花夹竹桃、紫蝉、黄蝉、软枝黄蝉及狗牙花共 8 种,观花类草本有马利筋和长春花共 2 种,藤本有眼树莲和络石 2 种。树种观赏性多样,花色种类多样,并且花季有全年型、春夏型、夏秋型、秋冬型; 此外还有海芒果可观果,应用的鸡蛋花属和鸡骨常山属植物可观形。大多数植物具有喜光、喜湿、喜高温的特性,部分具有很好的抗旱性和耐贫瘠性。其中,应用的乡土树种只有糖胶树、盆架树、海芒果、狗牙花、络石、眼树莲 5 种,占应用总中数的 29. 4%,引种栽培种数则占据 70. 6%。

4.1.2　海南夹竹桃科植物园林应用特点

在调查的 4 个绿地类型样点中,夹竹桃科植物在 4 类绿地应用物种类似、数量不同、应用方式稍有差异。在 4 类绿地的自然式及混合式植物景观中,糖胶树和盆架树形成乔木层构造主景或配景,鸡蛋花、夹竹桃、黄花夹竹桃小乔木或大灌木群植、丛植、孤植形成主景或配景; 规则式配置较少。灌木类在 4 类绿地应用方式类似,主要丛植或群植应用于生境多样的自然式景观中,少部分修剪应用于规则式、混合式植物景观中。草本在 4 类绿地应用最多的是长春花,构成地被层,丰富整个配置群落。此外,在一些老公园自然野生植被保护良好的区域会有眼树莲和络石附生于树干。

4.1.3　海南夹竹桃科植物景观评价

从定性和定量的角度研究海南 4 个不同绿地类型中夹竹桃科植物景观质量,计算了 80 个样地的综合评价指数,并进行排序和分级。从最终评价结果中得知道路广场、企事业单位绿地的整体植物景观需改善综合质量问题,适当提升主要干道、部分重要单位(如海南省人民医院、海南大学等重要医疗、教育机构附属绿地) 的绿化质量,一些优秀的公园、居住区绿地植物景观需要继续加强养护维持,部分较差的点需要改善来满足市民、居民的生活、观赏、游憩需求。

并且,从 4 个绿地类型中Ⅰ级、Ⅱ级以上(综合

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得分指数在70以上）的样点植物景观可看出其配置特点有：规则式植物景观营造需要具备物种、树形造型多样性、景观节奏与韵律、四季有景可赏、易接近等特征。自然式植物景观营造中，要具备因地制宜、师法自然、超越自然、物种多样、层次丰富、立面天际起伏有致线、群落疏密得当、景观吸引性、地标性等特征。混合式植物景观营造中要具备几何美与天然美融合、高物种多样性、观赏多样性、立面高低错落有致、视线有开有合、层次丰富等特征，适当应用大面积图案花篱、绿篱、球状大灌木、造型盆景等具有很强吸引力的植物，景观停留度高，增强观察者的愉悦感和新奇感。

4.1.4 植物景观设计探讨与夹竹桃科野生观赏植物推介

通过对园林设计人员的调查问卷结果分析得知，植物设计师夹竹桃科植物种类、习性特征不熟悉，对植物种类需要加强认知，植物群落设计时植物质感、均衡稳重的艺术质量成分和郁闭度、乡土植物多样性的生态质量成分欠缺考虑，可停留度、抗干扰和标志性的功能性得到了考虑，但是植物散发的香气可以净化空气、治疗疾病的功能没有得到重视，此外，野生观赏植物在显示乡土性、地域性、生态性以及自然性具有很高的作用也未能得到重视。根据查阅海南夹竹桃科野生植物资源状况，推介了一些海南分布的高观赏性野生夹竹桃科植物，乔木类有止泻木、蕊木、红花蕊木、倒吊笔等；灌木类有紫蝉花、球兰、萝芙木、红酒杯花、纽子花等；藤本有吊灯花、海南鹿角藤、眼树莲等；草本有马利筋。

4.2 讨论

4.2.1 夹竹桃科已用种类应用范围可扩大应用方式可多样

在海南城市绿地中应用的种类稍多，但是其中多用的海芒果、白花夹竹桃、红酒杯花、紫蝉、络石、马利筋、眼树莲等应用的数量、频率都很低，可根据各自习性加强应用于各类绿地景观以及建筑的立体绿化，但要注意在人多密集区禁止使用剧毒之物，防止意外事故发生。肇庆七星岩多处景点利用夹竹桃科植物与其他植物巧妙搭配，得到了较好的美化效果，有些甚至可以称为精美[8]。调查出的观赏性高、抗逆性强的夹竹桃科植物可以应用于气候、土壤环境相似的其他地区城市绿化。

4.2.2 景观评价方法的局限性

本文对海南夹竹桃科植物景观调查只是观察了较短时间的景观状况，而植物景观是动态的，四季变化，因此不能全面评价样点。而建立的AHP模糊评价模型定量评价因子数量少，定性评价因子主观性大，会受到评价者多方面的影响。对于不同绿地的结构和功能有差异性，因而本次评价因子不够齐全完善。并且，评价者分数是否标准化处理对最终的评价结果有一定的影响，一些绿地类型中的样点植物景观在上述两种不同处理后的评价地位显著不同。关于评价分数是否标准化需要进一步验证正确性。

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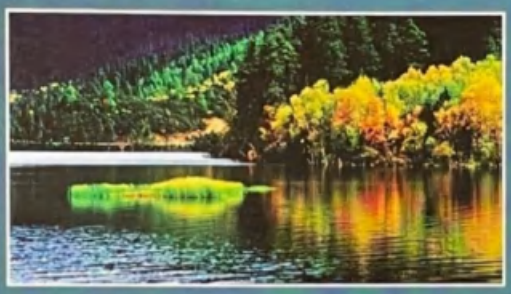
ISSN 1005-0094
CODEN SHDUEM

BIODIVERSITY SCIENCE

生物多样性

第25卷 第10期
2017年10月

Vol. 25 No. 10
October 2017












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SHENGWU DUOYANGXING

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封面： 中国国家公园体制建设试点在12个省(直辖市)的10个区域成功开展。从上到下、从左到右依次为云南香格里拉普达措，湖北神农架，浙江钱江源，福建武夷山，甘肃、青海祁连山，青海三江源，吉林、黑龙江东北虎豹，四川、陕西和甘肃大熊猫，湖南南山，北京长城等10个国家公园体制试点区域。(图片提供者：铁伟、杨敬元、余问清、丁晖、郝生清、樊尚珍、吉林珲春东北虎国家级自然保护区管理局、张志和、湖南省南山国家公园管理局、蔡春雷)

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Cover Illustration: China's National Park System pilot testing units are successfully implemented in 10 areas of 12 provinces. Start from the left upper corner, from the left to right, from the upper to bottom, these pilot areas are Yunnan Xiangri-La Pudacuo, Hubei Shennongjia, Zhejiang Qianjiangyuan, Fujian Wuyishan, Gansu and Qianghai Qilianshan, Qinghai Sanjiangyuan, Jilin and Heilongjiang Amour Tiger and Amur Leopard, Sichuan, Shaanxi and Gansu Giant Panda, Hunan Nanshan and Beijing Great Wall. (Photographed by Wei Tie, Jingyuan Yang, Wenqing Yu, Hui Ding, Shengqing Hao, Shangzhen Fan, Administration of Hunchun Amour Tiger National Nature Reserve in Jilin, Zhihe Zhang, Administration of Hunan Nanshan National Park, and Chunlei Cai)

生物多样性 2017, **25** (10): 1065–1074 doi: 10.17520/biods.2017095
Biodiversity Science http://www.biodiversity-science.net

•研究报告•

海南尖峰岭热带山地雨林2种夹竹桃科植物的空间分布格局与关联性

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摘要: 根类药用植物在生产栽培过程中常产生连作障碍, 原因之一是其容易产生化感作用, 而化感作用是密度制约产生的主要原因之一。夹竹桃科植物是重要的药用植物, 也是热带植物区系的主要科。为探究自然条件下密度制约是否存在于根类药用植物中, 本文以海南尖峰岭60 ha森林动态监测样地中两种常见的夹竹桃科根类药用植物盆架树(*Alstonia rostrata*)和尖蕾狗牙花(*Tabernaemontana bufalina*)为研究对象, 采用点格局分析的成对相关函数Ripley's *g*(*r*), 结合完全随机零模型和异质泊松零模型, 分析了它们的空间分布格局、种内和种间空间关联, 并采用Berman-test方法分析了地形因子对其种群分布的影响。结果表明: (1)盆架树和尖蕾狗牙花在0–100 m的研究尺度上主要表现为聚集分布, 但随着尺度的增大, 聚集程度降低, 逐渐变为随机分布。(2)盆架树和尖蕾狗牙花各龄级的分布特征类似: 幼树和中龄树个体在较大尺度范围内为聚集分布, 而成年树个体在0–100 m尺度上为随机分布或均匀分布。(3)在小尺度上, 盆架树的幼树与中龄树呈空间正关联, 与成年树呈空间负关联, 而中龄树与成年树空间无关联。尖蕾狗牙花各龄级间在0–65 m的尺度范围内以空间正关联为主。(4)在0–49 m尺度内盆架树与尖蕾狗牙花呈显著空间正相关。盆架树的中龄树和成年树与同龄级的尖蕾狗牙花都表现为空间无显著关联, 而幼树与尖蕾狗牙花幼树存在明显的空间正关联。(5)盆架树和尖蕾狗牙花幼树的分布与海拔、凹凸度显著正相关, 中龄树的分布与凹凸度显著正相关, 而成年树中只有盆架树的分布与海拔正相关。从现有格局推断: 生境异质性和扩散限制影响盆架树和尖蕾狗牙花空间格局的形成, 相对于尖蕾狗牙花, 密度制约对盆架树空间格局形成的影响更显著。

关键词: 盆架树; 尖蕾狗牙花; 根类药用植物; 化感作用; 种间联结; 尖峰岭

Spatial distribution patterns and association of two Apocynaceae plants in the tropical mountain rainforests of Jianfengling, Hainan Island, China

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Abstract: Medicinal root plants often produce a continuous crop obstacle due to allelopathy during cultivation. Apocynaceae plants are important medicinal plants belonging to tropical flora. Allelopathy is one of the major causes of density dependence. To explore whether density dependence likely exists in root type medicinal plants under natural conditions, we analyzed the species distribution and spatial intraspecific and interspecific correlations of two root medicinal plants of Apocynaceae (*Alstonia rostrata* and *Tabernaemontana bufalina*), using a point pattern analysis of pair correlation function Ripley's *g*(*r*) method with complete spatial randomness (CSR) and heterogeneous Poisson (HP). The impacts of topographic factors on the distributions of

收稿日期: 2017-03-23; 接受日期: 2017-07-01
基金项目: 中国林业科学研究院中央级公益性科研院所基本科研业务费专项资金(CAFYBB2017ZE001, RITFYWZX201505)、国家自然科学基金(31670628)和尖峰岭国家级森林生态站运行费
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the two species were analyzed using a Berman-test. Results showed that the spatial patterns of the *A. rostrata* and *T. bufalina* were mainly aggregated at 0–100 m scales, while the former's spatial pattern was still aggregated and the latter became a random pattern within this scale. The spatial patterns of *A. rostrata* and *T. bufalina* changed similarly with increases in age stage, as young and middle-aged trees showed aggregated distributions within a larger scale, while adult trees became randomly or uniformly distributed. The spatial association between different age classes individuals of *A. rostrata* showed that the relationship between young and middle-aged trees was positively associated at the small scale, while it was negatively associated between young and adult trees, and there was no association between middle-aged and adult trees. Positive associations were found between different age classes individuals of *T. bufalina* within the larger scale (0–65 m), which indicated that different DBH class individuals were consistent with environmental selection. Interspecific associations between *A. rostrata* and *T. bufalina* showed positive associations at 0–49 m scale. The spatial association between middle-aged, adult trees of *A. rostrata* and similarly aged trees of *T. bufalina* showed no significant correlation, while obvious positive spatial correlation was found between young trees of these two species. Significant positive correlation was found between young trees of these two species and elevation and convexity. We also found significant positive correlations between convex and middle-aged trees of these two species, while only adult trees of *A. rostrata* showed positive correlation with the degree of slope. We inferred that environmental heterogeneity and diffusional limitation played important roles in the formation of current spatial patterns of woody Apocynaceae in the tropical montane rainforest of Jianfengling, while compared to *T. bufalina*, density dependence plays a more significant impact on the spatial patterns of *A. rostrata*.

Key words: *Alstonia rostrata*; *Tabernaemontana bufalina*; root medicinal plants; allelopathy; interspecific association; Jianfengling

种群空间格局指种群内的所有个体在一定水平空间范围内的分布状况, 它最直接地体现了自然界各种共存机制相互作用的结果(李海涛, 1995)。研究种群空间格局有助于认识种内、种间关系及种群与环境因子的相互作用规律, 了解各种群在群落中的地位和生态学功能(李海涛, 1995; 张金屯, 1998; Guo et al, 2013)。密度制约、扩散限制、生境异质性和Janzen-Connell假说等都会影响种群空间格局(Connell, 1971; 农友等, 2015; 郭屹立等, 2015a; 陈云等, 2016)。目前, 对空间格局的研究主要集中在群落优势种或主要种(梁爽等, 2014; 农友等, 2015)、珍稀濒危植物(黄明钗等, 2013)等类群上, 而对群落专科或专属植物(马建梅等, 2013; 龙成等, 2015)及根类药用植物(张鲜花等, 2012)等的空间格局研究较少。

盆架树(*Alstonia rostrata*)和尖蕾狗牙花(*Tabernaemontana bufalina*)都为夹竹桃科萝芙木亚科的根类药用植物, 盆架树为乔木, 是热带山地雨林典型的伴生种类(曾庆波等, 1997), 尖蕾狗牙花为灌木。这 2个物种含量最多的一类化合物是生物碱, 且大部分为单萜吲哚类生物碱, 其中的含氧单萜具有很强的化感活性(张秋菊等, 2012; Zhang et al, 2015; Yang et al, 2016)。绝大多数根类药用植物在生产中会产生连作障碍, 原因之一是其药效成分常为化感物质(张爱华等, 2011), 而化感作用也是密度制约效应产生的原因之一(Wright, 2002)。对根类药用植物化感作用的研究通常只在实验室中进行(王田涛等, 2012), 但在自然条件下, 化感物质经过自然途径进入土壤, 并与土壤及其微生物等环境因子相互作用后, 才对植物的种子萌发和幼苗生长等产生影响(张爱华等, 2011)。因此, 有必要研究自然生态条件下根类药用植物的空间分布格局以及密度制约效应是否影响其空间格局的形成。

扩散限制和生境异质性也是影响物种空间分布格局的重要原因(郭屹立等, 2015a; 农友等, 2015)。从植物的空间格局来推测格局形成的过程是目前广泛使用的方法(Mcintire & Fajardo, 2009)。基于此, 本文选取尖峰岭热带山地雨林这2种常见的夹竹桃科根类药用植物为研究对象, 采用点格局方法分析了它们的空间分布格局、种内和种间空间关联, 并采用Berman-test方法分析了地形因子对其种群分布的影响, 试图从其格局推断密度制约效应是否存在, 以及生境异质性和扩散限制在格局形成中的作用, 以期为研究根类药用植物的化感作用以及科学地保护和利用药用植物资源提供参考。

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1　材料与方法

1.1　研究区概况

尖峰岭地区(18°20′–18°57′ N, 108°41′–109°12′ E)位于海南省西南部乐东县和东方市交界处, 总面积约64,000 ha (李艳朋等, 2016)。最高峰海拔1,412.5 m, 其气候、土壤和植被具有明显的垂直带谱, 其中在海拔650–1,350 m的热带山地雨林是尖峰岭地区分布面积最广的植被类型(蒋有绪和卢俊培, 1991; 李意德等, 2002)。

海南尖峰岭60 ha森林动态监测样地海拔介于866.3–1,016.7 m间, 正好处在热带山地雨林区的中间, 土壤类型主要为砖黄壤–黄壤, 属低纬度热带岛屿季风气候, 雨热同期, 干湿两季明显。2010–2012年间, 年均降水量1,305–3,686 mm, 年平均温度19.8℃, 最冷和最热月平均气温分别为10.8℃和27.5℃(李意德等, 2012; 许涵等, 2015)。

1.2　研究方法

1.2.1　调查方法

海南尖峰岭热带山地雨林60 ha样地是参照美国史密森热带研究所(Smithsonian Tropical Research Institute)热带森林研究中心(Center for Tropical Forest Science, CTFS)的调查技术规范(Condit, 1998)于2012年建立的。样地南北宽600 m, 东西长1,000 m。整个样地划分为1,500个20 m × 20 m样方。野外调查记录样地内所有胸径(DBH) ≥ 1 cm 的乔灌木树种的学名、胸径及生长情况, 并测量个体空间位置坐标, 坐标值直接用距离(m)表示。同时利用每个20 m × 20 m样方4个顶点的海拔数据计算每个样方的海拔、坡度、凹凸度等参数: 海拔为4个顶点海拔的平均值; 凹凸度为该样方的平均海拔减去与其相邻8个样方海拔的平均值, 处在样地边缘的样方的凹凸度为该样方中心点的海拔减去4个顶点海拔的平均值; 样方4个顶点组合成4个平面, 这4个平面与样方投影面夹角的平均值即为该样方的坡度值(Yamakura, 1995)。尖峰岭样地海拔介于866.3–1,016.7 m, 凹凸度介于–7.68至7.19, 坡度介于1.74°–49.25°。

1.2.2　不同龄级阶段划分标准

采用径级结构代替年龄来划分种群的不同龄级。样地中, 盆架树的平均胸径为15.2 cm, 最大胸径为95.0 cm; 尖蕾狗牙花的平均胸径为1.7 cm, 最大胸径为11.1 cm。根据不同物种的生物学特性和生长情况, 采用不同的方式划分幼树、中龄树和成年树。盆架树是乔木, DBH在1–10 cm为幼树, 10–20 cm为中龄树, ≥ 20 cm为成年树; 尖蕾狗牙花为灌木或小乔木, DBH在1–2 cm为幼树, 2–3 cm为中龄树, ≥ 3 cm为成年树。虽然这样划分径级并不能非常科学准确地定义幼树、中龄树和成年树, 但有利于分析的简化。表1和图1分别为按此方式划分的各龄级的株数及其在样地中的散点分布图。

1.2.3　点格局分析方法

Ripley's $g(r)$函数是由Ripley's $K(r)$函数衍化而来(Ripley, 1976), 运用Ripley's $g(r)$函数对样地中的盆架树和尖蕾狗牙花整体和各龄级的分布格局及其空间关联进行分析。

Ripley's $K(r)$函数是以任意点为圆心, r为半径的圆内期望点数与样方内点密度的比值。公式为:

$$K(r)=\frac{A}{n^2}\sum_{i=1}^{n}\sum_{j=1}^{n}\frac{I_r(d_{ij})}{W_{ij}}(i\neq j) \quad (1)$$

式中, A为样地面积; n为样地中个体总数; r表示空间尺度; d_{ij}为圆心点i到点j之间的距离, 当$d_{ij} \le r$时, $I_r(d_{ij}) = 1$, $d_{ij} > r$时, $I_r(d_{ij}) = 0$。W_{ij}为边界效应修正的权重(祝燕, 2009)。

双变量的Ripley's $K(r)$函数:

$$K_{12}(r)=\frac{A}{n_1 n_2}\sum_{i=1}^{n_1}\sum_{j=1}^{n_2}\frac{I_r(d_{ij})}{W_{ij}}(i\neq j) \quad (2)$$

表1　海南尖峰岭60 ha森林动态监测样地中盆架树和尖蕾狗牙花种群各龄级株数

Table 1　Number of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island.

树种 Tree species	幼树 Young trees (%)	中龄树 Middle-aged trees (%)	成年树 Adult trees (%)	总数 Total (%)
盆架树 *Alstonia rostrata*	1,098 (56.25)	296 (15.16)	558 (28.59)	1,952 (100)
尖蕾狗牙花 *Tabernaemontana bufalina*	2,459 (74.05)	751 (22.61)	111 (3.34)	3,321 (100)

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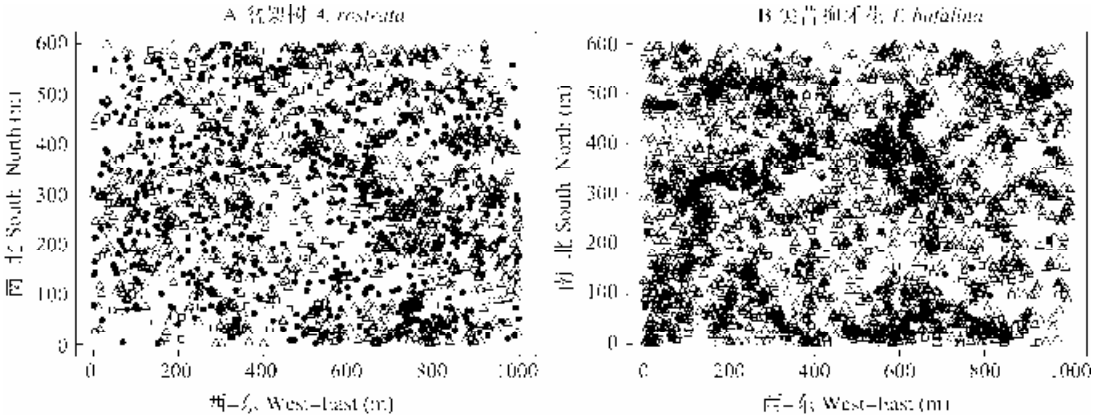


图1 海南尖峰岭**60 ha**森林动态监测样地中盆架树和尖蕾狗牙花各龄级的散点分布图。△ 幼树; □ 中龄树; ● 成年树。
Fig. 1 Scatter distribution patterns of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island. △ Young trees; □ Middle-aged trees; ● Adult trees.

n_1与n_2表示具有不同属性(如不同种群、不同龄级)的个体数量, 其余参数与式(1)相同。

$g(r)$函数以圆环代替$K(r)$函数中的圆, 分析的是圆环内所有植株的总多度, 因而消除了Ripley's $K(r)$函数的累积效应, 表示在某一特定距离种群具有何种空间分布关系, 表达式为(Illian et al, 2008):

$$g(r)=\frac{1}{2\pi r}\cdot\frac{dK(r)}{dr} \quad (3)$$

对应Ripley's $K(r)$函数, $g(r)$函数也有相应的单变量和双变量公式。

本文使用的零模型有两种: (1)完全空间随机模型(CSR), 假设种群的空间分布不受任何生物或非生物过程的影响, 常用来检验生境异质性是否影响种群的空间分布; (2)异质泊松模型(HP), 是一种排除生境异质性的零假设模型, 主要用于模拟物种与其生境之间的相互关系(郭屹立, 2015a)。本文采用高斯核函数(Diggle, 2003)进行密度估计, 选取标准差sigma = 15 m以消除大尺度上的生境异质性对空间格局的影响。通过199次Monte Carlo随机模拟, 分别利用模拟的最大值和最小值生成上下两条包迹线, 计算99%的置信区间。若实际分布的$g(r)$值落在包迹线内, 则符合零模型, 为随机分布或种间无关联; 若在包迹线以上, 则呈聚集分布或种间显著正关联; 若在包迹线以下, 则呈均匀分布或种间显著负关联。

1.2.4 地形因子对物种分布格局的影响

用Berman-test法检验物种种群总体及各生长阶段个体分布是否依赖于某一环境变量。计算所有个体在位置x_i处的环境变量$v(x_i)$的平均值S_{obs}, 以20 m × 20 m样方为单位沿x轴或y轴每次移动一个单位产生零假设模型, 计算每个零假设模型相应的S_{sim}, 显著度由S_{obs}在S_{sim}中的排序位置决定(Zhu et al, 2013; 梁爽等, 2014; 郭屹立等, 2015b)。本研究分别选用每个20 m × 20 m样方的海拔、坡度、凹凸度为环境变量进行Berman-test分析。

全部统计分析和绘图均在R3.3.2 (https://www.r-project.org/)软件中完成。

2 结果

2.1 种群的空间分布格局

基于完全空间随机模型(CSR)的成对相关函数分析结果表明(图2A、B、C、D): 盆架树总体在2–98 m的尺度上为聚集分布, 其他尺度为随机分布; 幼树在研究尺度上都为聚集分布; 中龄树在4–20 m和41–99 m聚集分布; 成年树在0–4 m的尺度上均匀分布。剔除生境异质性的异质泊松模型(HP)的成对相关函数分析结果显示(图2A、B、C、D): 盆架树总体在6–16 m的尺度上为聚集分布, 幼树在0–22 m聚集分布, 中龄树在研究尺度上为随机分布, 成年树在0–5 m为均匀分布。表明剔除生境异质性后, 盆架树总体、幼树及中龄树在较大尺度上的聚集分布变为随机分布, 即生境异质性对盆架树大尺度上的分布有显著影响。

基于完全空间随机模型(CSR)的成对相关函数分析结果表明(图2E、F、G、H): 尖蕾狗牙花总体在0–81 m尺度上为聚集分布, 其他尺度为随机分

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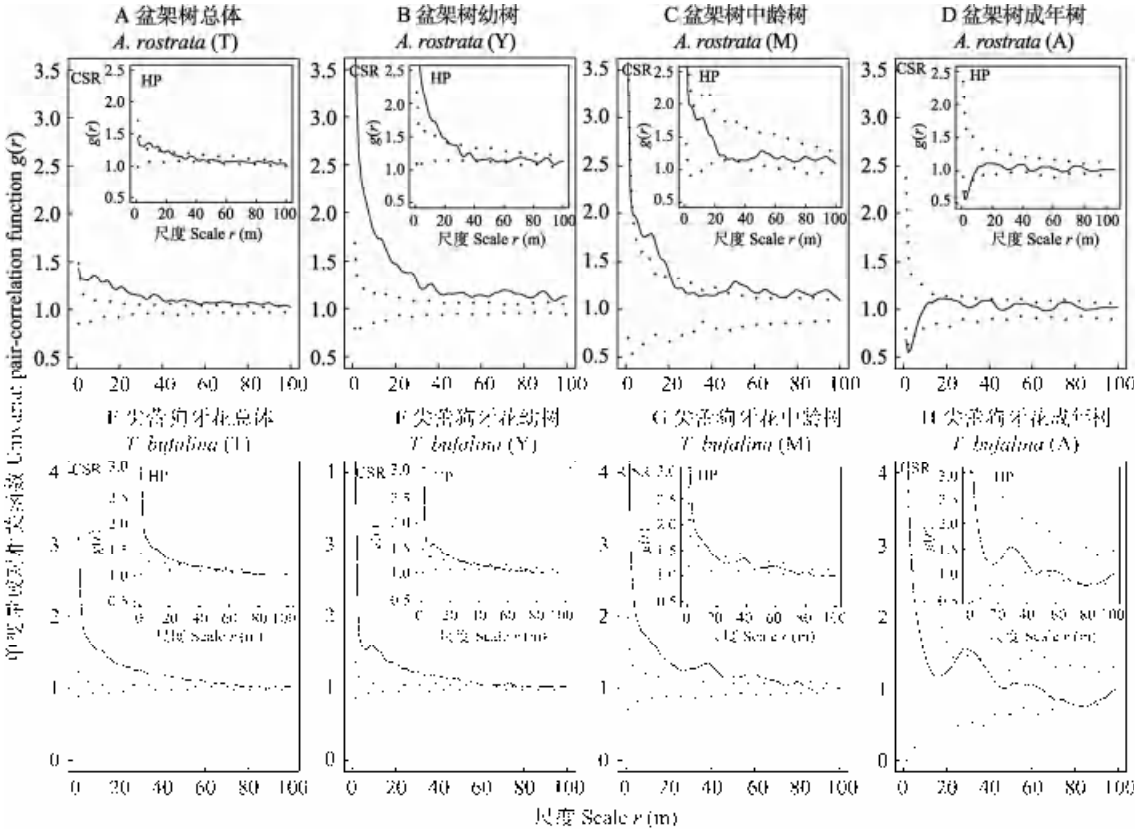


图2　海南尖峰岭60 ha森林动态监测样地中盆架树和尖蕾狗牙花各龄级的点格局分析。实线表示成对相关函数，虚线表示99%包迹线。零模型为完全空间随机模型(CSR)和sigma = 15 m的异质泊松模型(HP)。

Fig. 2　Point pattern analysis of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island. (T), (Y), (M), (A) represent the total, young trees, middle-aged trees and adult trees, respectively. Solid lines are pair-correlation functions, and dotted lines are 99% confidence envelopes. Null models: complete spatial randomness (CSR) model and Heterogeneous Poission (HP) model with sigma = 15 m.

布；幼树在0–80 m尺度上为聚集分布；中龄树在0–71 m聚集分布；成年树在0–3 m和25–33 m的尺度上呈微弱的聚集分布。基于异质泊松模型(HP)的成对相关函数分析结果显示(图2E、F、G、H): 尖蕾狗牙花总体在0–33 m尺度上为聚集分布；幼树在0–31 m聚集分布；中龄树在0–16 m聚集分布；成年树在78–86 m的尺度上为微弱的均匀分布，表明生境异质性对尖蕾狗牙花分布的影响与对盆架树的类似。

2.2　种内关联

盆架树各龄级间的空间关联表现为(图3A、B、C): 盆架树中龄树与幼树在0–21 m的尺度上空间正关联；成年树与幼树在0–7 m的小尺度上呈空间负关联, 44–53 m的大尺度上呈微弱的空间正关联；成年树与中龄树在0–100 m的尺度上无关联。

尖蕾狗牙花各龄级之间的空间关联表现为(图3D、E、F): 幼树与中龄树在0–74 m的尺度上呈空间正关联；幼树与成年树在0–65 m的尺度上大体为空间正关联；成年树与中龄树在0–34 m和52– 65 m的尺度上大体为空间正关联。综上，尖蕾狗牙花各龄级之间在0–65 m的尺度上以空间正关联为主，可能是因为同一物种所有个体对环境资源的选择是相同的。

2.3　种间关联

盆架树总体与尖蕾狗牙花总体在0–49 m的尺度呈显著空间正关联，其他尺度空间无关联(图4A)。盆架树为热带山地雨林中典型的伴生乔木种，而尖蕾狗牙花主要为灌木层树种，两者在一定尺度上的正相互作用有利于充分利用资源，从而保持物种稳定共存。

盆架树幼树与尖蕾狗牙花幼树在0–47 m的尺度上大体为空间正关联，这与两种群总体空间正关联相似；与尖蕾狗牙花中龄树在29–57 m的尺度上大体为空间正关联；与尖蕾狗牙花成年树在

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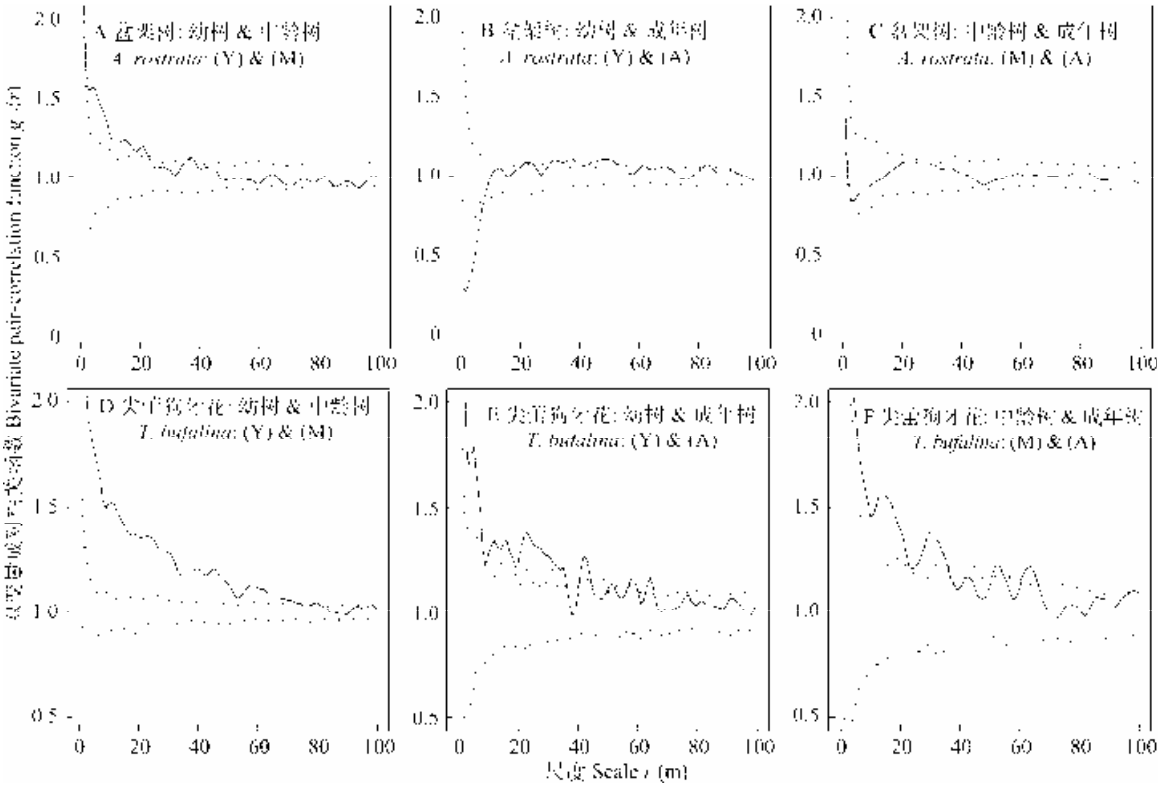


图3 海南尖峰岭60 ha森林动态监测样地中盆架树和尖蕾狗牙花各龄级的种内空间关联。实线表示成对相关函数，虚线表示99%包迹线。零模型为完全空间随机模型(CSR)。

Fig. 3 Spatial association of intraspecific individuals of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island. (T), (Y), (M), (A) represent the total, young trees, middle-aged trees and adult trees, respectively. Solid lines are pair-correlation functions, and dotted lines are 99% confidence envelopes. Null model: complete spatial randomness (CSR) model.

49–52 m的尺度呈微弱的空间负关联；其他尺度空间无关联。

盆架树中龄树与尖蕾狗牙花幼树在19–31 m空间正关联，与尖蕾狗牙花中龄树、成年树在研究尺度上无显著空间关联。

盆架树成年树与尖蕾狗牙花幼树在7–52 m尺度上大体为空间正关联，与尖蕾狗牙花中龄树在0–51 m的尺度内以空间正关联为主，与尖蕾狗牙花成年树为随机分布。

2.4 地形因子对两个种群个体空间分布的影响

Berman-test分析结果表明(表2)：盆架树和尖蕾狗牙花种群的所有个体分别与其不同生长阶段的个体和某一地形因子的关联性具有很好的一致性。在变化范围内，样地的3个地形因子与盆架树和尖蕾狗牙花都不存在负相关。其中盆架树总体与坡度、海拔、凹凸度都正相关，成年树仅与坡度正相关，中龄树仅与凹凸度正相关，幼树与海拔、凹凸度正相关，其他无关联。尖蕾狗牙花总体及各龄级均与坡度无关联；与海拔呈正相关，主要体现在其幼树与海拔的正关联上；与凹凸度也呈正相关，主要体现在其幼树、中龄树与凹凸度的正关联上。

3 讨论

盆架树和尖蕾狗牙花在研究尺度上主要表现为聚集分布，与自然界大部分群落优势种群或主要种群在一定尺度呈聚集分布的规律一致(祝燕等, 2011; 郭屹立等, 2015a; 龙成等, 2015)。影响种群空间分布的因素很多，如生境异质性、扩散限制、密度制约等(梁爽等, 2014; 郭屹立等, 2015a; 陈云等, 2016)。尖蕾狗牙花和盆架树在30–81 m的较大尺度范围内都呈聚集分布，而排除生境异质性后，两者在大尺度上的聚集分布变为随机分布(图2)，可以推测生境异质性影响这两个种群的空间分布格局。盆架树和尖蕾狗牙花的幼树和中龄树个体在较大尺度范围内为聚集分布，而其成年树个体在研究尺度上为随机分布或均匀分布(图2)。可见生境异质性对

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盆架树和尖蕾狗牙花幼树和中龄树的分布格局表现出明显影响, 而对其成年树的影响却不明显。地形是多种环境因子的复合, 影响温度和降水的空间再分配及土壤养分的空间分布, 部分反映了环境因子对植物空间分布的影响(区余端等, 2011; 张昌顺等, 2012)。本文地形因子的分析结果也表现出生境

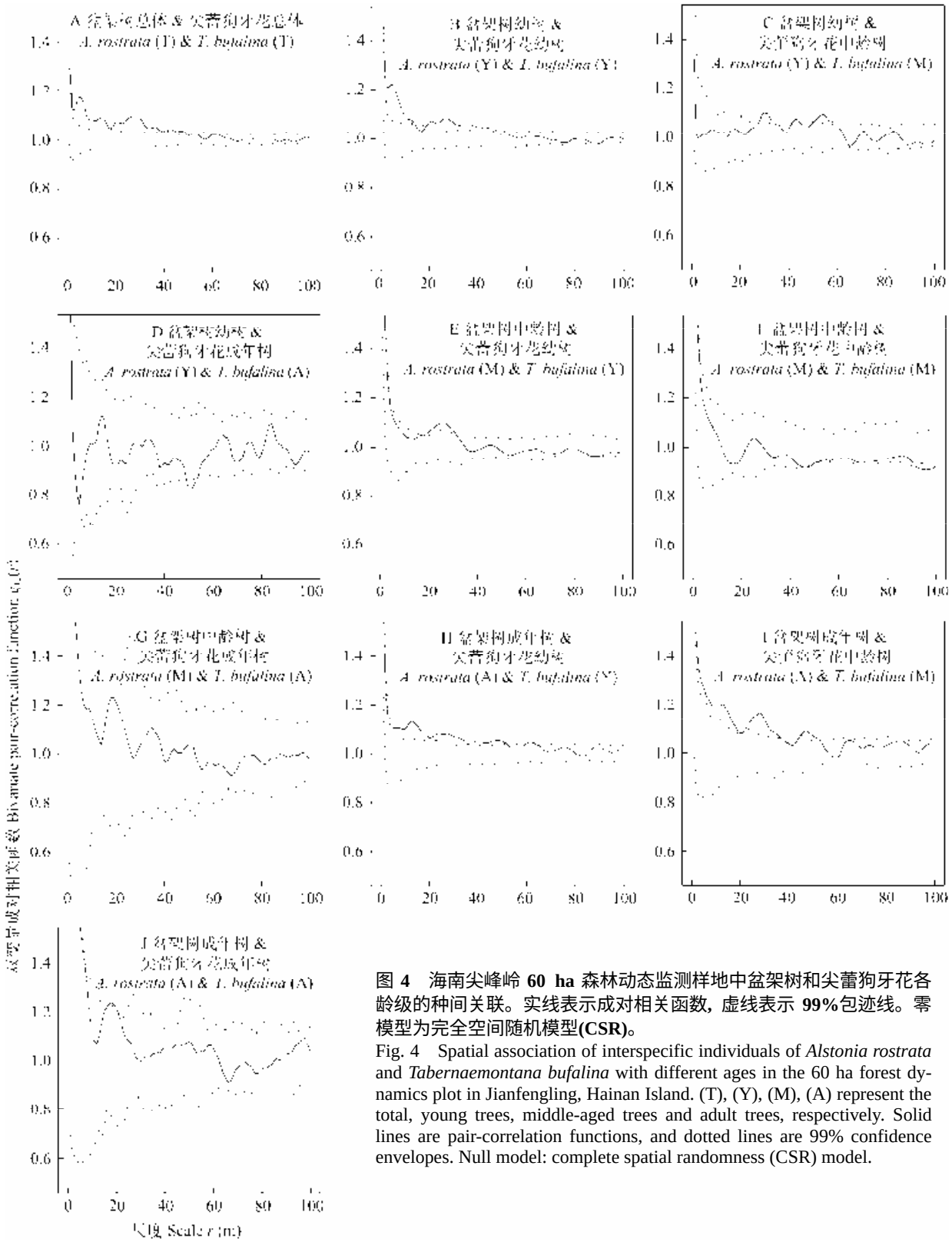


图 4　海南尖峰岭 **60 ha** 森林动态监测样地中盆架树和尖蕾狗牙花各龄级的种间关联。实线表示成对相关函数, 虚线表示 **99%**包迹线。零模型为完全空间随机模型**(CSR)**。

Fig. 4　Spatial association of interspecific individuals of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island. (T), (Y), (M), (A) represent the total, young trees, middle-aged trees and adult trees, respectively. Solid lines are pair-correlation functions, and dotted lines are 99% confidence envelopes. Null model: complete spatial randomness (CSR) model.

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表2 地形因子对海南尖峰岭60 ha森林动态监测样地中盆架树和尖蕾狗牙花各龄级个体分布格局的影响
Table 2 Influences of topographic factors on the distribution of the individuals of *Alstonia rostrata* and *Tabernaemontana bufalina* with different ages in the 60 ha forest dynamics plot in Jianfengling, Hainan Island

地形因子 Topographic factors	盆架树 *Alstonia rostrata*				尖蕾狗牙花 *Tabernaemontana bufalina*			
	总体 Total	幼树 Young tree	中龄树 Middle-aged tree	成年树 Adult tree	总体 Total	幼树 Young tree	中龄树 Middle-aged tree	成年树 Adult tree
坡度 Slope	+	n	n	+	n	n	n	n
海拔 Elevation	+	+	n	n	+	+	n	n
凹凸度 Convex	+	+	+	n	+	+	+	n

+代表显著正相关; n代表无相关性, 显著度$P \leq 0.025$。
+, Significant positive correlation; n, Uncorrelated; $P \leq 0.025$.

异质性对两个树种的幼树和中龄树的影响比成年树更加明显: 两树种幼树的分布与海拔、凹凸度显著正相关, 中龄树的分布与凹凸度显著正相关, 而成年树中只有盆架树的分布与海拔正相关。成年树的分布格局是幼树、中龄树经过多年的生境筛选作用而形成的, 它的分布更能体现出一个种群对生境的偏好(郭屹立等, 2015b)。在本研究中, 生境异质性对两树种成年树的影响不明显, 这可能是因为盆架树和尖蕾狗牙花的负密度制约超过了生境异质性对其聚集分布的影响。

密度制约是作用于邻体之间的一种机制, 它产生的内在原因有资源竞争、化感作用等(Wright, 2002)。在较小的尺度上, 盆架树的成年树不仅表现出均匀分布, 还与其幼树空间负关联, 而尖蕾狗牙花成年树表现出随机分布, 与其幼树、中龄树空间正关联(图2, 3)。可以推测密度制约效应影响了盆架树的空间格局形成, 而对尖蕾狗牙花影响不明显。这可能与两个树种的生活型有关: 盆架树为小乔木, 尖蕾狗牙花为灌木, 盆架树的成年树个体比尖蕾狗牙花根系更庞大, 因而分泌化感物质的范围更大, 影响的同种邻近个体范围更广; 也可能是因为盆架树的成年树对资源(光照、营养、空间等)的需求更大, 竞争能力也更强, 而使同种个体难以在其周围生存。盆架树的成年树与其幼树表现为空间负关联, 而与尖蕾狗牙花幼树、中龄树表现为空间正关联, 这可能是因为盆架树的化感作用可能更多的是自毒作用, 而对尖蕾狗牙花的他感作用并不显著, 这也符合Janzen-Connell假说。

当使用消除生境异质性的HP零模型分析, 盆架树种群整体及其幼树仍为聚集分布, 且主要集中在大于22 m的尺度上, 而尖蕾狗牙花及其幼树的聚集分布主要集中在0–31 m的尺度上, 且其聚集尺度范围和聚集程度比盆架树更大(图2), 这很可能是受扩散限制的影响。扩散限制使种群只能生活在靠近母株的一定范围内, 从而使物种呈聚集分布。而种子的传播方式和树种所属的林层都会影响种子的扩散过程, 进而影响种群分布格局, 一般靠重力传播种子的植物及林下层植物传播种子的能力更弱, 形成的聚集度更高(Wang et al, 2010)。尖蕾狗牙花是灌木层树种, 且其每个蓇葖果具10–20粒种子, 种子无毛, 较多的种子只能由重力扩散在母树周围; 而盆架树是属于10–30 m林层的乔木树种, 每个蓇葖果的种子数多, 且种子扁平, 两端被棕黄色的缘毛。对比可见, 盆架树比尖蕾狗牙花种子的传播能力更强, 传播范围更广, 故尖蕾狗牙花在小尺度上的聚集度比盆架树更大。

综上所述, 生境异质性、扩散限制都影响盆架树和尖蕾狗牙花空间格局的形成, 而由化感作用产生的自毒作用或对非生物资源的竞争而引起的负密度制约对盆架树空间格局的影响比对尖蕾狗牙花更显著。扩散限制和密度制约对盆架树和尖蕾狗牙花空间格局的影响程度与其生活型有关, 这从某种程度上也说明物种生活型能够用来预测物种分布格局, 这与郭屹立等(2015a)的结论一致。

致谢: 感谢大样地建设及调查过程中参与的各位调查人员的辛勤工作, 华南农业大学的庄雪影教授、黄久香副教授、周庆副教授、林元震副教授、林家怡副研究员、郑明轩实验师、梁爽、钟泳林、曾思金、周玉洁、林伟通等在数据处理分析过程中提供了大力支持和帮助, 在此表示感谢!

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(责任编委: 王绪高 责任编辑: 黄祥忠)

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中国科协精品科技期刊TOP50 (2015–2017)
中国科协精品科技期刊择优支持(2008–2014)
中国科学院科学出版基金择优支持(2013–2015)
百种中国杰出学术期刊(2007–2010, 2012–2013, 2015–2016)
中国精品科技期刊(2008–2020)
北京大学《中文核心期刊要目总览》收录期刊
中国科技核心期刊(中国科技论文统计源期刊)
RCCSE中国核心学术期刊(2013–2016年A类期刊)
中国国际影响力优秀学术期刊(2012, 2014–2016)

生 物 多 样 性

SHENGWU DUOYANGXING

(月刊, 1993 年 10 月创刊)

第 25 卷 第 10 期 2017 年 10 月

BIODIVERSITY SCIENCE

(Monthly)

(Started in October, 1993)

Vol. 25 No. 10 October, 2017

编 辑 《生 物 多 样 性》 编 辑 部
(北京香山南辛村 20 号, 邮政编码: 100093)
电子信箱: biodiversity@ibcas.ac.cn
网址: www.biodiversity-science.net
电话: 010-62836137, 62836665
主 编 马克平
主管单位 中 国 科 学 院
主办单位 中国科学院生物多样性委员会
中国植物学会
中国科学院植物研究所
中国科学院动物研究所
中国科学院微生物研究所
出 版 《生物多样性》编辑部
印 刷 北京科信印刷有限公司
发 行 北 京 报 刊 发 行 局
订 购 全 国 各 地 邮 局
国外总发行 中国国际图书贸易总公司
(北京 399 信箱, 邮政编码: 100044)
广告经营许可证 京海工商广字第 8010 号

Edited by the Editorial Office of Biodiversity Science
(20 Nanxincun Xiangshan, Beijing 100093, China)
E-mail: biodiversity@ibcas.ac.cn
http: //www.biodiversity-science.net
Tel: 86-10-62836137, 62836665
Editor-in-Chief: Keping Ma
Responsible Institution: The Chinese Academy of Sciences
Sponsored by Biodiversity Committee of the Chinese Academy of Sciences (CAS), Botanical Society of China, Institute of Botany, Institute of Zoology and Institute of Microbiology, CAS
Published by the Editorial Office of Biodiversity Science
Printed by Beijing Kexin Printing Company
Distributed by
Domestic: Beijing Bureau for Distribution of Newspapers and Journals
Foreign: China International Book Trading Corporation
(P.O. Box 399, Beijing 100044, China)
E-mail: zw@ww.cibtc.com.cn

国内外公开发行 ISSN 1005-0094 CN 11-3247/Q 国内邮发代号: 82-858 国外发行代号: 1395 BM 国内定价: 80.00 元

生物多样性官网

生物多样性微信号

ISSN 1005-0094

廣東園林

Guangdong Landscape Architecture

广东园林学会主办

2015 6

1979年创刊

Vol. 37 总第169期 双月刊

■《中国学术期刊（光盘版）》收录期刊
■《中国核心期刊（遴选）数据库》收录期刊
■《中文科技期刊数据库》收录期刊
■《中文电子期刊服务（CEPS）》收录期刊

本期要目：

风景名胜区总体规划编制——以西樵山为例基于土地利用协调专项规划研究
部分落叶类杜鹃品种在广州的引种栽培试验和生长开花观测
西方古代至19世纪园林景观设计方法的演变

本期专题：风景名胜区规划管理
杜鹃花研究



主管单位：广东省科学技术协会
主办单位：广东园林学会
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编辑出版：《广东园林》编辑部
地　　址：广州市先烈中路 120 号
邮政编码：510070
电话（传真）：020-36377332
电子邮箱：gdla2000@tom.com
广东园林学会网址：http://www.gdylxh.org

主　　编：吴　敏
执行主编：朱　纯
副 主 编：庄雪影（兼）李　青 叶创兴
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编　　务：黄晓虹 刘　炜 朱柳芳
排　　版：广州百彤文化传播有限公司

国内统一连续出版物号：CN44—1219/S
国际标准连续出版物号：ISSN 1671—2641
广告经营许可证：440000100159
国内发行：广东省报刊发行局
国内邮发代号：46-331
订　　阅：全国各地邮局
国外发行：中国出版对外贸易总公司
国外邮发代号：BM7470
发行范围：国内外发行

制版印刷：广州市人杰彩印厂
出版日期：2015 年 12 月
定　　价：15.00 元



刊名题字：秦咢生

JOURNAL OF GUANGDONG LANDSCAPE ARCHITECTURE
CN44—1219/S, ISSN 1671—2641

Sponsor :
GUANGDONG SOCIETY OF LANDSCAPE ARCHITECTURE

Edited by : EDITORIAL DEPARTMENT OF THE CANTONESE LANDSCAPE INSTITUTE'S JOURNAL

Domestic Distributor :
Guangdong Newspaper & Subscription and Distribution Bureau(Mail Code 46-331)

Overseas Distributor :
CHINA NATIONAL PUBLISHING INDUSTRY TRADING CORPORATION

Office Address :
No.120 Xianlie-zhong Road, Guangzhou, 510070, Guangdong, China

Tel & Fax : 0086-20-36377332
E-mail : gdla2000@tom.com
Price : 15 RMB

《广东园林》2015 年第 6 期（第 37 卷，169 期）

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广州市广雅中学植物造景特点浅析 *

The Plant Landscape Characteristics of Guangya Highschool, Guangzhou, China

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摘要：通过实地调查广州市广雅中学校园园林植物种类及其配置现状，共统计园林植物 195 种，隶属于 77 科 150 属，其中乔木类 74 种，占 38%；灌木类 71 种，占 36%；草本类 48 种，占 25%，藤本类 2 种，占 1%。对广雅校园内景观植物物种组成、应用频率、观赏特性及季相景观进行了分析，总结出校园植物造景具精致性、多样性、地域性、文化性、主体性五大特点。

关键词：广州广雅中学；校园植物造景；植物多样性；岭南园林文化　**文章编号**：1671-2641(2015)06-0066-04
中图分类号：S688　**收稿日期**：2015-01-09
文献标志码：A　**修回日期**：2015-03-30

Abstract: According to field survey of the landscape application of campus plants in Guangzhou Guangya high school, a total amount of 195 vascular plants belonging to 77 families and 150 genera were recorded. 74 trees make up 38% of the total; 71 shrubs make up 36%; 48 herbs make up 25%, and 2 vines make up 1%. Based on the analysis of the composition, applied frequency, ornamental characteristics and seasonal phenomena of the plants, five features including exquisite, diversity, territoriality, cultural and subjectivity of campus landscape were summarized.

Key words: Guangzhou Guangya highschool; Plant landscape in school; Plant diversity; Lingnan garden culture

历经风雨的百年名校，都有深厚的人文历史、令人称道的历史建筑、浓郁的地方特色、成熟的校园景观建设。良好的校园环境能够满足师生对于教学、学习、生活、娱乐等诸多方面的需求，植物景观作为校园景观的重要组成要素，可以美化环境、陶冶人的情操。要营造优良的育人环境和探寻校园植物造景的一般方法，就必须把研究的视角放在有深刻文化底蕴的历史名校，在老校园景观构成要素中吸收营养。然而目前有关历史名校的研究较少，仅见有历史名校资源与优势、景观更新和优化的一般方法以及校园文化等方面的研究[1-4]，对历史名校植物景观专项研究涉及较少，本文特选取广州市具有代表性的历史名校广雅中学作为研究对象，通过对校园植物及其景观应用的研究，探讨其植物造景特点，并对其存在问题提出改进意见。

1 研究地概况

广雅中学位于广东省广州市荔湾区广雅路，占地面积达 10.5 万 m^2，创建于 1888 年，前身是清朝两广总督张之洞创办的广雅书院，并与湖北自强学堂、两湖书院、上海南洋公学合称为当时中国“四大书院”。2002 年，广雅书院与中山大学校内建筑群“康乐园早期建筑”成为第四批广东省文物保护单位[5]。

126 年的办学历史造就了广雅中学良好的园林绿化环境，百岁山长楼、冠冕楼、百岁桥、湖心亭依然挺立，瓦印上刻有“广雅书院”字样的围墙历经百年仍屹立不倒，校园内植物物种多样性丰富，植物景观古朴厚重，263 年的樟树 *Cinnamomum camphora* 依然郁郁葱葱，植物造景精雕细琢，充满地域风情，极具文化底蕴，在同类别植物造景上堪称广东省乃至华南地区的经典，荣获“全国创建绿色学校活动先进学校”“全国百年名校”等荣誉[5]。

2 调查方法

在查阅广雅中学园林绿化有关资料的基础上，于 2014 年 10 月对广雅中学进行了实地调查，对校园内植物应用种类、频率、应用形式、观赏特性等进行采样、拍摄，记录统计，并对调查到的植物进行分类鉴定，分析校园植物组成、应用频率、观赏特性及景观特点。其中，应用频率是指调查记录的同种园林植物在校园各样方中出现的次数。

3 结果与分析

3.1 植物组成

校园共统计记录园林植物 195 种，隶属于 77 科 150 属，木本落叶植物 20 种，木本常绿植物 127 种，落叶树种与常绿树种的比值为 1:6。

* 基金项目：广州市科技计划项目（编号：2013KP043）资助。

其中种类应用最多的科包括棕榈科(12 种)、桃金娘科(10 种)、桑科(9 种)、竹亚科(8 种)、天南星科(8 种)、龙舌兰科(8 种)、百合科(7 种)、大戟科(6 种)、夹竹桃科(6 种)及楝科(5 种),乔木类 74 种、灌木类 71 种、草本类 48 种、藤本类 2 种。

3.2 应用频率

排在前 10 位的植物种类包括榕树 *Ficus microcarpa*(17 次)、大叶榕 *Ficus virens* var. *sublanceolata*(10 次)、木棉 *Bombax ceiba*(8 次)、散尾葵 *Dypsis lutescens*(8 次)、朱蕉 *Cordyline fruticosa*(8 次)、蒲葵 *Livistona chinensis*(7 次)、白兰 *Michelia alba*(6 次)、印度橡胶榕 *Ficus elastica*(6 次)、假连翘 *Duranta erecta*(6 次)、鹅掌藤 *Schefflera arboricola*(6 次)等。应用次数最多的科是桑科(36 次),其次有棕榈科(30 次)、桃金娘科(20 次)、天南星科(17 次)、夹竹桃科(14 次)、木兰科(13 次)、龙舌兰科(13 次)及竹亚科(13 次)。

3.3 植物观赏特性及季相景观

将校园植物按照其观赏特性进行分类统计得出,观形植物 77 种,占 39%;观叶植物 56 种,占 29%;观花植物 55 种,占 28%;观果植物 12 种,占 6%。其中观花植物种类繁多,大红花 *Hibiscus rosa-sinensis*、叶子花 *Bougainvillea spectabilis*、夹竹桃 *Nerium oleander*、黄槐 *Senna surattensis* 等花色丰富花期长的植物构成校园四季如春、花开不断的生动画面。观叶植物中彩叶植物 19 种,视觉效果鲜明的红色系有变叶木 *Codiaeum variegatum*、朱蕉、红背桂 *Excoecaria cochinchinensis* 和红花檵木 *Loropetalum chinense* var. *rubrum* 等;黄色系的花叶艳山姜 *Alpinia zerumbet*'Variegata'、黄金榕 *Ficus microcarpa*'Golden Leaves' 等;紫色系包括小蚌兰 *Tradescantia spathacea* 'Compacta'、吊竹梅 *Tradescantia zebrina* 等;具斑块和条纹的彩虹龙血树 *Dracaena marginata*'Tricolor'、花叶假连翘 *Duranta repens*'Variegata'、百合竹 *Dracaena reflexa*、花叶冷水花 *Pilea cadierei* 等,为校园景观增添了色彩斑斓的效果。

校园落叶植物种类较少,一些落叶树种如大叶榕、木棉、洋紫荆 *Bauhinia variegata*、鸡蛋花 *Plumeria rubra* 'Acutifolia' 等应用次数达 6 次以上,朴树 *Celtis sinensis*、落羽杉 *Taxodium distichum*、大花紫薇 *Lagerstroemia speciosa*、垂柳 *Salix babylonica* 等季相景观效果显著。其次,一些盛花期不同的观花植物,如早春观花植物木棉、锦绣杜鹃 *Rhododendron* × *pulchrum*、洋紫荆,夏秋季观花植物金苞花 *Pachystachys lutea*、大花紫薇、莲 *Nelumbo nucifera*、水鬼蕉 *Hymenocallis littoralis*、狗牙花 *Tabernaemontana divaricata*、鸡蛋花及秋冬季观赏植物美丽异木棉 *Chorisia speciosa*、山茶 *Camellia japonica*、红花羊蹄甲 *Bauhinia blakeana* 等也增加了校园景观的季相变化。

3.4 造景特色

3.4.1 精致性

校园环境整洁优美,亲切宜人,主要体现在校园各区对植物材料的精心选择、精细养护管理及对植物造景的精心营造等方面。如校园古树养护管理支架采用仿自然树干形式做支撑,使之与自然环境相融合;丛植的 3 株金边宝巾 *Bougainvillea spectabilis* 'Lateritia Gold' 叶片密集、姿态各异、清秀可爱,倾斜的姿态使它们呈相互顾盼之势;建筑墙基植物造景采用福建茶 *Carmona microphylla*、金叶假连翘 *Duranta erecta* 'Variegata'、小蚌兰 3 种不同色彩的造型植物交替配置,形成节奏和韵律;蘑菇型造型木在校园中大量应用,株型圆整,新颖别致,使校园整体植物景观统一并富于自身特色(图 1)。

3.4.2 丰富性

丰富性主要体现在校园植物种类及造景方式的多样。精致的养护管理使各具特色的观赏性植物呈现优美的形态、绚丽的色彩,发出沁人的芳香,构成丰富多彩的景观。据实地调查,共统计记录校园植物 195 种,隶属于 77 科,乔灌草植物资源丰富,藤本植物较少,然而垂直绿化景观丰富,使君子 *Quisqualis indica* 附着墙壁向高处延展,气势壮观,薜荔 *Ficus pumila* 造景形式灵活多样,应用广泛。草质藤本麒麟叶 *Epipremnum pinnatum*、五爪金龙 *Ipomoea cairica*、圆叶牵牛 *Ipomoea purpurea*、绿萝 *Epipremnum aureum* 等植物也丰富了垂直绿化的形式,赋予物体生机,使环境更加整洁美观、生动活泼。

植物造景既采用古典植物造景写意手法,展现少而精的个体美,通过植物体现文化内涵,追求深远的意境(图 2);同时又结合现代植物造景及西方造景手法,以孤植(图 3)、丛植、色块种植等手法,造景生动、自然,形式灵活多样,或与建筑相配,相互借景,相互衬托,

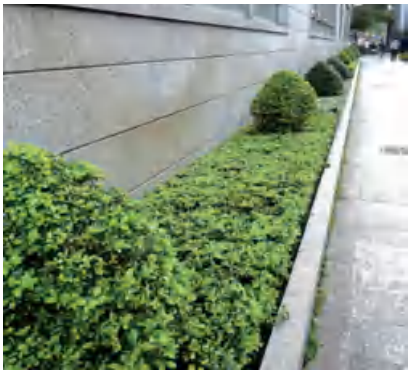


图 1 墙基植物造景



图 2 植物造景



图 3 孤植



图 4　建筑前植物造景



图 5　角隅植物造景



图 6　植物与山石相配



图 7　庭院水景

协调而柔和，使建筑及其环境更加优美动人和富有生气；或与山石相配，增添野趣，凸显主题；或与水景相配，探向水面的枝条，或斜展，或拱曲，在水面都可形成优美的线条，显出自然景观的朴素和宁静；或于建（构）筑入口及道路两侧等地采用规则式对植、列植、模纹、色块等配置，形成疏朗明快、规整有序的景观（图 4 ~ 7）。

3.4.3 地域性

广州市地处我国南亚热带，邻近热带，在植物造景上体现出南亚热带向热带过渡的特色，体现这种特色的植物主要是棕榈科、桑科榕属、南洋杉类、桃金娘科、苏木科等科属的植物[2]。棕榈科植物形体轻盈，给人感觉潇洒飘逸，散发出热带特有的韵味，校园棕榈科植物种类多达 12 种，居各科植物之首，其中散尾葵、蒲葵应用次数仅次于桑科榕属植物，桃金娘科种类 10 种，仅次于棕榈科植物，苏木科如黄槐以及南洋杉类景观效果显著。

此外，校园植物造景多使用具浓厚岭南风土文脉的植物，如岭南传统民居喜栽竹类，无论住房村舍，或河沿山旁均可见到竹类丛生[6]，校园竹亚科植物 8 种，粉单竹 *Bambusa chungii*、小琴丝竹 *Bambusa multiplex* 'Alphonso-Karrii'、黄金间碧竹 *Bambusa vulgaris* 'Vittata'、佛肚竹 *Bambusa ventricosa* 应用于校园各处，其他园景树如罗汉松 *Podocarpus macrophyllus* 在广东地区民间素有“家有罗汉松，世世不受穷”的说法；苏铁 *Cycas revoluta* 叶硬如铁，被认为具有避邪镇宅的作用，常在岭南庭院大门入口对植；岭南佳果龙眼 *Dimocarpus longan*、荔枝 *Litchi chinensis*、杨桃 *Averrhoa carambola*、人心果 *Manilkara zapota*、芭蕉 *Musa basjoo*、枇杷 *Eriobotrya japonica*、番石榴 *Psidium guajava*、杧果 *Mangifera indica*、黄皮 *Clausena lansium* 以及榕树、洋紫荆、木棉、三角梅等在校园植物景观中的配置应用，不仅丰富了岭南植物景观特色，而且重现了岭南风土神韵，有效增强岭南植物景观的人文内涵[7]。

3.4.4 文化性

校园室外环境文化氛围浓郁，主要体现在尊重历史、植物造景精致及植物材料具有文化寓意等方面。

校园中保留了入口处的护院河以及冠晃楼两侧的荷塘，建筑前的古石桥将楼前的河渠分为两个方形池塘（图 8），两棵高大的木棉树分列于楼的两侧，开花时，满树一片火红；池中种满荷花，盛开时，荷香“心人心脾，岸边垂柳轻飘”。整体既保留了百年前校园布局的精华部分，又结合了功能性布局的现

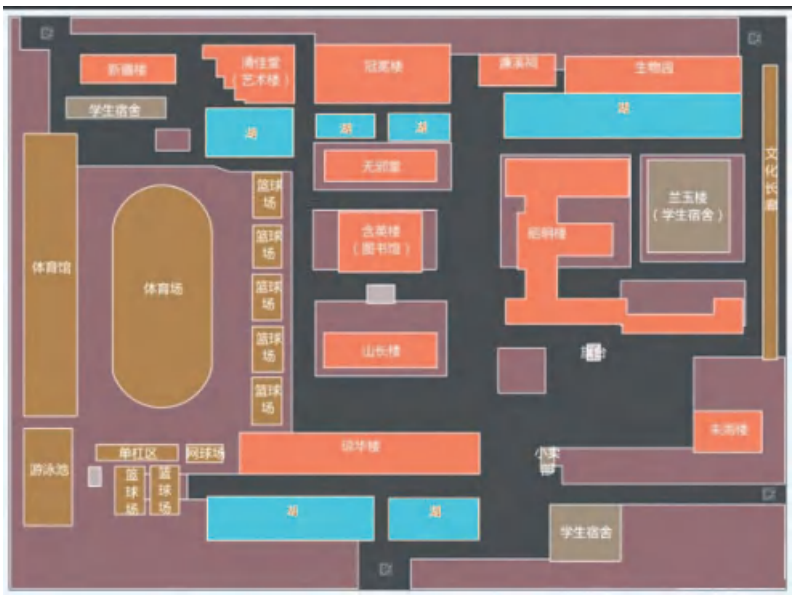


图 8　校园布局

代设计理念，对学校来说保留的是一份珍贵史料，对学生来说保留的是源远流长的学校精神。这具有深刻历史文脉的校园布局让广雅学子受到文化的熏陶，感受到校园文化源源不断的生机活力。广雅中学有一由广雅校友的资助建造的百米长的汉白玉浮雕长廊，记录着广雅中学的百年光荣历史，展现广雅百年历史的沧桑变迁，也象征着中国百年来的风云变幻。浮雕长廊的建造，不仅仅展示了广雅中学深厚的文化底蕴，重现了张之洞的办学理念，还勉励了在读学生要不断进取，与时俱进，成为走在时代前端之人。学校十分重视对古树的保护，校园内有百年古树 24 棵，树龄最大的樟树已有 263 年，它们见证了广雅中学的历史，对古树进行挂牌标识，能激发学生对植物探知的乐趣 [4]。

在植物材料的选择上，注重选用具传统文化内涵及岭南风土文脉的植物进行造景，如校园大量应用竹亚科植物：或与景石相配，突显主题；或与建筑相配，柔化建筑边角；或与水景相配，形成一道秀丽的屏障；或片植做障景分割空间。在文化史上，竹既是“岁寒三友”之一，也是“植物四君子”之一，象征人品清逸、气节高尚。自古文人雅士钟爱竹，如史上著名的“竹林七贤”，他们不同流俗，率真洒脱而归隐竹林，形成中国历史上绝无仅有的“魏晋风流”。大文豪苏轼盛赞竹子“宁可食无肉，不可居无竹，无肉使人瘦，无竹令人俗”，表达中国文人淡泊、清高、自持、正直的品格。荷花冰清玉洁，比喻了人性的至善、清净和不染，校园内湖心亭下满塘莲花，如一片神圣的净土，涤荡人们的心灵，让人们在世俗的熏染下，仍然保留一份纯真；木棉历来被视为英雄的象征，是广州市的市花，庭院中雄伟的木棉树鲜艳似火的大红花，比喻英雄奋发向上的精神……广雅校园内植物景观巧妙利用了植物的象征意义，完成了植物对于人精神的陶冶，达到育人于景的目的。

3.4.5 主体性

广雅中学是广州市百年历史名校之一，校园植物景观的空间布局及景观营造具民族风格和园林特色，规划布局规整，景观整洁有序，空间序列收放自如，或开敞明朗，或曲径通幽，各区景观风格迥异，植物材料的选择也不尽相同，展现一派勃勃生机的自然风光。入口广场古树彰显历史名校的厚重感；中庭休闲活动区或结合水池，或结合微地形营造自然活泼的休闲活动空间；建筑末端则是主景区，大片荷塘辉映着主体景观湖心亭，岸边景色明媚，壮阔的景观使人豁然开朗；校园尽头则是寓教于乐的生物园，走进小门，阵阵桂花香气扑鼻，园内种类丰富，特色植物众多，园中景亭供学生学习交流娱乐；穿过生物园则是另一处幽静的场所，古老的建筑前丛生几株桂花，掩映在大片黄金间碧竹中，人们流连在此校园美景中心情亦开朗而宁静。张之洞定名“广雅”，取义“广者大也，雅者正也”，强调所培养的人要“知识广博，品行雅正”，即“德”与“才”的和谐 [5]，校园植物景观丰富雅致而整洁有序，与规则式整体布局相统一，景观环境美观大方、典雅别致，给人以欣欣向荣的感觉，可谓景如其名。

校园植物造景除了富有特色鲜明的主题，即造景符合校园特色的景观观赏性、科普教育性、文化性、历史性以及地域性等，还结合各种休闲设施，如中庭树池下设置的坐凳，林下、草地及各处布置的石桌等满足人们进入绿地进行休闲、娱乐和交流等的需求，做到景为人用，富有人情味，充分体现了以人为本的设计理念。

4 结论与建议

历经百年的历史沉淀，广雅中学已经发展形成一座古朴、雅致、韵味深厚的岭南文化特色校园。校内以棕榈植物、榕属植物、开花乔灌木、彩叶植物、岭南特色果树、竹子及开阔的荷塘或清幽的水池与岭南古典建（构）筑物相互配合，形成具有强烈南亚热带特色的自然风光，校内百岁山长楼、冠冕楼、百岁桥、湖心亭掩映在具有浓厚岭南风土文脉的植物中，蕴含着浓郁的历史文化韵味。

校园植物景观充分发挥植物造景的科学性、艺术性与文化性，注重以人为本的设计理念。走进广雅中学，人们能够感受到与其他学校截然不同的校园文化氛围，而景观步移景异、各具特色让人陶醉。改建的建筑与历史遗址的完美融合，既保留了珍贵的历史文脉、延续了优秀的校园精神，又体现了具有时代气息的校园文化 [4]。综合可见，校园通过营造丰富的植物景观，既可以展示一个学校的精神风貌、文化气质和校园环境，又可以体现它的历史沉淀、文化底蕴及时代特色。

调查还发现广雅中学校园局部地块土壤裸露，大块绿地只有地毯草覆盖，未能得到很好的利用，并且草坪中也被践踏出小路。较偏僻角落景观显得杂乱，有待进一步管理，在做好保护的基础上，还应进一步完善。此外，植物造景的文化特性比较隐晦，如学校采用的岭南传统植物材料大多具有浓郁的地方特色以及文化色彩，应引起人们的重视，使之得到更好保护及宣扬，充分发挥其景观和教育的功能。

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ISSN 1671-2641 国内邮发代码:46-331
CN44-1219/S 定价:每期15.00元
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9 771671 264053

廣東園林

Guangdong Landscape Architecture

广东园林学会主办

2015 5

1979年创刊

Vol. 37 总第168期

双月刊

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编辑出版：《广东园林》编辑部
地　　址：广州市先烈中路 120 号
邮政编码：510070
电话（传真）：020-36377332
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排　　版：广州百彤文化传播有限公司

国内统一连续出版物号：CN44—1219/S
国际标准连续出版物号：ISSN 1671—2641
广告经营许可证：440000100159
国内发行：广东省报刊发行局
国内邮发代号：46-331
订　　阅：全国各地邮局
国外发行：中国出版对外贸易总公司
国外邮发代号：BM7470
发行范围：国内外发行

制版印刷：广州市人杰彩印厂
出版日期：2015 年 10 月
定　　价：15.00 元



刊名题字：秦咢生

JOURNAL OF GUANGDONG LANDSCAPE ARCHITECTURE
CN44—1219/S, ISSN 1671—2641

Sponsor :
GUANGDONG SOCIETY OF LANDSCAPE ARCHITECTURE

Edited by : EDITORIAL DEPARTMENT OF THE CANTONESE LANDSCAPE INSTITUTE'S JOURNAL

Domestic Distributor :
Guangdong Newspaper & Subscription and Distribution Bureau(Mail Code 46-331)

Overseas Distributor :
CHINA NATIONAL PUBLISHING INDUSTRY TRADING CORPORATION

Office Address :
No.120 Xianlie-zhong Road, Guangzhou, 510070, Guangdong, China

Tel & Fax : 0086-20-36377332
E-mail : gdla2000@tom.com
Price : 15 RMB

《广东园林》2015 年第 5 期（第 37 卷，168 期）

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广州市培正中学园林植物及其应用现状研究*

A Study on Application of Landscape Plants in Guangzhou Pui Ching Middle School

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摘要：通过实地调查培正中学校园绿化植物种类、频度以及配置形式，共记录了维管植物 84 科 161 属 194 种。其中校园绿化用园林植物 60 科 123 种，依据景观应用分类统计得出：乔木 47 种，占总数 38%；灌木 50 种，占 41%；地被植物 26 种，占 21%。总结得出：培正中学校园植物景观具有物种丰富、植物景观丰富、造景形式新颖等特点。

关键词：培正中学；植物；校园植物景观应用
中图分类号：S688
文献标志码：A
文章编号：1671-2641(2015)05-0003-56
收稿日期：2014-12-05
修回日期：2015-03-23

Abstract: The campus landscape construction of Pui Ching Middle School as one of the famous oldest schools in Guangzhou city is representative. Based on the field investigation of the plant species, frequency and configuration of campus landscaping in Pui Ching Middle School, a total amount of 194 vascular plants belonging to 84 families and 161 genera were recorded, 123 landscape plants belonging to 60 families (not including the biological garden plants) were applied to campus greening. by undertaking classified statistical method that the tree applied in campus has 47 species, accounting for 38% of the total; shrub has 50 species, accounting for 41%; herb has 26, accounting for 21%. On the basis of plant application characteristics summarized in Pui Ching middle school ,campus plants landscape has the following features:(1) Richness in species, with typical lingnan plant landscape characteristics (2) Richness in plants landscape, landscape forms were novel, (3) Landscape styles different in each function, reflected the campus culture, (4) Large tree landscapes revealed the campus historical sense.

Key words:Pui Ching Middle School;Plants; Plant landscaping application in campus

中学阶段是世界观、人生观形成的关键时期，优美的校园环境可以成为课堂教育的有益补充，有利于促进学生的健康品格的塑造，植物景观在校园环境中扮演着非常重要的角色。因此，对校园植物景观的研究就显得尤为重要。目前相关研究仅是部分城市中小学校园植物景观的调查及分析，如植物配置、环境心理学、植物文化性设计以及生物教学等方面对植物景观设计的探讨[1-7]，有关广州市中学校园植物景观的研究罕见涉及，因此本文选取广州市具有代表性的培正中学作为研究对象，对校园植物种类及造景特点进行分析，为校园绿化提供一定的参考。

1 研究对象概况

培正中学创办于 1889 年，是广州市百年名校之一。在历史上享有“北有南开，南有培正”之美誉。学校坐落在广州市越秀区培正路，占地面积近 7 万 m^2，绿化面积 43 048 m^2。校舍多是上世纪初的建筑，校门、美洲楼、图书馆、澳洲楼、王广昌楼等都是广州市文物建筑，显得古朴典雅。校内古木参天，枝繁叶茂，优雅宁静，百年的发展使得学校景观建设日趋完善，历史的沉淀也浓缩着学校自身景观特色，获得“广州市花园式单位”“省一级学校”“全国百所名校”“省绿色学校”“国际生态学校绿旗”等荣誉。

2 调查对象及方法

为了解广州市中学校园植物景观概况，笔者于 2014 年 3 月对培正中学进行了实地调查，记录了植物种类、应用方式、在校园各区分布及各种植物在校园中出现频率（即同种园林植物在校园各块绿地植物造景中以各种景观应用形式出现次数）等信息，同时拍摄校园绿地植物以及典型植物景观图片，通过查阅文献资料，对校园植物材料按生活型、观赏特性以及园林应用进行分类统计，分析校园植物物种组成及景观特点，对其校园植物景观造景及存在问题进行了讨论，并提出优化建议。

3 结果与分析

本次调查植物种类包括校园内园林绿化植物和生物园栽培植物，共计 194 种，隶属于 84 科 161 属，植物种类多样性较高，其中灌木树种 85 种，占总数的 45%；乔木与草本植物各 54 种，占 27%，藤本植物应用较少。对校园绿化应用植物进行分类统计，其中乔木 47 种，占总数的 38%；灌木 50 种，占 41%；

* 基金项目：广州市科技计划项目（编号：2013KP043）资助。

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地被植物 26 种，占 21%。根据植物调查出现次数进行统计，乔木共计 120 次，灌木 180 次，地被 83 次。对植物造景形式统计，乔木配置方式主要是孤植、丛植、列植；灌木和草本有色块种植、基础种植（绿篱、模纹色块、花带）、丛植以及片植（地被）等。

3.1 校园植物物种组成分析

3.1.1 乔木树种

调查结果显示，校园绿化用乔木树种 47 种，隶属于 26 科 38 属。其中，落叶树 11 种，隶属于 10 科 11 属；常绿树 33 种，隶属于 20 科 24 属；落叶树种与常绿树种的比值为 1:3。排在前四位的科是：桑科（7 种，25 次）、棕榈科（3 种，15 次）、木兰科（3 种，9 次）、苏木科（3 种，9 次）。乔木树种出现频率排在前五位的是蒲葵 *Livistona chinensis*、假槟榔 *Archontophoenix alexandrae*、大叶榕 *Ficus virens* var. *sublanceolata*、榕树 *Ficus microcarpa*、白兰 *Michelia alba*。其次还有香樟 *Cinnamomum camphora*、木棉 *Bombax ceiba*、洋紫荆 *Bauhinia variegata*、鸡蛋花 *Plumeria rubra* ‘Acutifolia’、幌伞枫 *Heteropanax fragrans* 等。

3.1.2 灌木树种

调查结果显示，校园绿化用灌木树种 50 种，隶属于 27 科 40 属，其中常绿灌木 48 种，占总数的 96%，排在前 4 位的科是棕榈科（8 种，20 次）、五加科（1 种，18 次）、龙舌兰科（5 种，12 次）和马鞭草科（2 种，10 次），应用最多的是鹅掌藤 *Schefflera arboricola*；其次有朱蕉 *Cordyline fruticosa*、假连翘 *Duranta erecta*、苏铁 *Cycas revoluta*、海桐 *Pittosporum tobira* 等。

3.1.3 地被植物

校园绿化应用的地被植物种类繁多，有 18 科 26 种，其中观叶植物 22 种，彩叶植物 6 种，观花植物 5 种，主要包括百合科（4 种，10 次）、肾蕨科（6 次）、鸭跖草科（2 种，6 次）及天南星科（3 种 6 次），应用最多的是肾蕨 *Nephrolepis cordifolia*、蚌兰 *Tradescantia spathacea*、白蝴蝶 *Syngonium podophyllum* ‘Albovirens’，其次有玉龙草 *Ophiopogon japonicus* ‘Nanus’、吊兰 *Chlorophytum comosum*、花叶冷水花 *Pilea cadierei*、巴西鸢尾 *Neomarica gracilis* 及银边草 *Arrhenatherum elatius* 等。

3.2 培正中学园林植物应用特色分析

3.2.1 棕榈科植物体现热带风情

具有浓郁的热带和南亚热带风光特色的棕榈科植物在现代岭南园林中被大量采用，或植于路旁，或草地，或水边，或成岛，或成林，或成行，蔚然成风，堪称岭南园林植物最显著的特色[8–9]。据实地调查，棕榈科植物在校园绿化中应用广泛，常用的棕榈科植物共有 10 种，应用频率排在前五位的是蒲葵、假槟榔、散尾葵 *Dypsis lutescens*、王棕 *Roystonea regia*、棕竹 *Rhapis excelsa*，它们作为姿态优美的园景树配置在校园建筑、道路周边、草地、焦点及入口处等，向人们展现出独有的姿态、干径、树叶等。

3.2.2 热带观花植物景观丰富

校园绿地共使用观花植物 43 种（隶属于 34 科 41 属），其中观花乔木 18 种，花灌木 19 种，草本花卉 7 种，花色丰富，花期遍布一年四季之中。校园绿化所应用的开花乔木中落叶树与常绿树各占 9 种，如春季开花乔木有木棉、洋紫荆、黄花风铃木 *Handroanthus chrysantha*，夏秋季开花乔木有鸡冠刺桐 *Erythrina crista-galli*、鸡蛋花、白兰、大花紫薇 *Lagerstroemia speciosa*，秋冬季观花乔木有红花羊蹄甲 *Bauhinia blakeana* 等，不但具有很好的美化效果，同时又赋予校园景观具季相变化；花灌木春季有锦绣杜鹃 *Rhododendron* × *pulchrum*、石斑木（春花）*Raphiolepis indica*，夏秋季有朱缨花 *Calliandra haematocephala*、狗牙花 *Tabernaemontana divaricata*、夹竹桃 *Nerium oleander*、假连翘、桂花 *Osmanthus fragrans*、大花鸳鸯茉莉 *Brunfelsia pauciflora*、龙船花 *Ixora chinensis* 以及花期持续全年的琴叶珊瑚 *Jatropha integerrima*、簕杜鹃 *Bougainvillea spectabilis* 等，花色有红、粉、蓝、黄、白和紫等；草本花卉有非洲凤仙 *Impatiens walleriana*、巴西鸢尾、美人蕉 *Canna indica*、草豆蔻 *Alpinia hainanensis*、文殊兰 *Crinum asiaticum*、鹤望兰 *Strelitzia reginae* 等，这些植物使校园花开不断、四季如春。

3.2.3 彩叶植物营造青春活跃的氛围

丰富的彩叶植物使得校园四季色彩缤纷，主要有 12 科 19 种，为龙舌兰科、鸭跖草科、金缕梅科、大戟科及爵床科等植物。视觉效果鲜明的红色系有变叶木 *Codiaeum variegatum*、朱蕉、红背桂 *Excoecaria cochinchinensis* 和红花檵木 *Loropetalum chinense* var. *Rubrum* 等；黄色系的花叶艳山姜 *Alpinia zerumbet* ‘Variegata’、黄金榕 *Ficus microcarpa* ‘GoldenLeaves’、金脉爵床 *Sanchezia oblonga* 和金边龙舌兰 *Agave americana* var. *marginata* 等；紫色系包括蚌兰、小蚌兰 *Tradescantia spathacea* ‘Compacta’、吊竹梅 *Tradescantia zebrina* 等；具斑块和条纹的彩虹龙血树 *Cordyline fruticosa*、花叶假连翘 *Duranta erecta* ‘Variegata’、百合竹 *Dracaena reflexa*、花叶冷水花等。

3.2.4 生物园增加植物多样性

生物园植物种类丰富，有 117 种维管植物，隶属于 62 科。种类较多的有龙舌兰科（9 种）、芸香科（7 种）、大戟科（7 种）、蔷薇科（5 种）、桑科（4 种）、桃金娘科（4 种）和天南星科（4 种）等。栽培方式为盆栽和地栽。绿地栽培植物中乔木有 14 种，包括洋蒲桃 *Syzygium samarangense*、黄皮 *Clausena lansium*、南岭黄檀 *Dalbergia balansae* 和菩提树 *Ficus religiosa* 等；小乔（高 6–10 m）7 种，包括牛蹄豆 *Pithecellobium dulce*、班克木 *Banksia integrifolia*、木芙蓉 *Hibiscus mutabilis* 以及罗汉松 *Podocarpus macrophyllus* 等；灌木 32 种，有竹节蓼 *Homalocladium platycladum*、光棍树 *Euphorbia tirucalli*、岭南山竹子 *Garcinia oblongifolia*、夜合花 *Magnolia coco*、枸骨 *Ilex cornuta*、玉麒麟 *Euphorbia neriifolia* var. *cristata* 和巴西野牡丹 *Tibouchina semidecandra* 等；草本植物 15 种，有大叶仙茅 *Curculigo capitulata*、蚌花和芸香 *Ruta graveolens* 等；蕨类植物有槲蕨 *Drynaria roosii*、巢蕨 *Neottopteris nidus*、铁线蕨 *Adiantum*

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capillus-veneris 和圆盖阴石蕨 *Humata griffithiana* 等。盆栽植物约 30 种，其中盆景造型植物 8 种，有榔榆 *Ulmus parvifolia*、胡椒木 *Zanthoxylum beecheyanum*、树马齿苋（金枝玉叶）*Portulacaria afra* 等；盆栽观赏植物四季秋海棠 *Begonia cucullata*、斜纹亮丝草 *Aglaonema* spp.、红雀珊瑚 *Pedilanthus tithymaloides* 等。生物园丰富的植物资源使学生们可以接触到不同种类的植物，而特色植物的应用可引起他们对植物学的兴趣，是一项重要的科普教育资源。

3.3 培正中学校园植物景观特色分析

3.3.1 物种丰富，具典型的岭南植物景观特色

校园里植物资源丰富，种类达 194 种（含种下单位）。植物的应用充分体现了岭南植物景观特色，如具有南国风光的棕榈科植物、榕属景观、丰富多彩的灌木和草花、七彩的色叶造景植物、美丽的室内观叶植物及其他独特的骨干树种 [9]。

3.3.2 植物景观丰富，造景形式新颖

校园植物造景形式多样，景观丰富。中心绿地区建筑立面利用一些形体较为低矮的树种，如将三药槟榔 *Areca triandra*、棕榈 *Trachycarpus fortunei*、棕竹以及蒲葵等用作耐荫中层植物与高大棕榈科植物搭配成热带景观，蒲葵以乔木、灌木两种形式造景，形成多层次的景观效果；草坪绿地通过种植小蚌兰色块衬托丛植的苏铁，成为该处景观的焦点，而远处龙舌兰、金边龙舌兰、软叶针葵 *Phoenix roebelenii* 丛植与该处景观相互衬托，使整个景观灵活而生动；花池部分将红果仔 *Eugenia uniflora* 以基础绿篱和灌木球两种形式组合进行绿化，红果仔新叶红色，且株型圆整，作花池组合绿化成为该处植物造景的一大亮点。

3.3.3 各功能区植物造景风格迥异，彰显校园文化

培正中学的校徽由红色和蓝色组成，这两个颜色是培正中学的校色，百年来培正中学的优良传统被校友们概括为“红蓝精神”。红色代表热情、积极向上，蓝色代表冷静、理智，表现出了培正人热情沉稳的精神 [8]。校园各区景观设计或典雅庄重，或朴素自然，或活泼开放，植物造景各具特色：在一些光照充足的地方种植木棉、鸡冠刺桐等观花树种，营造出一派明媚灿烂的景观环境，给人以积极、明朗的感觉，彰显校园文化的红色精神；而在背阴处选择一些耐阴植物如蕨类、花叶冷水花、米仔兰 *Aglaia odorata* 及天南星科的一些观叶植物等形成静谧的环境氛围，让人心情平静，显示出校园沉稳的蓝色精神。

3.3.4 大型乔木景观，彰显校园历史厚重感

学校历史悠久，古树数量多且树龄大多在 50 年以上，主要有榕树、印度橡胶榕 *Ficus elastica*、木棉、银桦 *Grevillea robusta* 和石栗 *Aleurites moluccana* 等。这些大型乔木有一个显著的共同点，就是有高大的外形和粗壮的干径，体现出一定的气势，在校园绿地中孤植、对植或散植，与校园古建筑营造出一种古朴幽静的氛围环境和一种古老原始的自然面貌。

4 结论与讨论

培正中学校园绿化具有现代岭南植物景观特色，古树名木以及人工引种栽培植物资源众多，不仅能丰富校园植物种类、保存物种资源，还能服务于教学科研。大型古乔木彰显了校园历史厚重感；植物造景形式灵活多样，营造出不同的空间氛围，彰显出校园文化，同时满足了校园绿化、美化、生态以及学校师生交往活动等需求。

然而部分植物景观造景及养护管理水平有待提高，如操场区与生活区交界设置的一道绿色屏障，满足了植物造景的功能性要求，但中层灌木应用了朱槿、狗牙花、朱蕉、海桐、紫薇 *Lagerstroemia indica*、锦绣杜鹃、红花檵木、花叶艳山姜、龙船花等十多种植物，却没有考虑植物之间疏密、层次以及色彩的搭配，景观效果拥塞而繁杂。又如，教学区地被采用多种植物材料，如百合竹、蚌花、翠云草 *Selaginella uncinata* 等分片种植，形式呆板，丛植的朱蕉作为景观主景显得薄弱，应丰富其造景形式，增加植物之间的协调性，突出景观主题。此外，校园多处植物景观因缺乏管理，任植物自然生长而显得杂乱，应加强植物景观的养护与管理工作，适当疏除、修建等以保持校园景观的整洁、美观。可给校园绿化植物挂标牌，注明中文名、学名、习性和功用等，传播植物学科普知识，更好地发挥服务教学的功能 [10]。

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廣東園林

園林建设与管理

园林植物研究与应用

ISSN 1671-2641 国内统一刊号代码 46-331
CN44-1219/S 定价：RMB15.00

中文核心期刊
中国科技核心期刊
中国农业核心期刊
RCCSE中国核心学术期刊
中国科学引文数据库库源期刊

ISSN 1001-4829
CN51-1213/S
CODEN XNXUEF

西南农业学报

SOUTHWEST CHINA JOURNAL OF AGRICULTURAL SCIENCES

2014
272
第27卷 第2期
Vol.27 No.2

《西南农业学报》编辑委员会

ISSN 1001-4829

西南农业学报
XINAN NONGYE XUEBAO

第27卷 第2期
2014年4月28日

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期刊基本参数:CN51-1213/S*1985*b*A4*442*zh*P*¥20.00*1500*83*2014-04

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文章编号: 1001 - 4829(2014) 02 - 0797 - 04

9 种鹅绒藤属(萝藦科) 植物种子微形态特征研究

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摘 要: 利用数码体视镜和环境扫描电子显微镜(ESEM) 对 9 种鹅绒藤属(*Cynanchum* Linn.) 植物种子微形态特征进行观测。结果表明,该属植物种子形状、大小及表皮纹饰在各个种间存在差异,催吐白前组(*C.* Sect. *Vincetoxicum*) 中种子外观、种子大小及种皮纹饰等方面具有相对一致性,牛皮消组(*C.* Sect. *Endotropis*) 种皮纹饰特征明显不同,主要表现在于牛皮消(*C. auriculatum*) 表面凹陷呈嚼烂状,网孔不规则,而峨眉牛皮消(*C. giraldii*) 表面凹陷呈网状,网孔较规则。本文研究结果支持《中国植物志(第 63 卷) 》中对催吐白前组的分组处理。

关键词: 鹅绒藤属; 种子; 微形态; 分类
中图分类号: S682.36 文献标识码: A

Seed Micromorphology of 9 Species of *Cynanchum*(Asclepiadaceae)

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Abstract: Seed morphology characters of 9 species of *Cynanchum* Linn. were observed under stereoscope and environmental scanning electron microscope (ESEM) . The results showed that the seeds of *Cynanchum* had some differences in shape, size and epidermal ornamentation among species. Seeds of *Cynanchum* Sect. *Vincetoxicum* were relative consistency in appearance, size and epidermal ornamentation. Seed ornamentation characteristics in *Cynanchum* Sect. *Endotropis* were significantly different. The seed surface of *C. auriculatum* presents immersed rumination, irregular mesh and that of *C. giraldii* immersed reticulation with more regular mesh. These results supported the treatment of *C.* Sect. *Vincetoxicum* in *Flora reipublicae Popularis sinicae* (Vol. 63) .

Key words: *Cynanchum*; Seed; Micromorphology; Taxonomy

鹅绒藤属(*Cynanchum* Linn.) 隶属于萝藦科(Asclepiadaceae) ,是一个具有重要经济价值和学术价值的类群。全球约 200 种,非洲、美洲、欧洲和亚洲均有分布; 中国有 57 种,在全国大部分省区都有分布,主要分布在西南各省区[1~2]。由于该属地理分布广,生活型多样等特点,很多种之间性状很相似,近缘种之间不易区分,所以积累其微观分类学资料仍有必要。由于种子处于相对封闭的环境中,与其他营养器官相比,受外界环境因子影响较少,其性状在分类学上的意义不亚于花粉形态[3]。近年来,国内对鹅绒藤属药用植物资源、植物叶表皮和花粉器官研究较多[4~7],种子研究至今尚未见报道。为探讨植物种子形态在鹅绒藤属植物中的分类学意义,本研究对 9 种鹅绒藤属植物的种子进行扫描电子显微镜观察,结果可供该属植物分种鉴定作参考。

收稿日期: 2013 - 05 - 12
基金项目: 国家自然科学基金项目(31000095) ; 广东省大学生创新实验项目(1056413065、1056411009) ; 国家高等学校本科特色专业建设点——林学(教高函 [201015] 号)
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1 材料与方法

1.1 供试材料

实验材料来自中国科学院华南植物园标本馆(IBSC) 馆藏的腊叶标本,凭证标本见表 1。

1.2 仪器

10 ~ 80X 数码体视镜和 FEI-XL30 环境扫描电子显微镜。

1.3 方法

将成熟的种子置于数码体视镜下,记录种子的形状和颜色。每种随机选取 5 粒用游标卡尺测量种子长和宽。扫描电镜观察时每个种随机取 2 粒种

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表 1 鹅绒藤属植物种子的试验材料及凭证标本

Table 1 Seed materials and voucher specimens of *Cynanchum*

种名 Name of species	采集点 Collection locality	采集时间 Collection time	凭证标本 Voucher specimens
合掌消 *C. amplexicaule*	江西省	1932-7-14	蒋英 10281
潮风草 *C. ascyrifolium*	日本	1956-3-20	采集不详 21248
牛皮消 *C. auriculatum*	广东省乳源县西山乡	1957-11-12	邓良 5507
鹅绒藤 *C. chinense*	陕西省子长县	1937-4-9	傅坤俊 7686
刺瓜 *C. corymbosum*	广西省容县天唐山	1937-1-16	陈文 82150
大理白前 *C. forrestii*	云南省	1939-1-17	王启无 68145
峨眉牛皮消 *C. giraldii*	四川省甘洛县	1976-9-23	生物所 14305
竹灵消 *C. inamoenum*	四川省安宁镇	1958-8-26	李馨 78496
毛白前 *C. mooreanum*	江西省九江市庐山	1951-10-28	熊耀国 7049

子，用双面胶带纸粘于样品台上，用双面导电胶带将其粘贴在扫描电镜样品杯上，经离子溅射仪真空镀膜后在扫描电镜下观察并照相。形态描述术语参考文献[8]。

1.4 数据处理

用 SPSS19.0(Statistical Product and Service Solutions)统计软件对测量的种子大小数据进行处理，用平均值 ± 标准误表示，以代表种子的变异幅度；种子的大小指数以长度(平均值) × 宽度(平均值)计算[9]。

2 结果与分析

2.1 种子外观和颜色

9 种植物种子样品的形状正面观为扁卵状披针形，如牛皮消、峨眉牛皮消、毛白前、潮风草、大理白前、合掌消和鹅绒藤；刺瓜种子形状正面观为近球形；竹灵消种子形状正面观为卵状椭圆形。种子的颜色大多为黄褐色、褐色至黑褐色(表 2，图 1)。

2.2 种子大小

从测量 9 种植物种子大小和大小指数来看，最大的是刺瓜 11.32 mm × 7.74 mm，大小指数为 87.69，其次是牛皮消 7.70 mm × 3.21 mm，大小指数为 24.67，种子最小的是鹅绒藤 4.80 mm × 1.74 mm 大小指数为 8.35(表 2)。

2.3 表皮纹饰

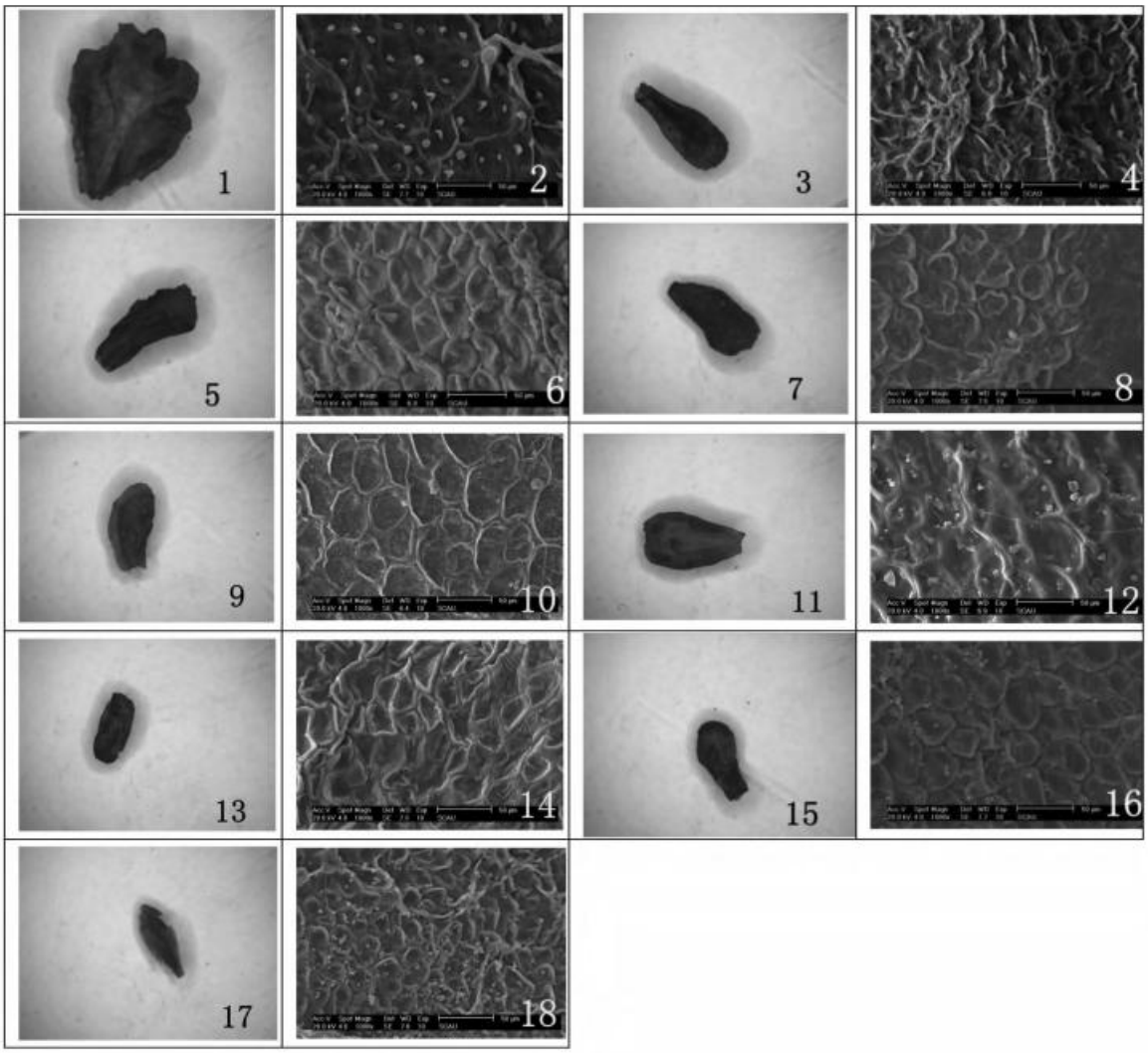
在扫描电镜下可见种子的表皮细胞有明显差异，利用种皮特征将成为 4 类：①种子表皮细胞边缘略隆起，表面凹陷呈网状且疏生乳头状突起，为颗粒

表 2 9 种鹅绒藤属植物种子的形态特征

Table 2 Seed characteristics of 9 species of *Cynanchum*

种名 Name of species	种子外观 Seed view		种子大小(长 × 宽)(mm) Seed size	大小指数 Size index	表面纹饰 Surface sculpture
	颜色 Colour	形状 Shape			
刺瓜 *Cynanchum corymbosum*	褐色	近球形	(11.32 ± 0.31) × (7.74 ± 0.17)	87.69	表皮细胞边缘明显隆起，表面疏生乳头状突起，凸起部分均匀，为颗粒状
牛皮消 *C. auriculatum*	黑褐色	扁卵状披针形	(7.70 ± 0.94) × (3.21 ± 0.47)	24.67	表皮细胞边缘略隆起，表面凹陷呈嚼烂状，网孔不规则
峨眉牛皮消 *C. giraldii*	黑褐色	扁卵状披针形	(7.44 ± 0.26) × (2.99 ± 0.29)	22.22	表皮细胞边缘略隆起，表面凹陷呈网状，网孔较规则
毛白前 *C. mooreanum*	黑褐色	扁卵状披针形	(6.52 ± 0.56) × (2.98 ± 0.21)	19.42	表皮细胞边缘略隆起，表面凹陷呈网状，网孔不规则
潮风草 *C. ascyrifolium*	褐色	扁卵状披针形	(5.49 ± 0.13) × (3.37 ± 0.20)	18.50	表皮细胞边缘略隆起，表面略凹陷呈网状且疏生乳头状突起，为颗粒状
竹灵消 *C. inamoenum*	褐色	卵状椭圆球形	(6.12 ± 0.25) × (3.03 ± 0.38)	18.50	表皮细胞边缘略隆起，表面凹陷呈网状且疏生乳头状突起，为颗粒状
大理白前 *C. forrestii*	褐色	扁卵状披针形	(4.32 ± 0.28) × (2.06 ± 0.28)	8.91	表皮细胞边缘略隆起，表面凹陷呈网状，网孔不规则
合掌消 *C. amplexicaule*	黑褐色	扁卵状披针形	(4.49 ± 0.37) × (1.94 ± 0.12)	8.70	表皮细胞边缘略隆起，表面凹陷呈网状且疏生乳头状突起，为颗粒状
鹅绒藤 *C. chinense*	黄褐色	扁卵状披针形	(4.80 ± 0.37) × (1.74 ± 0.50)	8.35	表皮细胞边缘明显隆起，表面密生乳头状突起，凸起部分均匀，近球形

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1、2: 刺瓜 *C. corymbosum* 3、4: 牛皮消 *C. auriculatum* 5、6: 峨眉牛皮消 *C. giraldii* 7、8: 毛白前 *C. mooreanum* 9、10: 潮风草 *C. ascyrifolium* 11、12: 竹灵消 *C. inamoenum* 13、14: 大理白前 *C. forrestii* 15、16: 合掌消 *C. amplexicaule* 17、18: 鹅绒藤 *C. chinense*

图 1　环境扫描电镜和数码体视镜下鹅绒藤属植物的种子表皮形态

Fig. 1　Seed epidermis of *Cynanchum* under stereoscope and ESEM

状,如合掌消(图 1-16) 、潮风草(图 1-10) 和竹灵消(图 1-12) ; ②表皮细胞边缘略隆起,表面凹陷呈嚼烂状,网孔不规则,如牛皮消(图 1-4) ; ③表皮细胞明显隆起,表面密生乳头状突起,凸起部分均匀,近球形或颗粒状,如鹅绒藤(图 1-18) 和刺瓜(图 1-2) ; ④表皮细胞边缘略隆起,表面凹陷呈网状,网孔较规则或不规则,如大理白前(图 1-14) 、峨眉牛皮消(图 1-6) 和毛白前(图 1-8) 。

3　讨论与小结

3.1　鹅绒藤属内的分类讨论

《中国植物志(第 63 卷) 》把鹅绒藤属分为 7 个组,本研究 9 种鹅绒藤属植物中鹅绒藤属于鹅绒藤组(*Cynanchum* Sect. *Cynanchum*) ,牛皮消和峨眉牛皮消属于牛皮消组(*C.* Sect. *Endotropis*) ,刺瓜属于青羊参组(*C.* Sect. *Cyathella*) ,合掌消、潮风草、大理白前、竹灵消和毛白前属于催吐白前组(*C.* Sect. *Vincetoxicum*) [2] 。种子微形态结果可以看出,在催吐白前组中,合掌消、潮风草、大理白前、竹灵消和毛白前的种子外观、种子大小指数及种皮纹饰差异不大,结果支持李玉玲等[6] 认为《中国植物志(第 63 卷) 》中对催吐白前组的分类是较为自然处理的观点。在牛皮消组,种子外观、种子大小和大小指数极为相似,但种皮纹饰特征明显不同,主要表现在于牛皮消表面凹陷呈嚼烂状,网孔不规则,而峨眉牛皮消表面凹陷呈网状,网孔较规则。鹅绒藤组与青羊参组种子大小指数和种皮纹饰差异较大。

3.2　种子分类学意义

种子微形态研究是植物系统学和野生药用植物鉴定中时值得考虑和重视的切入点之一,本实验种子形态研究支持《中国植物志(第 63 卷) 》对鹅绒藤组、牛皮消组、青羊参组和催吐白前组分类[2] ,种子微形态在萝藦科鹅绒藤属分组、分种中具有一定参考价值。

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致　谢: 实验取样与观察分别得到中国科学院华南植物园标本馆曾飞燕工程师和华南农业大学测试中心杨秉耀老师的指导与帮助,在此一并感谢。

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西南农业学报(双月刊)
Xinan Nongye Xuebao
2014年4月出版(公开发行)
2014年第27卷第2期

Southwest China Journal of
Agricultural Sciences(Bimonthly)
Vol.27 No.2 2014
Published on Apr. 28, 2014

本刊已加入或入编“中国知网”、“万方数据——数字化期刊群”和“中国核心期刊（遴选）数据库”，作者著作权使用费与本刊稿酬一次性给付，不再另行发放。作者如不同意将文章加入或入编，投稿时敬请说明。

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编辑出版：《西南农业学报》编辑部
编辑部地址：成都外东沙河大桥侧 (邮码：610066)
照　　排：四川省农科院情报所印刷厂
印　　刷：四川省农科院情报所印刷厂
国内订阅发行：四川省报刊发行局
国外订阅发行：中国出版对外贸易总公司 (北京782信箱)
中国标准刊号：CN51-1213/S　ISSN 1001-4829　CODEN XNXUEF

Sponsored by Sichuan,Yunnan,Guizhou,Guangxi, Tibet and Chongqing Academies of Agri.Sci.
Edited and Published by Editorial Department of Southwest China Journal of Agri.Sci.
Address:Shahe Daqiao,Chengdu,Sichuan 610066

Distributed by China Publish Foreign Trading Corporation(P.O.Box 782,Beijing,China)
E-mail: Jxuebao@sina.com
http://xnnyxb.periodicals.net.cn/default.html

2014
272

公开发行　　邮发代号：62-152　　国内订价：20.00元

中文核心期刊
中国科技核心期刊
中国农业核心期刊
RCCSE中国核心学术期刊
中国科学引文数据库库源期刊

ISSN 1001-4829
CN51-1213/S
CODEN XNXUEF

西南农业学报

SOUTHWEST CHINA JOURNAL OF AGRICULTURAL SCIENCES

2013
263
第26卷 第3期
Vol.26 No.3

《西南农业学报》编辑委员会

ISSN 1001-4829
06>
9 771001 482034

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2013年 第26卷 第3期

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期刊基本参数:CN51-1213/S·1985·b·A4·462·zh·P· ¥20.00·1500·91·2013-06

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文章编号: 1001 - 4829(2013) 03 - 1195 - 06

石灰岩特有植物圆叶乌桕土壤与叶片化学元素含量特征

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摘 要: 对石灰岩特有植物圆叶乌桕与同属的乌桕、山乌桕叶片及其生长地土壤化学元素进行测定，比较三者化学成分特征，分析了圆叶乌桕在广东石灰岩地区的环境适应特点。结果表明: 圆叶乌桕生长地的有机质、全 N 及全 P 含量均高于乌桕、山乌桕生长地，N 素和 P 素有效率较低，速效 N 仅占全 N 含量的 6.88 %，速效 P 仅占全 P 的 4.77 %，全 K 含量偏低，但圆叶乌桕生长地速效 K 含量(151.8 mg·kg^{-1}) 达到土壤速效 K 含量对应的适量 K(125 ~ 155 mg·kg^{-1}) 水平等级，属适量 K 型土壤，交换性 Ca 及交换性 Mg 含量均高于乌桕、山乌桕生长地，微量元素含量排序为 Mn > Pb > Cr > Zn > Ni > Fe > Cd > Cu，全 Pb、全 Zn 及全 Cu 含量均未超过国家规定的 3 级标准。圆叶乌桕叶片 Ca 含量(25.24 g·kg^{-1}) 、Cd 含量(0.45 mg·kg^{-1}) 高于乌桕、山乌桕。土壤中植物营养元素含量较低的元素如 K、Fe 和 Cu 在圆叶乌桕叶片中的生物吸收系数较高，而土壤中含量较高的元素如 N、Ca、P、Mg、Mn 和 Zn 在其叶片中生物吸收系数较低。在高温干旱的胁迫下，圆叶乌桕叶片会吸收一定量的 Ca，提高抗逆性。圆叶乌桕的化学元素特征反映了它对石灰岩生境的适应性较强。

关键词: 石灰岩; 圆叶乌桕; 乌桕; 山乌桕; 化学元素; 土壤; 叶片

中图分类号: Q946.91 **文献标识码:** A

Characteristics of Chemical-element Contents in Leaves and Growing Soils of *Triadica rotundifolia*, A Limestone Endemic Species

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Abstract: Chemical element contents within both soil and leaves of *Triadica rotundifolia*, *T. sebifera* and *T. cochinchinensis* were determined, and the environmental adaptive mechanisms of three *Triadica* species based on their chemical composition characteristics were also analyzed. The results showed that the contents of organic matter, total N and P were higher in the soil of *T. rotundifolia* than that in *T. sebifera* and *T. cochinchinensis* soil. The contents of available N and P were very low with the value of 6.88 % and 4.77 %, respectively, total K content in calcareous soil was also lower, while available K content (151.8 mg·kg^{-1}) in *T. rotundifolia* soil reached K-minimum soils (125 - 155 mg·kg^{-1}), so the limestone soil was classified as a K minimum soil. The contents of exchangeable Ca and Mg in *T. rotundifolia* soil were higher than that in *T. sebifera* and *T. cochinchinensis* soil. The microelement contents in limestone soil was in order of Mn > Pb > Cr > Zn > Ni > Fe > Cd > Cu. The contents of total Pb, Zn and Cu were not higher to the third State standards so that vegetation restoration was feasible in calcareous soil. the content of Ca and Cd in *T. rotundifolia* leaves were higher with the value of 25.24 and 0.45 mg·kg^{-1} than that in *T. sebifera* and *T. cochinchinensis* leaves. Those nutrient elements, which were lower in *T. rotundifolia* soil, had higher biological absorption coefficients in *T. rotundifolia* leaves, such as K, Fe and Cu, while those, which were higher in *T. rotundifolia* soil, had lower biological absorption coefficients in *T. rotundifolia* leaves, such as N, Ca, P, Mg, Mn and Zn. Under conditions of high temperature and drought, *T. rotundifolia* leaves absorbed a certain amount of Ca to enhance stress resistance. All of these indicated that *T. rotundifolia* could be well adapted to limestone habitats condition.

Key words: Limestone; *Triadica rotundifolia*; *Triadica sebifera*; *Triadica cochinchinensis*; Chemical elements; Soil; Leaf

收稿日期: 2012 - 07 - 20

基金项目: 广东省自然科学基金(8451064201001149) ; 国家高等学校本科特色专业建设点—林学(教高函 [201015] 号) ; 广东省林业科技创新专项资金(2009KJCX014) ; 广东省大学生创新实验计划(1056411009)

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圆叶乌桕 [*Triadica rotundifolia* (Hemsley) Esser] 是分布于中国南部和越南北部的石灰岩特有植物，多见于石灰岩缝隙和洞口等向阳处，是钙质土的

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表 1 材料来源

Table 1 Source of materials

种名 Species	树龄 Tree age	树高(m) Tree height	采集时间 Collecting time	采集地点 Areas of collecting samples
圆叶乌桕 *T. rotundifolia*	10	3.5	2009 年 6 月 9 日: 土壤、叶片	广东省广州市从化吕田镇石灰岩,山坡
乌桕 *T. sebifera*	40	10.0	2009 年 4 月 6 日: 土壤; 2009 年 10 月 26 日: 叶片	广东省广州市华南农业大学 7 号楼后,平地
山乌桕 *T. cochinchinensis*	7	5.0	2009 年 4 月 6 日: 土壤; 2009 年 10 月 26 日: 叶片	广东省广州市华南农业大学树木园,山沟

指示植物,具有喜钙、耐旱、生长快等特点。有关圆叶乌桕的报道集中于形态解剖结构的研究[1~2],而对圆叶乌桕的特有机制及其适应对策方面的研究相对较少。因植物生活习性的不同,植物从环境中吸收和积累化学元素的能力有较大差别,可用生物吸收系数来表示植物对化学元素的吸收和积累能力[3]。本文通过测定广东省自然生境中圆叶乌桕的土壤和叶片化学元素含量,并与同属非石灰岩特有植物乌桕[*T. sebifera* (Linn.) Small]和山乌桕(*T. cochinchinensis* Lour.)进行比较,探讨圆叶乌桕适应石灰岩生境的土壤环境特点,为石灰岩地区退化生态系统植被恢复中优良乡土造林树种的筛选与推广利用提供参考依据。

1 材料与方法

1.1 样品采集

研究材料包括野外生境中自然生长圆叶乌桕、乌桕、山乌桕的叶片及其根系周围土壤。材料具体信息见表 1。

在研究树种树基部 1 m 范围内选取东西南北 4 个方向采集混合土壤 1.0 kg,共采分析样 3 个。去除石砾与杂物,风干后过 20 和 100 目筛备用。在树冠的中上部,东西南北 4 个方向采集成熟叶片 0.5 kg,共采分析样 3 个。

1.2 测定方法

土壤 pH 值用玻璃电极法测定; 有机质用高温外热重铬酸钾氧化 - 容量法测定; 全 N 用开氏 - 蒸馏滴定法测定; 速效 N 用碱解扩散法测定; 全 P 用氢氧化钠熔融 - 钼锑抗比色法测定; 速效 P 用碳酸氢钠提取 - 钼锑抗比色法; 全 K 用氢氧化钠熔融 - 火焰原子吸收分光光度法测定; 速效 K、交换性 Ca、交换性 Mg 用乙酸铵提取 - 火焰原子吸收分光光度法测定; 有效 Cu、Zn、Fe、Mn 用 DTPA 提取 - 火焰原子吸收分光光度法测定; Cd、Pb、Cr、Ni(全量)用火焰原子吸收分光光度法测定。

植物样品全 N 用硫酸 - 双氧水消煮 - 蒸馏滴定法测定; 全 P 用硫酸 - 双氧水消煮 - 钼锑抗比色法测定; 全 K 用硫酸 - 双氧水消煮 - 火焰原子吸收分光光度法测定; Ca、Mg、Zn、Cu、Fe、Mn、Cd、Pd、Cr、Ni(全量)用干灰化 - 火焰原子吸收分光光度法测定。

1.3 数据处理

采用 Excel2003 进行实验数据的处理。生物吸收系数计算方法[3]如下。

生物吸收系数 = (生物体内某元素含量/土壤中该元素含量) ×100

2 结果与分析

2.1 土壤大量元素含量

从表 2 可以看出,圆叶乌桕生长的土壤类型为石灰土,pH 7.17,属于碱性土壤,在全国石灰(岩)土 pH 4.1 ~8.3[4] 的正常范围内; 乌桕、山乌桕的土壤类型属于赤红壤,乌桕 pH 6.17,属于酸性土壤,而山乌桕 pH 3.96,属于极强酸性土壤,两者同属正常范围(全国赤红壤 pH 4.0 ~8.0)[4]。

圆叶乌桕生长土壤有机质含量为 253.60 g·kg^{-1},约是乌桕有机质含量的 5.6 倍,而山乌桕有机质含量在三者中最少,只有 33.59 g·kg^{-1},表明圆叶乌桕土壤有机质含量较丰富。

土壤 N 素是植物必需的三大营养元素之一,在植物生长过程中占有重要地位,它是植物蛋白质的主要成分[5]。圆叶乌桕生长土壤全 N 含量为 13.39 g·kg^{-1},约是华南区的旱地全 N 含量平均值 1.39 g·kg^{-1}[6] 的 10 倍,约是全国石灰(岩)土全 N 含量平均值 1.82 g·kg^{-1}的 7.4 倍[7],表明该土壤中全 N 含量较为丰富; 乌桕和山乌桕生长的土壤全 N 含量分别为 2.15 和 1.07g·kg^{-1},约是全国赤红壤全 N 含量平均值 1.09 g·kg^{-1}[7] 的 1 ~2 倍,表明乌桕和山乌桕土壤中全 N 含量同比圆叶乌桕偏低。土壤中全 N 含量是衡量土壤 N 素供应状况的重要指标,而土壤速效 N 是土壤有效 N 的主要形式,它能反映土壤可供植物利用的有效 N 状况,可用 N 素有效率(速效 N 在全 N 含量中的百分比)衡量[8]。圆叶乌桕生长的土壤中 N 素有效率为 6.88 %,表明土壤中 N 素有效率较低,几乎约 93 % 的 N 素以有机态氮形式存在土壤中; 而乌桕 N 素有效率为 10.70 %,山乌桕 N 素有效率最高,为 11.33 %。

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表 2　土壤 pH 值及大量元素含量

Table 2　pH value and macroelement content in soil

种类 Species	pH	有机质 Organic matter (g·kg⁻¹)	全 N Total N (g·kg⁻¹)	全 P Total P (g·kg⁻¹)	全 K Total K (g·kg⁻¹)	交换性 Ca Exchangeable Ca (g·kg⁻¹)	交换性 Mg Exchangeable Mg (g·kg⁻¹)	速效 N Available N (mg·kg⁻¹)	速效 P Available P (mg·kg⁻¹)	速效 K Available K (mg·kg⁻¹)
圆叶乌桕 *T. rotundifolia*	7.17	253.60	13.39	1.25	2.71	10.11	0.45	921.40	26.23	151.80
乌桕 *T. sebifera*	6.17	45.37	2.15	0.41	9.47	1.38	0.08	230.20	4.87	91.76
山乌桕 *T. cochinchinensis*	3.96	33.59	1.07	0.18	24.89	0.43	0.03	120.80	3.29	49.43

我国土壤 P 的含量很低,全 P 含量在 0.13 ~ 1.53 g·kg⁻¹ 之间,变幅较大[9]。圆叶乌桕土壤全 P 含量为 1.25 g·kg⁻¹,高于全国土壤全 P 含量的平均水平,速效 P 为 26.23 mg·kg⁻¹,含量较高; 而乌桕和山乌桕土壤全 P 含量低于全国平均水平,速效 P 均在 5 mg·kg⁻¹ 以下,含量偏低。

圆叶乌桕生长土壤中全 K 含量为 2.71 g·kg⁻¹,与全国水平 4.15 ~ 20.75 g·kg⁻¹[9] 比较,属于偏低水平; 而乌桕全 K 含量为 9.47 g·kg⁻¹,属于中等水平; 山乌桕全 K 含量为 24.89 g·kg⁻¹,高于全国水平。速效 K 含量是决定 K 肥肥效的重要指标,根据许联芳等[10] 土壤速效 K 含量划分标准,圆叶乌桕生长土壤速效 K 含量为 151.80 mg·kg⁻¹,应为适量 K 型(速效 K 含量范围为 125 ~ 155 mg·kg⁻¹) 土壤,而乌桕速效 K 含量为 91.76 mg·kg⁻¹,为缺 K 型(速效 K 含量范围为 80 ~ 125 mg·kg⁻¹) 土壤,山乌桕速效 K 含量为 49.43 mg·kg⁻¹,为严重缺 K 型(速效 K 含量 < 80 mg·kg⁻¹) 土壤。

一般土壤中 Ca 的含量为 13.7 g·kg⁻¹,Mg 为 6.0 g·kg⁻¹[9]。土壤中 Ca、Mg 含量是与成土母岩密切相关的。圆叶乌桕生境成土母岩是石灰岩,其土壤的交换性 Ca、Mg 含量分别为 10.11、0.45 g·kg⁻¹,表明土壤中交换性 Ca 含量较高,而交换性 Mg 含量偏低; 而乌桕和山乌桕成土母岩主要为花岗岩,土壤是花岗岩发育的赤红壤,Ca、Mg 含量偏低,乌桕 Ca、Mg 含量分别为 1.38、0.08 g·kg⁻¹,山乌桕 Ca、Mg 含量分别为 0.43、0.03 g·kg⁻¹。

2.2　土壤微量元素含量

土壤微量元素是土壤的重要组成成分,是表征土壤质量的重要因子[11]。从表 3 可以看出,圆叶乌桕土壤中微量元素含量以 Mn 最高,为 87.36 mg·kg⁻¹,Cu 最低,仅 2.08 mg·kg⁻¹,二者相差 42 倍,微量元素含量高低排序为: Mn > Pb > Cr > Zn > Ni > Fe > Cd > Cu; 乌桕土壤中微量元素含量以 Fe 最高,为 78.05 mg·kg⁻¹,Cd 最低,仅 0.27 mg·kg⁻¹,二者相差 290 倍,微量元素含量高低排序为: Fe > Pb > Cr > Mn > Zn > Ni > Cu > Cd; 山乌桕土壤中微量元素含量以 Fe 最高,为 49.17 mg·kg⁻¹,Cd 最低,仅 0.08 mg·kg⁻¹,二者相差 592 倍,微量元素含量高低排序为: Fe > Pb > Mn > Cr > Ni > Zn > Cu > Cd。

将 3 种乌桕属植物土壤微量元素含量与广东省土壤背景值[4] 比较,可见 Pb、Cd 含量均高于广东省土壤背景值,其中圆叶乌桕的 Fe 含量低于平均值,乌桕接近最大值,山乌桕是平均值的 2 倍以上; 圆叶乌桕的 Ni 含量是平均值 2 倍以上,乌桕和山乌桕都低于平均值; 圆叶乌桕的 Pb 含量接近 2 倍平均值,Cd 含量接近最大值,而乌桕 Cd 含量是平均值 4 倍以上。根据不同土壤类型的元素背景值[4] 比较分析,圆叶乌桕土壤中 Fe、Cu 含量均低于石灰土该元素平均值 46.8、33 mg·kg⁻¹,Pb、Cd 含量均接近石灰土该元素平均值 38.7、1.115 mg·kg⁻¹ 的 2 倍,Mn、Zn、Ni、Cr 含量均低于石灰土该元素平均值 1011、139.2、49.1、108.6 mg·kg⁻¹; 乌桕和山乌桕土壤中 Fe、Pb、Cd 含量均高于赤红壤该元素平均值 33.1、35、0.048 mg·kg⁻¹,其中 Mn 含量均低于赤红壤该元素平均值 352 mg·kg⁻¹,Zn、Cu、Ni、Cr 含量均低于赤红壤该元素平均值 49.0、17.1、13.1、41.5 mg·kg⁻¹,而乌桕 Fe 含量约是赤红壤该元素平均值 33.1 mg·kg⁻¹ 的 2 倍,Cd 含量约是赤红壤该元素平均值 0.048 mg·kg⁻¹ 的 5 倍,山乌桕 Zn、Cu 含量均低于赤红壤该元素最小值 5.6、2.0 mg·kg⁻¹。

表 3　土壤微量元素含量

Table 3　Microelement content in soil　　mg·kg⁻¹

种类 Species	Fe	Mn	Zn	Cu	Ni	Pb	Cd	Cr
圆叶乌桕 *T. rotundifolia*	14.68	87.36	36.48	2.08	32.52	64.24	2.23	45.92
乌桕 *T. sebifera*	78.05	17.82	12.52	2.56	6.72	55.64	0.27	19.42
山乌桕 *T. cochinchinensis*	49.17	14.49	4.25	1.68	4.97	39.56	0.08	11.25

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表 4 叶片的化学元素含量(全量)

Table 4 Contents of chemical elements of plant leaves

种类 Species	大量元素(g·kg⁻¹) Macroelement					微量元素(mg·kg⁻¹) Microelement							
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Pb	Cd	Cr
圆叶乌桕 *T. rotundifolia*	32.46	0.84	3.54	25.24	2.54	148.90	89.37	12.95	15.84	0.63	1.25	0.45	0.43
乌桕 *T. sebifera*	40.31	1.38	2.71	12.83	2.24	221.40	118.40	19.96	10.25	1.00	2.73	0.24	0.69
山乌桕 *T. cochinchinensis*	41.83	1.14	11.61	13.33	2.04	212.60	2155	29.17	31.28	7.96	3.86	0.42	1.69

2.3 植物生长地土壤的生物吸收特征

2.3.1 叶片化学元素含量 叶片是植物代谢活动最活跃的器官,其化学元素含量可反映植物对元素的吸收和累积的特点[12~15]。本研究中 3 种植物叶片化学元素含量测定结果(表 4)。

从表 4 可以看出,3 种植物叶片中不同元素含量的差异很大。圆叶乌桕叶片内大量元素含量以 N 最高,为 32.46 g·kg⁻¹,P 最低,仅 0.84 g·kg⁻¹,二者相差 39 倍;微量元素则以 Fe 最高,达 148.90 mg·kg⁻¹,Cr 最低,仅 0.43 mg·kg⁻¹,两者相差竟达 347 倍。乌桕叶片内大量元素含量以 N 最高,为 40.31 g·kg⁻¹,P 最低,仅 1.38 g·kg⁻¹,二者相差 29 倍;微量元素则以 Fe 最高,达 221.40 mg·kg⁻¹,Cd 最低,仅 0.24 mg·kg⁻¹,两者相差竟达 934 倍。山乌桕叶片内大量元素含量以 N 最高,为 41.83 g·kg⁻¹,P 最低,仅 1.14 g·kg⁻¹,二者相差 37 倍;微量元素则以 Mn 最高,达 2155 mg·kg⁻¹,Cd 最低,仅 0.42 mg·kg⁻¹,两者相差竟达 5168 倍。同一元素含量在不同植物体内的变化范围很大,高低值一般相差几倍到十几倍,甚至几十倍。如山乌桕 Mn 含量最高,为 2155 mg·kg⁻¹,圆叶乌桕含量最低,仅 89.37 mg·kg⁻¹,二者相差 24 倍多,这与植物对土壤中各种化学元素的吸收和富集能力有密切关系。不同植物中大量营养元素和微量元素的平均含量均有一定的差异,大量营养元素平均含量以乌桕最低为 11.89 g·kg⁻¹,以山乌桕最高为 13.99 g·kg⁻¹;微量元素平均含量以圆叶乌桕最低为 33.73 mg·kg⁻¹,山乌桕最高为 305.25 mg·kg⁻¹。

2.3.2 叶片元素含量比值 3 种植物叶片中大量元素的质量分数比值见表 5。可见 N/P 在三者之间差异不显著;不同基质生境中 Ca/Mg、Ca/K、K/Mg 比值差异较大;生活在碱性石灰质土壤上的植物(圆叶乌桕)叶片 Ca/Mg、Ca/K 显著大于生活在酸性非石灰质土壤的植物(乌桕和山乌桕),而 K/Mg 圆叶乌桕与乌桕显著低于山乌桕,2 种生活在酸性土壤的植物间 Ca/Mg 比值没有显著差异。

2.3.3 生物吸收系数比较 生物吸收系数可以说明乌桕属植物对土壤化学元素的积聚程度。从表 6 可以看出,3 种植物叶片对土壤化学元素的积累能力可以分为 4 个层次。第 1 层次是吸收系数达 1000 以上的元素,表明植物叶片对该元素的积累能力最强;圆叶乌桕对 Fe 积累能力最强,吸收系数达 1014.31;乌桕对 Mg 积累能力最强,吸收系数达 2674.4,其次是 N,吸收系数是 1873.14;山乌桕对 Mn 的积累能力最强,吸收系数达 14872.33,其次是 Mg、N、Ca、Cu,吸收系数分别是 6883.42、3924.02、3104.61、1861.90。第 2 层次是吸收系数在 200~1000 之间元素;圆叶乌桕是 Cu、Mg、Ca、N;乌桕是 Ca、Mn、Cu、P、Fe;山乌桕是 Zn、P、Cd、Fe。第 3 层次是吸收系数在 10~200 之间的元素;圆叶乌桕是 K、

表 5 叶片元素含量比值

Table 5 Ratios of element contents in the leaves

种类 Species	N/P	Ca/Mg	Ca/K	K/Mg
圆叶乌桕 *T. rotundifolia*	38.83	9.94	7.12	1.40
乌桕 *T. sebifera*	29.25	5.74	4.74	1.21
山乌桕 *T. cochinchinensis*	36.66	6.52	1.15	5.68

表 6 叶片在土壤上的生物吸收系数

Table 6 Bio-absorption coefficient of plants leaves in soils

种类 Species	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	Ni	Pb	Cd	Cr
圆叶乌桕 *T. rotundifolia*	242.42	66.83	130.74	249.75	559.62	1014.31	102.30	35.50	761.54	1.95	1.94	20.34	0.93
乌桕 *T. sebifera*	1873.14	333.66	28.60	930.46	2674.40	283.66	664.42	159.42	400.39	14.85	4.91	88.10	3.57
山乌桕 *T. cochinchinensis*	3924.02	637.43	46.65	3104.61	6883.42	432.38	14872.33	686.35	1861.90	160.18	9.76	502.41	15.06

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Mn、P、Zn、Cd; 乌桕是 Zn、Cd、K、Ni; 山乌桕是 Ni、K、Cr。第 4 层次是吸收系数在 10 以下,表明植物叶片对该元素的积累能力最弱; 圆叶乌桕是 Ni、Pb 和 Cr; 乌桕是 Pb 和 Cr; 山乌桕是 Pb。

3　讨　论

3.1　圆叶乌桕土壤有机质与石灰岩生境适应关联

有机质是土壤固相部分的重要组成成分,含有植物生长所需要的各种营养元素[16]。它是表征土壤质量的重要因子,尤其在石漠化地区,土壤有机质含量直接影响石漠化土壤质量的高低,并对石漠化地区生态演化有直接的影响[17]。土壤有机质来源于动植物及微生物残体,其中高等植物为主要来源[9]。本研究中生长在石灰岩地区的圆叶乌桕土壤的有机质含量显著高于乌桕和山乌桕,样株圆叶乌桕的伴生植物包括铁灵花(*Celtis philippensis* var. *wightii*)、黄牛木(*Cratoxylum cochinchinense*)、竹叶花椒(*Zanthoxylum armatum*)、云实(*Caesalpinia decapetala*)、八角枫(*Alangium chinense*)和苎麻(*Boehmeria nivea*)等,伴生植物枯落物的积聚对土壤有机质的积累有一定影响。

3.2　圆叶乌桕土壤大量元素与石灰岩生境适应关联

石灰土中 N 素有效率低,仅占全 N 含量的 6.88%; 圆叶乌桕生长地全 P 的含量比乌桕和山乌桕生长地高,但 P 素有效率仍低,仅为全 P 含量的 4.77%,这与前人研究[18]显示动植物残体中的全 P 返回土壤后易被石灰土中的 Ca 固定的结果一致。有研究表明圆叶乌桕本身具有较高的光合能力[19],其群落凋落物 N 含量最高且降解快[20],本研究中交换性 Ca 和交换性 Mg 含量以圆叶乌桕生长地最高,且有机质、全 N、速效 N、全 P 和速效 P 含量均显著高于乌桕和山乌桕生长地,可见,圆叶乌桕对于喀斯特区域退化生态系统的土壤养分恢复具有较好的促进作用。

3.3　圆叶乌桕土壤微量元素与石灰岩生境适应关联

3 种土壤中最高微量元素含量与最低含量的比较结果显示石灰岩基质的圆叶乌桕土壤中多种微量元素含量较丰富,差距较小,而乌桕、山乌桕差距较大。赤红壤中的乌桕、山乌桕微量元素含量均以 Fe 的含量最高,高低排序基本一致,但两者与石灰岩生境中的圆叶乌桕排序明显不同,圆叶乌桕土壤中 Mn 的含量远高于 Fe。有机质的增加能够促进 Mn 向有效态转化[21],圆叶乌桕有机质含量相对较高,对其土壤 Mn 沉淀富集具有一定影响。有研究表明土壤中锰元素对植物光合作用、新陈代谢、促进生长、增强抗病性及其增加产量均有明显的作用[22],说明圆叶乌桕土壤中 Mn 对其适应长期高温、干旱的石灰岩生境起到重要作用。

根据我国土壤环境质量标准[23]规定,3 种植物土壤的 Zn、Cu、Ni、Cr 含量均未超过一级水平,Pb 含量均超过标准一级,未超过二级和三级的规定; 圆叶乌桕和乌桕土壤的 Cd 含量都超过标准一级,而且圆叶乌桕的 Cd 含量是三级标准的 2.0 ~ 2.3 倍。可见,在 3 种植物中,山乌桕生长的土壤环境质量最高,乌桕次之,圆叶乌桕的生境相对较差,但圆叶乌桕在广东省连州、从化等石灰岩地区的种群生长状况良好,显示其具有较强的抗逆性和环境适应性。

3.4　圆叶乌桕叶片化学元素与石灰岩生境适应关联

与单一的元素浓度相比,植物组织元素浓度比值更能真实指示环境的变化[24]。植物体内 N/P 值能用来衡量植物生长过程中受哪个元素的限制,当 N/P > 16 时,暗示植物生长受 P 限制,当 N/P 小于 14 时,表明植物生长受 N 限制,当 N/P 比值介于 14 ~ 16 时,表明 N 与 P 单独或者共同影响植物的生长[25],以此推断本研究的 3 种植物都属于 P 制约型植物。

叶片是植物进化过程中对环境变化较敏感且可塑性较大的器官,其结构特征能体现环境因子的影响或植物对环境的适应[25],钙与果胶酸形成果胶酸钙,被固定于相邻两个细胞壁之间,从而维持细胞壁结构和功能的稳定性,提高植物的抗逆性[26]。本研究中 3 种植物 Ca/Mg、Ca/K、K/Mg 比值存在显著差异性,圆叶乌桕叶片的 Ca 含量高于定居在酸性土壤的乌桕和山乌桕,这说明圆叶乌桕叶片因为环境因子的影响能做出适应性变化,即在高温干旱的胁迫下,叶片会吸收一定量的 Ca。

在 3 种植物中,圆叶乌桕土壤中植物营养元素含量较低的元素如 K、Fe 和 Cu 在其叶片中生物吸收系数高,而土壤中含量较高的元素如 N、Ca、P、Mg、Mn 和 Zn 在其叶片中生物吸收系数低。另外,本研究中全部所测重金属中,圆叶乌桕土壤中含量较高而在其叶片中生物吸收系数低。这表明石灰土一方面受石灰岩母岩所制约,另一方面受植被的生物富集作用影响[27]。圆叶乌桕虽然有选择吸收能力,但在石灰土上则又被迫接受土壤中某些过量的重金属元素。

高芳等[26]以花生为例,研究表明镉胁迫降低了花生叶片光合速率,施钙可增加叶片叶绿素含量和提高叶片光合速率,缓解镉胁迫造成的抑制作用。

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本研究中圆叶乌桕 Cd 的生物吸收系数低于乌桕和山乌桕，与其生长在 Cd 含量超标的石灰土中有密切的关系；尽管如此，圆叶乌桕单位重量的叶片所富集 Cd 的含量较乌桕、山乌桕多，达 0.45 mg·kg^{-1}，高于乌桕 0.24 mg·kg^{-1}、山乌桕 0.42 mg·kg^{-1}。但是这并不影响圆叶乌桕的生长，与其叶片富集大量的 Ca 有关，即通过叶片吸收和积累一定量的 Ca 来缓解镉对其造成的影响，提高叶片光合速率。圆叶乌桕叶片的这一特征，初步反映了圆叶乌桕在 Cd 含量严重超标的石灰岩地区具有较强的环境适应性。

上述研究表明，圆叶乌桕土壤和叶片具有典型的化学元素特征：土壤 Mn 含量高，土壤环境质量低，叶片的 Ca 含量高，K、Fe 和 Cu 的生物吸收系数高，富集 Cd 的能力强，这些特征显示圆叶乌桕在高温干旱的石灰岩地区具有较强的养分循环能力、抗逆能力和富集镉能力，适宜在石灰岩地区生长且能有效的改善土壤质量。

致　谢：衷心感谢华南农业大学资源环境学院朱夕珍老师和林学院 2007 级袁锡强、何敏宜、何敏贤同学，以及郑明轩老师对实验取样给予的大力支持。

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（责任编辑　李山云）

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西南农业学报(双月刊)
Xinan Nongye Xuebao
2013年6月出版(公开发行)
2013年第26卷第3期

Southwest China Journal of
Agricultural Sciences(Bimonthly)
Vol.26 No.3 2013
Published on June 28, 2013

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主　　办：四川、云南、贵州、广西、西藏及重庆省（区、市)农科院
编辑出版：《西南农业学报》编辑部
编辑部地址：成都外东沙河大桥侧 (邮码：610066)
照　　排：四川省农科院情报所印刷厂
印　　刷：四川省农科院情报所印刷厂
国内订阅发行：四川省报刊发行局
国外订阅发行：中国出版对外贸易总公司(北京782信箱)
中国标准刊号：CN51-1213/S　ISSN 1001-4829　CODEN XNXUEF

Sponsored by Sichuan,Yunnan,Guizhou,Guangxi, Tibet and Chongqing Academies of Agri.Sci.
Edited and Published by Editorial Department of Southwest China Journal of Agri.Sci.
Address:Shahe Daqiao,Chengdu,Sichuan 610066

Distributed by China Publish Foreign Trading Corporation(P.O.Box 782,Beijing,China)
E-mail: Jxuebao@sina.com
http://xnnyxb.periodicals.net.cn/default.html

2013
263
公开发行　　邮发代号：62-152　　国内订价：20.00元

中文核心期刊
中国科技核心期刊
中国农业核心期刊
RCCSE中国核心学术期刊
中国科学引文数据库库源期刊

ISSN 1001-4829
CN51-1213/S
CODEN XNXUEF

西南农业学报

SOUTHWEST CHINA JOURNAL OF AGRICULTURAL SCIENCES

2013
262
第26卷 第2期
Vol.26 No.2

《西南农业学报》编辑委员会

ISSN 1001-4829

西南农业学报
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期刊基本参数:CN51-1213/S·1985·b·A4·450·zh·P·¥20.00·1500·91·2013-04

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文章编号: 1001 - 4829(2013) 02 - 0742 - 08

中国鹅绒藤属(萝藦科) 植物叶表皮微形态扫描电镜研究

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摘 要: 在环境扫描电镜下对 29 种及 1 亚种分布于中国的鹅绒藤属(*Cynanchum*) 植物叶表皮进行观测。结果表明,本研究中鹅绒藤属植物叶表皮特征存在相似之处,主要表现在表皮细胞轮廓为多边形或不规则形; 多数种类上表皮气孔不明显,下表皮除了狭叶白前(*C. stenophyllum*) 外其他种均有气孔分布; 上、下表皮均具有较厚角质层,多数种类叶上表皮有表皮毛而下表皮没有。叶表皮形态学结果支持 *Flora of China*(Vol. 16) 中将木里白前(*C. muliense*) 、卵叶白前(*C. steppicolum*) 归并到大理白前(*C. forrestii*) 的观点; 不支持将羊角子草(*C. cathayense*) 归并到戟叶鹅绒藤(*C. acutum* subsp. *sibiricum*) 、老瓜头(*C. komarovii*) 归并到华北白前(*C. mongolicum*) 以及翅果杯冠藤(*C. alatum*) 是美翼杯冠藤(*C. callialatum*) 错误鉴定的观点。

关键词: 萝藦科; 鹅绒藤属; 叶表皮; 环境扫描电镜

中图分类号: S682. 36 文献标识码: A

Studies on Micromorphology of Leaf Epidermis of *Cynanchum*(Asclepiadaceae) from China under Environmental Scanning Electron Microscope

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Abstract: The micromorphology of leaf epidermis of 29 species and 1 subspecies of *Cynanchum* from China were examined by environmental scanning electron microscope (ESEM) . The results showed that the leaf epidermis' features of *Cynanchum* were similar. The cell contour of their leaf epidermis cells was usually polygonal or irregular. The abaxial epidermis of almost all but *C. stenophyllum* had stomata, and most of the shapes of the stomata were not sunken. Many species of *Cynanchum* had thick cuticular membrane on leaves. A few species were distinctively different from others in their size of stomata and ornamentation of cuticular membrane. In this paper, it is supported that *C. muliense* and *C. steppicolum* were treated as synonyms of *C. forrestii* in *Flora of China*(Vol. 16) , and it is not supported that *C. alatum* was treated as a misidentification of *C. callialatum*, *C. cathayense* as a synonym of *C. acutum* subsp. *sibiricum*, and *C. komarovii* as a synonym of *C. mongolicum*.

Key words: Asclepiadaceae; *Cynanchum*; Leaf epidermis; Environmental scanning electron microscope

鹅绒藤属(*Cynanchum* L.) ,又名白前属、牛皮消属,是萝藦科(Asclepiadaceae) 中种类最多的属,也是该科植物分类的难点之一。鹅绒藤属植物全球约 200 种,非洲、美洲、欧洲和亚洲均有分布; 中国约有 57 种,在全国大部分省区都有分布,主要分布在西南各省区[1~2]。鹅绒藤属属下类群的分类和归并问题一直是萝藦科分类争论的焦点之一,至今仍存在较大争议[3~6],以致对该属植物分类、资源保护与利用造成混乱和困难。叶表皮微形态特征对植物疑难类群的分类具有一定参考价值,为了探讨叶表皮微形态在鹅绒藤属植物中的分类学意义,笔者已对原产于中国的 13 种及 1 变种鹅绒藤属植物的叶表皮进行扫描电镜观察[7],本文在此基础上继续对原产于中国的 29 种及 1 亚种鹅绒藤属植物的叶表皮进行扫描电镜观察,研究其种间叶表皮微形态特征,以期为该属植物分类提供更多实验学科的证据。

收稿日期: 2012 - 08 - 20

基金项目: 国家自然科学基金项目(31000095) ; 广东省大学生创新实验项目(1056411009) ; 国家高等学校本科特色专业建设点——林学(教高函[201015] 号)

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1 材料与方法

1.1 供试材料

本研究的全部试验材料均取自中国科学院华南

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表 1　鹅绒藤属植物叶表皮的试验材料及凭证标本

Table 1　Materials and voucher specimens of leaf epidermis of *Cynanchum*

种名 Name of species	采集地 Locality	采集时间 Collection time	凭证标本 Voucher specimens
1. 戟叶鹅绒藤 *C. acutum* subsp. *sibiricum*	新疆	1972-8-1	蒋英和李秉滔 1272
2. 翅果杯冠藤 *C. alatum*	镇越县,回都(今西双版纳勐腊县)	1936-10-1	王启无 80298
3. 合掌消 *C. amplexicaule*	江西九江庐山归宗寺	1955-6-17	李丙贵 295
4. 潮风草 *C. acuminatifolium*	辽东临江三岔子(今辽宁)	1950-6-12	采集人不详 782
5. 白首乌 *C . bungei*	北平西山(今北京西山)	1930-6-30	刘慎谔 1535
6. 美翼杯冠藤 *C. callialatum*	云南	1933-11-2	采集人不详 12356
7. 羊角子草 *C. cathayense*	新疆吐鲁番红星农场第一场	1958-4-4	李安仁 5543
8. 鹅绒藤 *C. chinense*	锦州省彰武县附近(今辽宁锦州)	1941-8-22	采集人不详 21277
9. 豹药藤 *C. decipiens*	湖南郴州莽山猛坑石	1964-8-5	黄茂先 111845
10. 台湾杯冠藤 *C. formosanum*	台湾基隆	1989-10-2	D. E. Boufford et al. 25248
11. 大理白前 *C. forrestii*	重庆南川金佛山	1957-5-29	李国风 61596
12. 峨眉牛皮消 *C. giraldii*	陕西宁陕	1959	曲式曾 14474
13. 华北白前 *C. mongolicum*	河北	1972-1-18	李建藩 10709
14. 竹灵消 *C. inamoenum*	四川黑水芦花镇附近上游河岸上	1957-7-20	采集人不详 73700
15. 海南杯冠藤 *C. insulanum*	海南三亚崖城镇、黄流附近	1933-9-9	梁向日 62990
16. 老瓜头 *C. komarovii*	宁夏同心城西、中宁滩地	1952-8-15	张珍万 310
17. 广西杯冠藤 *C. kwangsiense*	广西	1928-5-27	秦仁昌 5412
18. 木里白前 *C. muliense*	云南中甸	1937-8-1	俞德浚 12562
19. 青羊参 *C. otophyllum*	四川峨眉山	1952-8-22	蒋兴麟和张秀实 21045
20. 西藏牛皮消 *C. saccatum*	德钦设治局(今云南迪庆)	1935-9-1	王启无 70077
21. 狭叶白前 *C. stenophyllum*	贵州	1962-10-1	蒋英 4494
22. 卵叶白前 *C. steppicolum*	检磨市刷马公路(今四川马尔康)	1957-7-7	张泽荣和周洪福 22660
23. 镇江白前 *C. sublanceolatum*	日本本州	1986-7-26	J. Iketsu, Y. Endo718
24. 四川鹅绒藤 *C. szechuanense*	云南	1962-4-9	俞德浚 7222
25. 台湾鹅绒藤 *C. taiwanianum*	台湾新白杨-洛韶	1983-9-9	H. Ohashi et al. 7090
26. 地梢瓜 *C. thesioides*	河北遵化东陵	1930-6-1	蔡希陶 50079
27. 变色白前 *C. versicolor*	兰县虎山(今江苏)	1976-7-26	刘昉熏 10045
28. 催吐白前 *C. vincetoxicum*	台湾	1936-7-20	采集人不详 21055
29. 昆明杯冠藤 *C. wallichii*	云南徽江东浦(今云南昆明)	1972-4-5	张宏达 460
30. 隔山消 *C. wilfordii*	四川奉节双虎乡(今重庆奉节)	1958-8-7	方明渊 24996

植物园标本馆(IBSC) 和华南农业大学林学院标本馆(CANT) 馆藏的腊叶标本,材料具体信息见表 1。

1.2　试验方法

用毛笔蘸取 φ 为 95 % 的乙醇轻刷叶表面,自然干燥后,切取面积约 1 cm × 0.5 cm 的样品,将上、下表皮分别粘在样品台上,真空喷金镀膜后在 FEI-XL30 环境扫描电子显微镜下观察、测量、拍照。气孔器的大小直接在电镜下随机选取 3 个进行测量内径及外径,取其平均值。叶表皮所用名词术语参考 Dilcher[8] 和 Wilkinson[9]。

2　结果与分析

2.1　表皮细胞的特征

本实验观察 29 种及 1 亚种鹅绒藤属植物中,可以清晰看到上表皮细胞轮廓的有戟叶鹅绒藤(图版 I: 1a) 、翅果杯冠藤(图版 I: 2a) 、白首乌(图版 I: 5a) 、鹅绒藤(图版 I: 8a) 、台湾杯冠藤(图版 I: 10a) 、峨眉牛皮消(图版 I: 12a) 、竹灵消(图版 I: 14a) 、海南杯冠藤(图版 I: 15a) 、老瓜头(图版 I: 16a) 、青羊参(图版 I: 19a) 、卵叶白前(图版 I: 22a) 、四川鹅绒

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表 2 环境扫描电镜下鹅绒藤属植物叶表皮特征

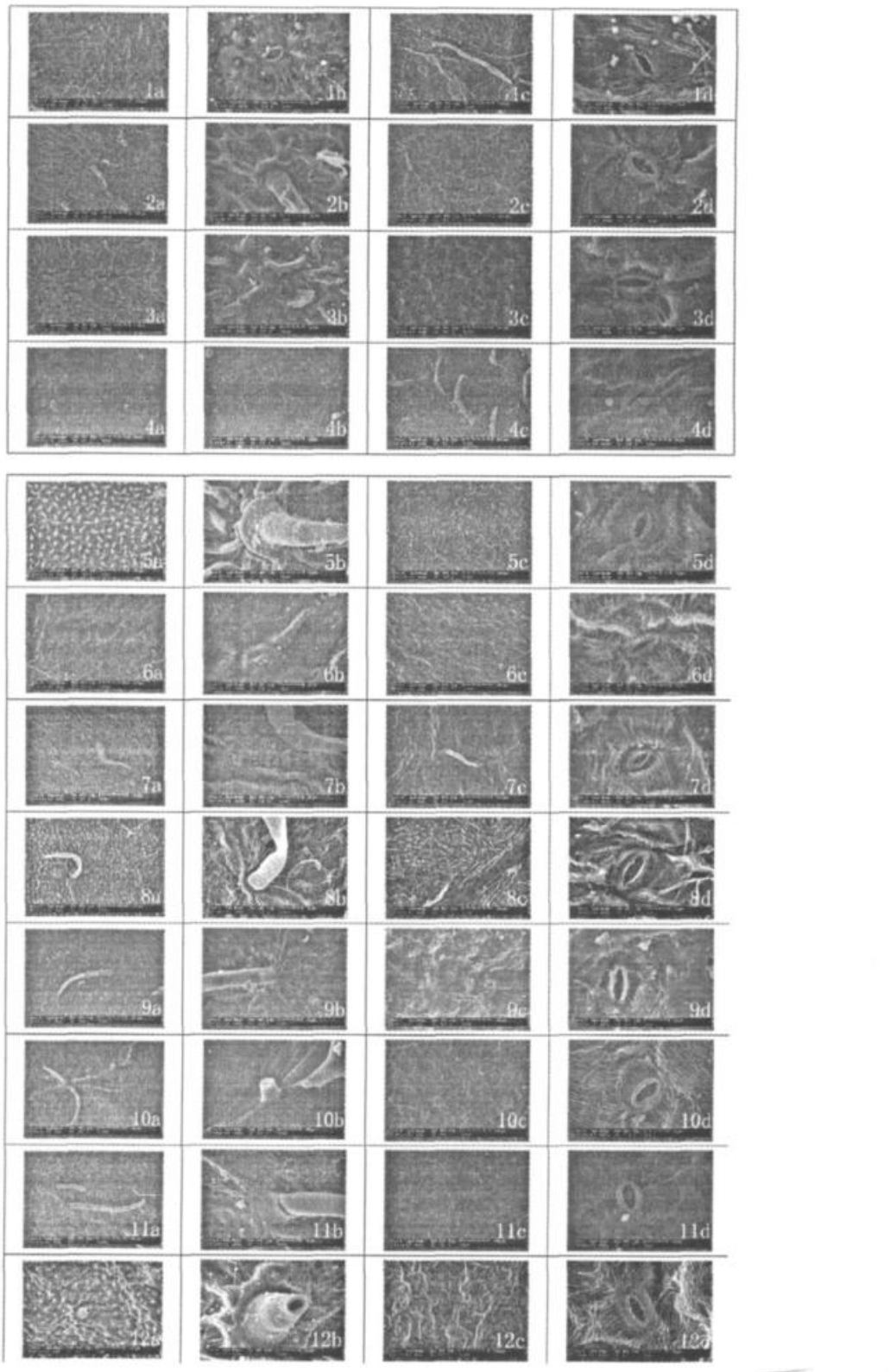
Table 2 Leaf epidermal characters of *Cynanchum* under ESEM

种名 Species	上表皮 Upper epidermis						下表皮 Lower epidermis					
	细胞轮廓	气孔形状	气孔外拱盖内缘	气孔大小(长×宽)(μm) 内径	外径	角质层	细胞轮廓	气孔形状	气孔外拱盖内缘	气孔大小(长×宽)(μm) 内径	外径	角质层
1. 戟叶鹅绒藤	清晰,多边形	非内陷,椭圆形	浅波状	14.4×6.0	18.1×9.0	具脊状隆起及辐射状条纹	清晰,多边形	非内陷,椭圆形	浅波状	11.8×4.5	15.2×7.0	具脊状隆起及辐射状条纹
2. 翅果杯冠藤	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	9.4×2.9	13.2×7.2	具脊状隆起
3. 合掌消	不清晰,不规则形	–	–			具脊状隆起	不清晰,不规则形	非内陷,椭圆形	浅波状	13.8×5.6	16.8×8.8	具脊状隆起
4. 潮风草	不清晰,不规则形	–	–	–	–	具脊状隆起	不清晰,不规则形	非内陷,椭圆形	近平滑	8.5×2.9	12.1×6.9	具脊状隆起及辐射状条纹
5. 白首乌	清晰,多边形	–	–			具乳突及辐射状条纹	清晰,多边形	非内陷,椭圆形	近平滑	11.0×2.8	14.7×6.8	具脊状隆起及辐射状条纹
6. 美翼杯冠藤	不清晰,不规则形	–	–	–	–	具条纹及小丘状隆起	清晰,多边形	浅内陷,椭圆形	近平滑	7.0×2.6	9.6×4.6	具脊状隆起
7. 羊角子草	不清晰,不规则形	浅内陷,椭圆形	近平滑	9.5×2.9	10.5×4.0	具脊状隆起	不清晰,不规则形	浅内陷,椭圆形	近平滑	9.6×3.6	11.9×5.8	具脊状隆起及辐射状条纹
8. 鹅绒藤	清晰,多边形	–	–	–	–	具乳突及辐射条纹	清晰,多边形	非内陷,椭圆形	浅波状	16.9×6.0	21.6×9.4	具脊状隆起及辐射状条纹
9. 豹药藤	不清晰,不规则形	–	–	–	–	具脊状隆起及辐射状条纹	不清晰,不规则形	浅内陷,椭圆形	近平滑	12.0×4.0	15.0×6.9	具脊状隆起及辐射状条纹
10. 台湾杯冠藤	清晰,多边形	–	–	–	–	具脊状隆起及辐射状条纹	清晰,多边形	非内陷,椭圆形	近平滑	13.4×7.5	17.5×12.1	具脊状隆起及辐射状条纹
11. 大理白前	不清晰,不规则形	–	–	–	–	具条纹及小丘状隆起	不清晰,不规则形	非内陷,椭圆形	近平滑	10.0×3.8	14.7×7.1	具脊状隆起及辐射状条纹
12. 峨眉牛皮消	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	波状	11.6×4.5	15.1×7.4	具脊状隆起及辐射状条纹
13. 华北白前	不清晰,不规则形	–	–	–	–	具脊状隆起	不清晰,不规则形	浅内陷,椭圆形	近平滑	12.9×4.5	16.4×8.1	具脊状隆起
14. 竹灵消	清晰,多边形	–	–	–	–	具条纹及小丘状隆起	清晰,多边形	非内陷,椭圆形	近平滑	11.7×3.8	17.3×8.9	具条纹及小丘状隆起
15. 海南杯冠藤	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	11.7×3.8	17.3×8.9	具脊状隆起及辐射状条纹
16. 老瓜头	清晰,多边形	非内陷,椭圆形	浅波状	11×3.1	13.4×5.1	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	浅波状	8.6×2.2	11.6×2.8	具脊状隆起
17. 广西杯冠藤	不清晰,不规则形	–	–	–	–	表面光滑	不清晰,不规则形	非内陷,椭圆形	浅波状	13.4×5.9	16.5×8.9	表面光滑
18. 木里白前	不清晰,不规则形	–	–	–	–	具条纹及小丘状隆起	不清晰,不规则形	非内陷,椭圆形	近平滑	7.6×2.3	10.9×4.6	具脊状隆起及辐射状条纹
19. 青羊参	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	9.1×2.7	12×4.2	具脊状隆起及辐射状条纹
20. 西藏牛皮消	不清晰,不规则形	–	–	–	–	具脊状隆起及辐射状条纹	清晰,多边形	浅内陷,椭圆形	近平滑	8.6×3.2	10.5×5.1	具脊状隆起及辐射状条纹
21. 狭叶白前	不清晰,不规则形	内陷,椭圆形	近平滑	9.9×2.5	13.6×4.3	具脊状隆起	不清晰,不规则形	–	–	–	–	具脊状隆起
22. 卵叶白前	清晰,多边形	–	–	–	–	具条纹及小丘状隆起	清晰,多边形	非内陷,椭圆形	浅波状	10.7×4.0	13.7×7.5	具脊状隆起及辐射状条纹
23. 镇江白前	不清晰,不规则形	–	–	–	–	具脊状隆起及辐射状条纹	清晰,多边形	非内陷,椭圆形	近平滑	13.9×5.0	17.2×7.5	具脊状隆起及辐射状条纹
24. 四川鹅绒藤	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	7.6×2.3	10.6×4.7	具脊状隆起及辐射状条纹
25. 台湾鹅绒藤	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	13.4×7.5	17.5×12.1	具脊状隆起及辐射状条纹
26. 地梢瓜	不清晰,不规则形	–	–	–	–	具脊状隆起	不清晰,不规则形	非内陷,椭圆形	近平滑	9.6×2.5	8.3×4.8	具脊状隆起及辐射状条纹
27. 变色白前	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	浅内陷,椭圆形	浅波状	10.5×4.0	13.9×6.7	具脊状隆起
28. 催吐白前	清晰,多边形	–	–	–	–	具条纹及小丘状隆起	清晰,多边形	内陷,椭圆形	近平滑	8.3×1.9	11.6×5.1	具脊状隆起及辐射状条纹
29. 昆明杯冠藤	清晰,多边形	–	–	–	–	具网状隆起及乳突	清晰,多边形	非内陷,椭圆形	近平滑	8.0×3.0	10.7×5.2	具条纹及小丘状隆起
30. 隔山消	不清晰,不规则形	非内陷,椭圆形	近平滑	11.4×4.9	16.5×7.6	具脊状隆起及辐射状条纹	不清晰,不规则形	非内陷,椭圆形	近平滑	13.6×6.2	18.5×10.6	具脊状隆起及辐射状条纹

注 “–”表示不存在或暂未观测到。

Note: '–' means there is no, or not yet observed.

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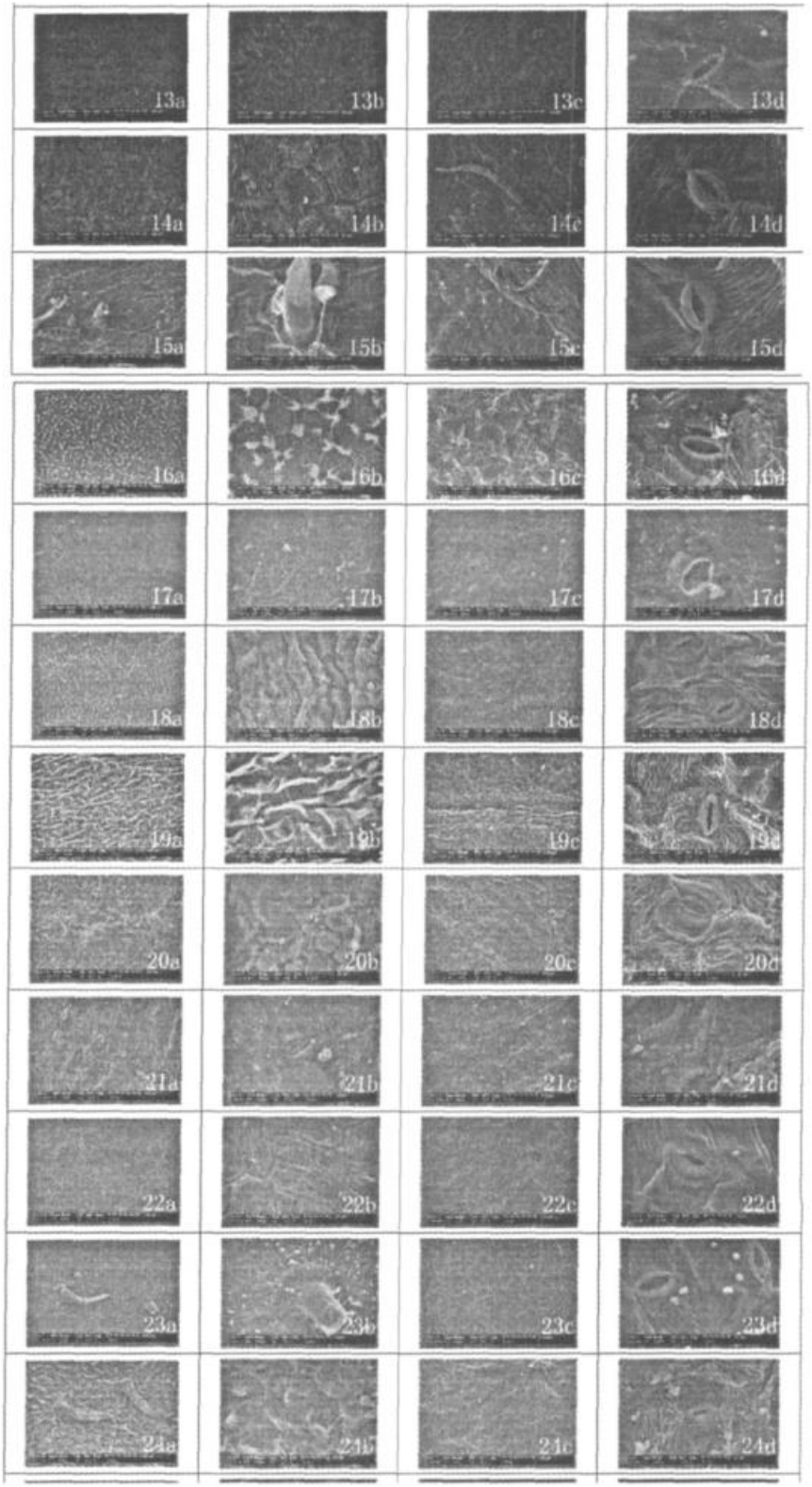


1a、1b、1c、1d: **戟叶鹅绒藤;** 2a、2b、2c、2d: **翅果杯冠藤;** 3a、3b、3c、3d: **合掌消;** 4a、4b、4c、4d: **潮风草;** 5a、5b、5c、5d: **白首乌;** 6a、6b、6c、6d: **美翼杯冠藤;** 7a、7b、7c、7d: **羊角子草;** 8a、8b、8c、8d: **鹅绒藤;** 9a、9b、9c、9d: **豹药藤;** 10a、10b、10c、10d: **台湾杯冠藤;** 11a、11b、11c、11d: **大理白前 i;** 12a、12b、12c、12d: **峨眉牛皮消**

图版 I-I　环境扫描电镜下鹅绒藤属植物叶表皮形态

Plate I-I　Leaf epidermis of *Cynanchum* under ESEM

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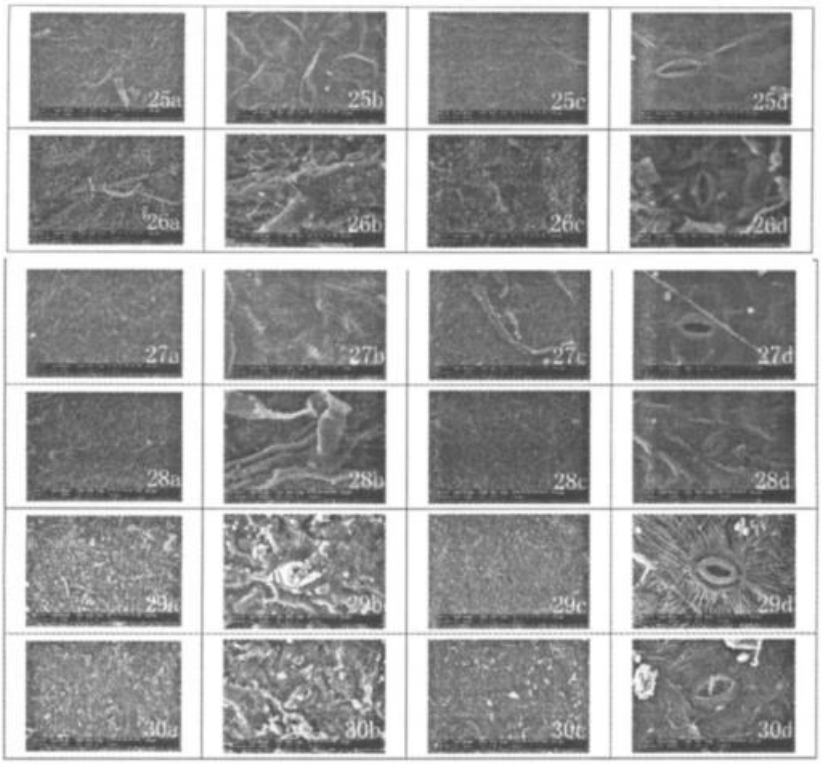


13a、13b、13c、13d: **华北白前**; 14a、14b、14c、14d: **竹灵消**; 15a、15b、15c、15d: **海南杯冠藤**; 16a、16b、16c、16d: **老瓜头**; 17a、17b、17c、17d: **广西杯冠藤**; 18a、18b、18c、18d: **木里白前**; 19a、19b、19c、19d: **青羊参**; 20a、20b、20c、20d: **西藏牛皮消**; 21a、21b、21c、21d: **狭叶白前**; 22a、22b、22c、22d: **卵叶白前**; 23a、23b、23c、23d: **镇江白前**; 24a、24b、24c、24d: **四川鹅绒藤**

图版 I-2 环境扫描电镜下鹅绒藤属植物叶表皮形态

Plate I-2 Leaf epidermis of *Cynanchum* under ESEM

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25a、25b、25c、25d: 台湾鹅绒藤; 26a、26b、26c、26d: 地梢瓜; 27a、27b、27c、27d: 变色白前; 28a、28b、28c、28d: 催吐白前; 29a、29b、29c、29d: 昆明杯冠藤; 30a、30b、30c、30d: 隔山消

图 I-3　环境扫描电镜下鹅绒藤属植物叶表皮形态

Plate I-3　Leaf epidermis of *Cynanchum* under ESEM

藤(图版 I: 24a) 、台湾鹅绒藤(图版 I: 25a) 、变色白前(图版 I: 27a) 、催吐白前(图版 I: 28a) 和昆明杯冠藤(图版 I: 29a) ,这些种类的表皮细胞均为多边形,而合掌消(图版 I: 3a) 、潮风草(图版 I: 4a) 、美翼杯冠藤(图版 I: 6a) 、羊角子草(图版 I: 7a) 、豹药藤(图版 I: 9a) 、大理白前(图版 I: 11a) 、华北白前(图版 I: 13a) 、广西杯冠藤(图版 I: 17a) 、木里白前(图版 I: 18a) 、西藏牛皮消(图版 I: 20a) 、狭叶白前(图版 I: 21a) 、镇江白前(图版 I: 23a) 、地梢瓜(图版 I: 26a) 和隔山消(图版 I: 30a) 表皮细胞轮廓不清晰,且多为不规则形。

下表皮细胞轮廓除合掌消(图版 I: 3c) 、潮风草(图版 I: 4c) 、羊角子草(图版 I: 7c) 、豹药藤(图版 I: 9c) 、大理白前(图版 I: 11c) 、华北白前(图版 I: 13c) 、广西杯冠藤(图版 I: 17c) 、木里白前(图版 I: 18c) 、狭叶白前(图版 I: 21c) 、地梢瓜(图版 I: 26c) 和隔山消(图版 I: 30c) ,其它种类都是清晰且为多边形。

上、下表皮细胞轮廓均清晰的种类包括戟叶鹅绒藤(图版 I: 1a,1c) 、翅果杯冠藤(图版 I: 2a,2c) 、白首乌(图版 I: 5a,5c) 、鹅绒藤(图版 I: 8a,8c) 、台湾杯冠藤(图版 I: 10a,10c) 、峨眉牛皮消(图版 I: 12a,12c) 、竹灵消(图版 I: 14a,14c) 、海南杯冠藤(图版 I: 15a,15c) 、老瓜头(图版 I: 16a,16c) 、青羊参(图版 I: 19a,19c) 、卵叶白前(图版 I: 22a,22c) 、四川鹅绒藤(图版 I: 24a,24c) 、台湾鹅绒藤(图版 I: 25a,25c) 、变色白前(图版 I: 27a,27c) 、催吐白前(图版 I: 28a,28c) 和昆明杯冠藤(图版 I: 29a,29c) 16 种。

2.2　气孔器的特征

根据上表皮气孔器的有无,可以将实验观察 29 种及 1 亚种鹅绒藤属植物分为 2 类: (A) 上表皮有气孔器,包括戟叶鹅绒藤(图版 I: 1b) 、羊角子草(图版 I: 7b) 、老瓜头(图版 I: 16b) 、狭叶白前(图版 I: 21b) 和隔山消(图版 I: 30b) 5 种,它们的气孔形状为椭圆形,戟叶鹅绒藤和老瓜头气孔外拱盖内缘为浅波状,其它 3 种均为内缘近平滑; (B) 上表皮未见气孔器分布,包括翅果杯冠藤(图版 I: 2b) 、合掌消(图版 I: 3b) 、潮风草(图版 I: 4b) 等 25 种。

表皮气孔大小也存在较大差异,气孔内径长度排在前 6 位由大到小分别是鹅绒藤(图版 I: 8d) 、合掌消(图版 I: 3d) 、台湾杯冠藤(图版 I: 10d) 、台湾鹅绒藤(图版 I: 25d) 、广西杯冠藤(图版 I: 17d) 和华北白前(图版 I: 13d) ,内径长度分别为 16.9 ×6.0、13.8 ×5.6、13.4 ×7.5、13.4 ×7.5、13.4 ×5.9 和 12.9 ×4.5 μm,长度排最后 3 位的是木里白前(图版 I:

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18d)、四川鹅绒藤(图版 I:24d)和美翼杯冠藤(图版 I:6d),内径长度分别为 7.6×2.3、7.6×2.3 和 7.0×2.6 μm。

气孔外径长度排在前 6 位由大到小别是鹅绒藤(图版 I:8d)、台湾杯冠藤(图版 I:10d)、台湾鹅绒藤(图版 I:25d)、竹灵消(图版 I:14d)、海南杯冠藤(图版 I:15d)和镇江白前(图版 I:23d),外径长度分别为 21.6×9.4、17.5×12.1、17.5×12.1、17.3×8.9、17.3×8.9 和 17.2×7.5 μm,长度排最后 3 位的是西藏牛皮消(图版 I:20d)、美翼杯冠藤(图版 I:6d)和地梢瓜(图版 I:26d),外径长度分别为 10.5×5.1、9.6×4.6 和 8.3×4.8 μm。

2.3 角质层纹饰的特征

本实验研究观察的 29 种及 1 亚种鹅绒藤属植物上、下表皮均有较厚的角质层,角质层表面纹饰多样化程度较高,根据叶表皮角质层特点可分为 6 类:①角质层具脊状隆起,包括潮风草(图版 I:4a)、羊角子草(图版 I:7a)、地梢瓜(图版 I:26a)的上表皮,翅果杯冠藤(图版 I:2c)、美翼杯冠藤(图版 I:6c)、老瓜头(图版 I:16c)、狭叶白前(图版 I:21c)变色白前(图版 I:27c)的下表皮,以及合掌消(图版 I:3a,3c)、华北白前(图版 I:13a,13c)和狭叶白前(图版 I:21a,21c)的上下表皮;②角质层具脊状隆起及辐射条纹,包括潮风草(图版 I:4c)、白首乌(图版 I:5c)、羊角子草(图版 I:7c)、鹅绒藤(图版 I:8c)、峨眉牛皮消(图版 I:12c)、海南杯冠藤(图版 I:15c)、木里白前(图版 I:18c)、青羊参(图版 I:19c)、卵叶白前(图版 I:22c)、四川鹅绒藤(图版 I:24c)、地梢瓜(图版 I:26c)和催吐白前(图版 I:28c)的下表皮,以及戟叶鹅绒藤(图版 I:1a,1c)、豹药藤(图版 I:9a,9c)、台湾杯冠藤(图版 I:10a,10c)、西藏牛皮消(图版 I:20a,20c)、镇江白前(图版 I:23a,23c)和隔山消(图版 I:30a,30c)的上、下表皮;③角质层具网状隆起及乳突,包括翅果杯冠藤(图版 I:2a)、峨眉牛皮消(图版 I:12a)、海南杯冠藤(图版 I:15a)、老瓜头(图版 I:16a)、青羊参(图版 I:19a)、四川鹅绒藤(图版 I:24a)、台湾鹅绒藤(图版 I:25a)、变色白前(图版 I:27a)和昆明杯冠藤(图版 I:29a)的上表皮;④角质层具乳突和辐射条纹,包括羊角子草(图版 I:7a)和鹅绒藤(图版 I:8a)的上表皮;⑤角质层具条纹和小丘状隆起,包括美翼杯冠藤(图版 I:6a)、大理白前(图版 I:11a)、木里白前(图版 I:18a)、卵叶白前(图版 I:22a)和催吐白前(图版 I:28a)的上表皮,昆明杯冠藤(图版 I:29c)的下表皮和竹灵消(图版 I:14a,14c)的上下表皮;⑥叶表皮表面光滑,包括广西杯冠藤(图版 I:17a,17c)的上、下表皮。

2.4 表皮毛的特征

根据叶表皮毛被情况可将研究的 29 种及 1 亚种鹅绒藤属植物分为以下 4 类:① 叶上表皮具多细胞单毛,下表皮没有多细胞单毛,包括白首乌(图版 I:5b)、美翼杯冠藤(图版 I:6b)、豹药藤(图版 I:9b)、台湾杯冠藤(图版 I:10b)、大理白前(图版 I:11b)、峨眉牛皮消(图版 I:12b)、西藏牛皮消(图版 I:20b)、镇江白前(图版 I:23b)、四川鹅绒藤(图版 I:24b)、台湾鹅绒藤(图版 I:25b)、催吐白前(图版 I:28b)和昆明杯冠藤(图版 I:29b)。② 叶上表皮无多细胞单毛,而下表皮有多细胞单毛,包括戟叶鹅绒藤(图版 I:1a,1c)、潮风草(图版 I:4a,4c)、竹灵消(图版 I:14a,14c)和变色白前(图版 I:27a,27c)。③叶上、下表皮都具有多细胞单毛,包括翅果杯冠藤(图版 I:2b,2c)、羊角子草(图版 I:7b,7c)、鹅绒藤(图版 I:8b,8c)、海南杯冠藤(图版 I:15b,15c)和地梢瓜(图版 I:26b,26c)。④叶上、下表皮都没有多细胞单毛,包括合掌消(图版 I:3b,3c)、华北白前(图版 I:13b,13c)、老瓜头(图版 I:16b,16c)、广西杯冠藤(图版 I:17b,17c)、木里白前(图版 I:18b,18c)、青羊参(图版 I:19b,19c)、狭叶白前(图版 I:21b,21c)、卵叶白前(图版 I:22b,22c)和隔山消(图版 I:30b,30c)。

3 讨论与结论

3.1 鹅绒藤属植物叶表皮性状的相似性

本实验研究结果显示大部分鹅绒藤属植物叶表皮微形态特征基本一致,但有部分种类存在明显差异,说明叶表皮微形态特征在鹅绒藤属分类中有一定参考价值,气孔的形状、气孔外拱盖内缘特征、气孔内外径以及角质层等特征均可作为鉴别性状。从叶表皮微形态特征看,表皮细胞轮廓为多边形(16 种),其他种为不规则形(13 种 1 亚种);多数种类上表皮气孔不明显(24 种 1 亚种),下表皮除了狭叶白前外其他种均有气孔分布,气孔外拱盖内缘多为近平滑(21 种),浅波状(6 种 1 亚种),波状(1 种);上、下表皮均具有较厚角质层,角质层的性状表现出较高的多样性,但也有一致性,如有 6 种上、下表皮和 12 种 1 亚种下表皮角质层具脊状隆起及辐射条纹;3 种上、下表皮,3 种上表皮和 5 种下表皮角质层具脊状隆起;仅有 1 种表面平滑。

3.2 叶表皮性状在鹅绒藤属植物分类中的意义

(1)在 Flora of China(Vol. 16)中翅果杯冠藤被认为是美翼杯冠藤的错误鉴定,羊角子草被归并到戟叶鹅绒藤,老瓜头被归并到华北白前,以及木里白

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前、卵叶白前被归并到大理白前[1,10]。本实验中叶表皮微形态的观测结果显示翅果杯冠藤与美翼杯冠藤在上表皮细胞轮廓和角质层有区别,翅果杯冠藤上表皮有表皮毛和具有表皮网状隆起及乳突,但美翼杯冠藤上、下表皮均无表皮毛且具有表皮角质层纹饰为短条纹和小丘状隆起; 羊角子草与戟叶鹅绒藤上、下表皮的角质层相同,但叶表皮细胞轮廓、表皮毛、气孔形状及气孔外拱盖内缘不同,羊角子草上、下表皮的细胞轮廓均为不清晰且不规则,均有表皮毛,气孔形状均为浅内陷,气孔外拱盖内缘均为近平滑,但戟叶鹅绒藤上、下表皮的细胞轮廓均为清晰多边形,仅下表皮有表皮毛,气孔形状均为非内陷,孔外拱盖内缘均为浅波状; 老瓜头与华北白前叶表皮微形态差异较大,老瓜头上、下表皮细胞轮廓均为清晰多边形,上、下表皮均有非内陷椭圆形的气孔器分布,气孔外拱盖内缘均为浅波状,上表皮角质层具有网状隆起及乳突,而华北白前上、下表皮细胞轮廓均为不清晰且不规则,仅下表皮有浅内陷椭圆形气孔器分布气孔外拱盖内缘为近平滑,上表皮角质层具有脊状隆起。木里白前、卵叶白前与大理白前的叶表皮角质层有较高的相似性,故本实验结果支持 Flora of China(Vol. 16) 中将木里白前、卵叶白前归并到大理白前的观点; 不支持将羊角子草归并到戟叶鹅绒藤、老瓜头归并到华北白前,以及翅果杯冠藤是美翼杯冠藤错误鉴定的观点。

(2) 鹅绒藤属属内多数种类的叶表皮特征存在相似性,但有的种类存在较大差异,主要表现在: ①戟叶鹅绒藤被分属在鹅绒藤组(Sect. *Cynanchum*) 中[2],但叶表皮扫描电镜观察结果表明戟叶鹅绒藤仅在上表皮有气孔器分布与鹅绒藤组其他种有明显不同,其余种类叶表皮微形态特征基本一致; ②四川鹅绒藤、台湾鹅绒藤、白首乌、峨眉牛皮消和昆明杯冠藤这 5 种被分在 3 个不同组中的种类,但它们的叶表皮微形态特征在上表皮均无气孔器分布,均有表皮毛,上、下表皮细胞轮廓均为清晰多边形,气孔形状为非内陷椭圆形,下表皮气孔外拱盖内缘均为近平滑和角质层纹饰都具有脊状隆起及辐射状等方面相对接近; ③西藏牛皮消、镇江白前和台湾杯冠藤被分在 3 个不同组中,但叶表皮微形态的观测结果显示它们在上、下表皮的形态特征极为相似。④催吐白前组和青羊参组(Sect. *Cyathella*) 中的部分种类相似性较高,如催吐白前组中的合掌消、木里白前和卵叶白前这 3 种和青羊参组中的青羊参的叶表皮微形态特征较为接近,建议进行重新归类。另外,一些种类被虽然分在同一组,但其叶表皮微观特征差别较大,如在青羊参组的羊角子草和广西杯冠藤,它们无论是在表皮毛还是在上表皮气孔形状、气孔外拱盖内缘等方面均有较为明显的区别。

致　谢: 实验取样与观察分别得到中国科学院华南植物园标本馆曾飞燕工程师、华南农业大学林学院标本馆郑明轩老师以及华南农业大学测试中心杨秉耀老师的指导与帮助,在此一并感谢。

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西南农业学报(双月刊)
Xinan Nongye Xuebao
2013年4月出版(公开发行)
2013年第26卷第2期

Southwest China Journal of Agricultural Sciences(Bimonthly)
Vol.26 No.2 2013
Published on Apr. 28, 2013

本刊已加入或入编“中国知网”、“万方数据——数字化期刊群”和“中国核心期刊（遴选）数据库”，作者著作权使用费与本刊稿酬一次性给付，不再另行发放。作者如不同意将文章加入或入编，投稿时敬请说明。

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主　　办：四川、云南、贵州、广西、西藏及重庆省（区、市)农科院
编辑出版：《西南农业学报》编辑部
编辑部地址：成都外东沙河大桥侧 (邮码：610066)
照　　排：四川省农科院情报所印刷厂
印　　刷：四川省农科院情报所印刷厂
国内订阅发行：四川省报刊发行局
国外订阅发行：中国出版对外贸易总公司 (北京782信箱)
中国标准刊号：CN51-1213/S　ISSN 1001-4829　CODEN XNXUEF

Sponsored by Sichuan,Yunnan,Guizhou,Guangxi, Tibet and Chongqing Academies of Agri.Sci.
Edited and Published by Editorial Department of Southwest China Journal of Agri.Sci.
Address:Shahe Daqiao,Chengdu,Sichuan 610066

Distributed by China Publish Foreign Trading Corporation(P.O.Box 782,Beijing,China)
E-mail: Jxuebao@sina.com
http://xnnyxb.periodicals.net.cn/default.html

2013
262

公开发行　　邮发代号：62-152　　国内订价：20.00元

ISSN 1000-4025
CN61-1091/Q

西北植物学报

ACTA BOTANICA BOREALI-OCCIDENTALIA SINICA

第32卷 第9期
Vol.32 No.9



9

西北农林科技大学 主办
科学出版社出版

2012

09>
9 771000 402125

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西北植物学报

(Xibei Zhiwu Xuebao,1980 年创刊)

2012 年 9 月　第 32 卷　第 9 期

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[期刊基本参数] CN 61－1091/Q＊1980＊m＊A4＊216＊zh＊P＊￥35.00＊1500＊32＊2012-09

ACTA BOTANICA BOREALI-OCCIDENTALIA SINICA
September 2012 Vol.32 No.9
(Started publication in 1980)

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西北植物学报，2012，32(9)：1758－1762
Acta Bot. Boreal.-Occident. Sin.

文章编号：1000-4025(2012)09-1758-05

17 种 1 亚种鹅绒藤属植物花粉器形态学研究

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摘　要：利用光学显微镜对萝藦科鹅绒藤属 17 种 1 亚种植物花粉器的形态特征进行观察。结果表明：(1)该属植物花粉器形状大小在各个种间差异较大：花粉块下垂，通常呈球形、长球形和超长球形，平均大小为 327.2 μm×183.9 μm；着粉腺呈长圆形、近圆形、近方形和近三角形，平均大小为 406.1 μm×231.4 μm。(2)翅果杯冠藤的花粉块柄最不发达，豹药藤的花粉块柄最发达。(3)白薇与朱砂藤、刺瓜与轮叶白前的花粉器特征均较相近。研究结果支持《中国植物志(第 63 卷)》中对催吐白前组(Sect. *Vincetoxicum*)的分组处理；支持将娃儿藤属(*Tylophora*)作为一个独特类群的观点；因国内翅果杯冠藤和美翼杯冠藤的花粉器形态存在差别，故不支持 Flora of China(Vol. 16)中认为翅果杯冠藤是美翼杯冠藤的错误鉴定与处理。

关键词：鹅绒藤属；花粉器；萝藦科；分类

中图分类号：Q944.58　　**文献标志码**：A

Pollinarium Morphology of 17 Species and 1 Subspecies of *Cynanchum* (Asclepiadaceae)

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Abstract: The pollinarium morphology of 17 species and 1 subspecies of *Cynanchum* were observed under light microscope(LM). The results showed that: (1) The sharp and size of pollinarium of *Cynanchum* were different from various kinds of species. The pollinia were sagging, and their shape were usually spheroidal, prolate, and perprolate. The average size of pollinia was long 327.2 μm × wide 183.9 μm. The shape of retinaculum were oblong, near roundness, near squares, and near triangle, and their average size was long 406.1 μm × wide 231.4 μm. (2) The caudicle of *C. alatum* was the least developed, while that of *C. decipiens* was the most developed. (3) The pollinarium morphology of *C. atratum* and *C. officinale*, *C. corymbosum* and *C. verticillatum* were similar. The results supported the treatment of *Cynanchum* Sect. *Vincetoxicum* in Flora Reipublicae Popularis Sinicae (Vol. 63) and supported that *Tylophora* should be a unique group. It was considered that *C. alatum* was the false identification of *C. callialatum* in Flora of China (Vol. 16), since the results in this paper showed their pollinarium morphology were different.

Key words: *Cynanchum*; pollinarium; Asclepiadaceae; taxonomy

鹅绒藤属(*Cynanchum* L.)是萝藦科中包含种类最多的属，全球约 200 种，分布于非洲东部、地中海地区及欧亚大陆的热带、亚热带及温带地区；中国现记录有 55 种、1 亚种和 1 变种，主要分布在华南、西南各省区[1-2]。鹅绒藤属早期的分类研究主要是依据宏观形态学特征，缺乏实验学科的综合证据，导

* 收稿日期：2012-05-10；修改稿收到日期：2012-08-08

基金项目：国家自然科学基金项目(31000095)；广东省大学生创新实验项目(1056411009)；国家高等学校本科特色专业建设点—林学(教高函[201015]号)

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致鹅绒藤属分类较为混乱，属的系统位置和属下分类系统争议较大，一些疑难类群至今仍悬而未决。花粉器是萝藦科植物分类的重要依据，但目前对萝藦科植物花粉器微观形态的研究较少，仅在鹅绒藤属、娃儿藤属（*Tylophora*）和牛奶菜族（Trib. *Marsdenieae*）中的部分种类有研究报道[3-5]。笔者通过查阅中国科学院华南植物园标本馆（IBSC）馆藏的鹅绒藤属标本，对 17 种 1 亚种鹅绒藤属植物的花粉器进行光学显微镜观察，比较分析花粉器形态特征，以探讨花粉器形态在鹅绒藤属植物中的分类学意义。

1　材料和方法

1.1　材　料

本研究试验材料均取自中国科学院华南植物园标本馆的腊叶标本，材料具体信息见表 1。

1.2　方　法

从腊叶标本上取花，用 10% 的 KOH 复水 5～10 min 后，取出置于载玻片上，在解剖镜下用解剖针轻轻拔下花粉器。在体视镜下观察，并用 Image-pro Express 5 对花粉器进行拍照，对着粉腺、花粉块的高度和直径进行测量，并对花粉块柄的长度进行测量。每次测量 3 个花粉器，取平均值。

花粉器、着粉腺和花粉块等特征类型术语参考中国科学院中国植物志编委会[2]、王伏雄[6]和 Hesse[7]等资料。

2　结果与分析

本研究对鹅绒藤属 17 种 1 亚种植物的花粉器形态进行了观察和比较，特征见表 2 和图版Ⅰ。

2.1　花粉块的特征

在所观察的 17 种 1 亚种鹅绒藤属植物中，花粉块在每个药室内藏 1 个，下垂，每个花粉器有花粉块 2 个。依据观察结果可以将花粉块的形态分为 3 种类型：（A）球形[（高度：直径）≤1.5]，包括粉绿白前（图版Ⅰ，1）和广西杯冠藤（图版Ⅰ，2）；（B）长球形[1.5＜（高度：直径）≤2.0]，包括白薇（图版Ⅰ，3）、刺瓜（图版Ⅰ，4）、豹药藤（图版Ⅰ，5）、大理白前（图版Ⅰ，6）、白前（图版Ⅰ，7）、太行白前（图版Ⅰ，8）、华北白前（图版Ⅰ，9）、朱砂藤（图版Ⅰ，10）和四川鹅绒藤（图版Ⅰ，11）；（C）超长球形[（高度：直径）＞2]，包括戟叶鹅绒藤（图版Ⅰ，12）、翅果杯冠藤（图版Ⅰ，13）、合掌消（图版Ⅰ，14）、美翼杯冠藤（图版Ⅰ，15）、镇江白前（图版Ⅰ，16）、变色白前（图版Ⅰ，17）、轮叶白前（图版Ⅰ，18）。花粉块的平均大小为 327.2 μm×183.9 μm，其中粉绿白前的花粉块最小，为 185.0 μm×128.3 μm；翅果杯冠藤的花粉块最大，为486.7 μm×228.5 μm。花粉块的高度与直径之比介于 1.33（豹药藤）至 2.49（轮叶白前）之间。

2.2　着粉腺的特征

表2显示，17种1亚种鹅绒藤属植物着粉腺可

表 1　鹅绒藤属植物花粉器研究的试验材料及凭证标本

Table 1　Materials and voucher specimens of pollinarium of *Cynanchum*

种名 Name of species	采集地 Locality	凭证标本 Voucher specimen
戟叶鹅绒藤 *C. acutum* subsp. *sibiricum*	新疆高家农场附近 Near Gaojiang Farm, Xinjiang	林有润（Y. R. Lin）417506
翅果杯冠藤 *C. alatum*	镇越县（今西双版纳勐腊县） Hwei-du, Jenn-yeh Hsien	王启无（Q. W. Wang）124860
合掌消 *C. amplexicaule*	湖南望城南附近 Near Wangchengnan, Hu'nan	杨祥学（X. X. Yang）241102
白薇 *C. atratum*	湖南 Hu'nan	何观渊（K. C. Ho）151595
美翼杯冠藤 *C. callialatum*	不详 Location unknown	采集人不详（Anonymous）65974
粉绿白前 *C. canescens*	四川甘孜州乡城县 Xiangcheng, Ganzi, Sichuan	四川植物调查队（Sichuan Veg. Exp.）385322
刺瓜 *C. corymbosum*	广东乐昌 Lechang, Guangdong	叶育石，曹照忠（Y. S. Ye & Z. Z. Cao）255187
豹药藤 *C. decipiens*	四川马尔康 Maerkang, Sichuan	周宏富，张泽荣（H. F. Zhou & Z. R. Zhang）155187
大理白前 *C. forrestii*	西康. 察瓦龙. 折梅（今四川境内）Djer-mai. Tsa-wa-rung	王启无（Q. W. Wang）139566
白前 *C. glaucescens*	不详 Location unknown	采集人不详（Anonymous）79485
广西杯冠藤 *C. kwangsiense*	不详 Location unknown	采集人不详（Anonymous）45620
华北白前 *C. mongolicum*	宁夏同心 Tongxin, Ningxia	张珍万（Z. W. Zhang）585024
朱砂藤 *C. officinale*	不详 Location unknown	E. H. Wilson 91998
镇江白前 *C. sublanceolatum*	不详 Location unknown	T. Makino 150874
四川鹅绒藤 *C. szechuanense*	不详 Location unknown	俞德浚（T. T. Yu）139369
太行白前 *C. taihangense*	不详 Location unknown	刘慎谔、钟补求（T. N. Liou & P. Q. Tsoong）591202
变色白前 *C. versicolor*	云南昆明西山 Western Hill, Kunming, Yunnan	陈振东（T. T. Chen）250320
轮叶白前 *C. verticillatum*	广西那坡 Napo, Guangxi	华南分队（South China Detachment）616458

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表 2 鹅绒藤属 17 种 1 亚种植物花粉器形态

Table 2 Pollinarium morphology of 17 species and 1 subspecies of *Cynanchum*

种名 Name of species	花粉块 Pollinia				着粉腺 Retinaculum				花粉块柄 Caudicle	
	形态 Shape	高 Height /μm	直径 Diameter /μm	高度/直径 Height/diameter	形态 Shape	高 Height /μm	直径 Diameter /μm	高度/直径 Height/diameter	长 Length /μm	柄长度/块长度 Length of caudicle/pollinia
戟叶鹅绒藤 *C. acutum* subsp. *sibiricum*	超长球形 Perprolate	328.5	156.9	2.09	长圆形;顶端钝圆 Oblong with blunt end	322.3	185.7	1.74	84.4	0.26
翅果杯冠藤 *C. alatum*	超长球形 Perprolate	486.7	228.5	2.13	长圆形;顶端钝圆 Oblong with blunt end	420.2	224.5	1.87	56.9	0.12
合掌消 *C. amplexicaule*	超长球形 Perprolate	285.3	132.5	2.15	长圆形;顶端钝圆 Oblong with blunt end	297.8	178.1	1.67	105.6	0.37
白薇 *C. atratum*	长球形 Prolate	375.5	231.3	1.62	近三角形;顶端尖锐 Near triangle with pointed end	669.1	278.8	2.40	183.3	0.49
美翼杯冠藤 *C. callialatum*	超长球形 Perprolate	430.0	195.7	2.20	近圆形;顶端凹缺 Near roundness with concave blunt	443.2	319.0	1.39	124.1	0.29
粉绿白前 *C. canescens*	球形 Spheroidal	185.0	128.3	1.44	长圆形;顶端钝圆 Oblong with blunt end	253	105.4	2.40	90.5	0.49
刺瓜 *C. corymbosum*	长球形 Prolate	429.0	231.5	1.85	长圆形;顶端凹缺 Oblong with concave blunt	412	220.0	1.87	217.5	0.51
豹药藤 *C. decipiens*	长球形 Prolate	420.5	315.0	1.33	近圆形;顶端钝圆 Near roundness with blunt end	475.5	436.5	1.05	237.5	0.56
大理白前 *C. forrestii*	长球形 Prolate	238.0	140.2	1.70	长圆形;顶端凹缺 Oblong with concave blunt	466.6	180.8	2.58	120.0	0.50
白前 *C. glaucescens*	长球形 Prolate	276.5	183.3	1.51	长圆形;顶端钝圆 Oblong with blunt end	441.7	240.1	1.84	101.6	0.37
广西杯冠藤 *C. kwangsiense*	球形 Spheroidal	378.3	279.3	1.36	长圆形;顶端钝圆 Oblong with blunt end	466.2	299.3	1.56	150.3	0.40
华北白前 *C. mongolicum*	长球形 Prolate	226.4	129.2	1.75	近方形;顶端钝圆 Near square with blunt end	330.1	148.8	2.22	107.7	0.48
朱砂藤 *C. officinale*	长球形 Prolate	354.5	183.5	1.93	近三角形;顶端尖锐 Near triangle with pointed end	503.2	225.6	2.23	151.9	0.43
镇江白前 *C. sublanceolatum*	超长球形 Perprolate	204.1	97.8	2.09	近三角形;顶端钝圆 Near triangle with blunt end	302.7	183.0	1.65	73.8	0.36
四川鹅绒藤 *C. szechuanense*	长球形 Prolate	371.8	227.1	1.64	近圆形;顶端凹缺 Near roundness with concave blunt	413.1	296.0	1.40	166.0	0.45
太行白前 *C. taihangense*	长球形 Prolate	317.6	179.6	1.77	近方形;顶端钝圆 Near square with blunt end	508.4	284.1	1.79	166.0	0.52
变色白前 *C. versicolor*	超长球形 Perprolate	312.8	156.1	2.00	近圆形;顶端钝圆 Near roundness with blunt end	273.6	201.2	1.36	66.7	0.21
轮叶白前 *C. verticillatum*	超长球形 Perprolate	286.6	114.9	2.49	长圆形;顶端钝圆 Oblong with blunt end	310.5	157.4	1.97	109.7	0.41

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分为 4 种类型：长圆形、近圆形、近方形和近三角形：(A)长圆形，包括戟叶鹅绒藤、翅果杯冠藤、合掌消、粉绿白前、刺瓜、大理白前、白前、广西杯冠藤、轮叶白前；(B)近圆形，包括美翼杯冠藤、豹药藤、四川鹅绒藤、变色白前；(C)近方形，包括太行白前、华北白前；(D)近三角形，包括白薇、朱砂藤、镇江白前。本研究中着粉腺的背面均有一条竖直的腺缝，大部分种的着粉腺 2 个侧壁均宽且厚，仅合掌消、粉绿白前、轮叶白前的着粉腺侧壁较薄。着粉腺的高度和直径在各个种之间变异很大，其中粉绿白前的着粉腺高度与直径均最小，为 253.0 μm×105.4 μm，而白薇的着粉腺高度最大，为 669.1 μm，大小为669.1 μm×278.8 μm。着粉腺的高度和直径的比值介于 1.05(豹药藤)和 2.58(大理白前)之间。

2.3　花粉块柄的特征

花粉块柄与花粉块的长度比值可用于评价花粉块柄的发达程度[5]。表 2 显示，花粉块柄与花粉块的长度比值介于 0.12(翅果杯冠藤)和 0.56(豹药藤)之间。表明豹药藤的花粉块柄最发达，太行白前和刺瓜次之，而翅果杯冠藤的花粉块柄最不发达。

3　讨　论

3.1　鹅绒藤属内的分类讨论

《中国植物志(第 63 卷)》把鹅绒藤属分为 7 个组，本研究 17 种 1 亚种鹅绒藤属植物中戟叶鹅绒藤、四川鹅绒藤属于鹅绒藤组(*Cynanchum* Sect. *Cynanchum*)，朱砂藤属于牛皮消组(*Cynanchum* Sect. *Endotropis*)，豹药藤属于豹药藤组(*Cynanchum* Sect. *Cryptoglossum*)，翅果杯冠藤、美翼杯冠藤、刺瓜、广西杯冠藤属于青羊参组(*Cynanchum* Sect. *Cyathella*)，合掌消、白薇、粉绿白前、大理白前、白前、太行白前、华北白前、镇江白前、变色白前、轮叶白前属于催吐白前组(*Cynanchum* Sect. *Vincetoxicum*)[2]。本研究根据花粉器观测结果可以看出，白薇虽与催吐白前组中的粉绿白前、大理白前等花粉块柄的发达程度相对一致，但无论是在花粉块的形态和大小、着粉腺的形态和大小、花粉块柄的长度等均存在着较大差异。而白薇与朱砂藤的花粉块、着粉腺的形态和大小更为相近：两者的花粉块均为长球形且大小相近(白薇：375.5 μm×231.3 μm，朱砂藤：354.5 μm×183.5 μm)；着粉腺均为三角形，顶端尖，大小相近(白薇：669.1 μm×278.8 μm，朱砂藤：503.2 μm×225.6 μm)；花粉块柄都较长(白薇：183.3 μm，朱砂藤：151.9 μm)，且花粉块柄与花粉块长度的比值接近(白薇：0.49、朱砂藤：0.43)，表明两者花粉块柄的发达程度大致处于同一水平。刺瓜和同为青羊参组的翅果杯冠藤、广西杯冠藤、美翼杯冠藤形态差异也较大，而与催吐白前组的轮叶白前较为相似。

在催吐白前组中，除变色白前以外，镇江白前、合掌消、白前、粉绿白前、大理白前、太行白前、华北白前、轮叶白前的花粉块柄在本研究中观察的所有种类中均相对更发达，结果支持李玉玲等[3]认为《中国植物志(第 63 卷)》中对催吐白前组的分类是较为自然处理的观点。Flora of China(Vol. 16)[1]中认为国内的翅果杯冠藤是美翼杯冠藤的错误鉴定，本研究中两者花粉块大小接近(翅果杯冠藤：486.7 μm×228.5 μm；美翼杯冠藤：430.0 μm×195.7 μm)，但着粉腺高度与直径比值差异较大(翅果杯冠藤：1.87；美翼杯冠藤：1.39)，而花粉块柄与花粉块长度比值也存在较大差异，分别为 0.12 和 0.29，显示美翼杯冠藤比翅果杯冠藤具有更为发达的花粉块柄，建议不作错误鉴定处理。

3.2　鹅绒藤属与其近缘亲属的分类讨论

本研究中 17 种 1 亚种鹅绒藤属植物的花粉块均下垂，且花粉块柄大都比较发达，与李玉玲等[3]对 12 种鹅绒藤属植物的花粉器形态研究结果一致；而李丽文等[4]对娃儿藤属 13 种植物的花粉器形态研究表明娃儿藤属的花粉块为平展；莫罗坚等[5]对牛奶菜族 7 属 11 种植物的花粉器形态研究表明娃儿藤属的花粉块柄并不发达。本实验结果支持李玉玲等[3]不赞成把娃儿藤属归入马利筋族(Trib. Asclepiadeae)的观点，同样也支持莫罗坚[5]将娃儿藤属作为一个独特类群的观点。本研究结果显示鹅绒藤属植物的花粉块、着粉腺的形态大小和花粉块柄的长度变异较大，因此对鹅绒藤属植物进行分类时需综合考虑花粉块和着粉腺的形态大小、花粉块柄的长度以及花粉块柄与花粉块长度的比值等性状。

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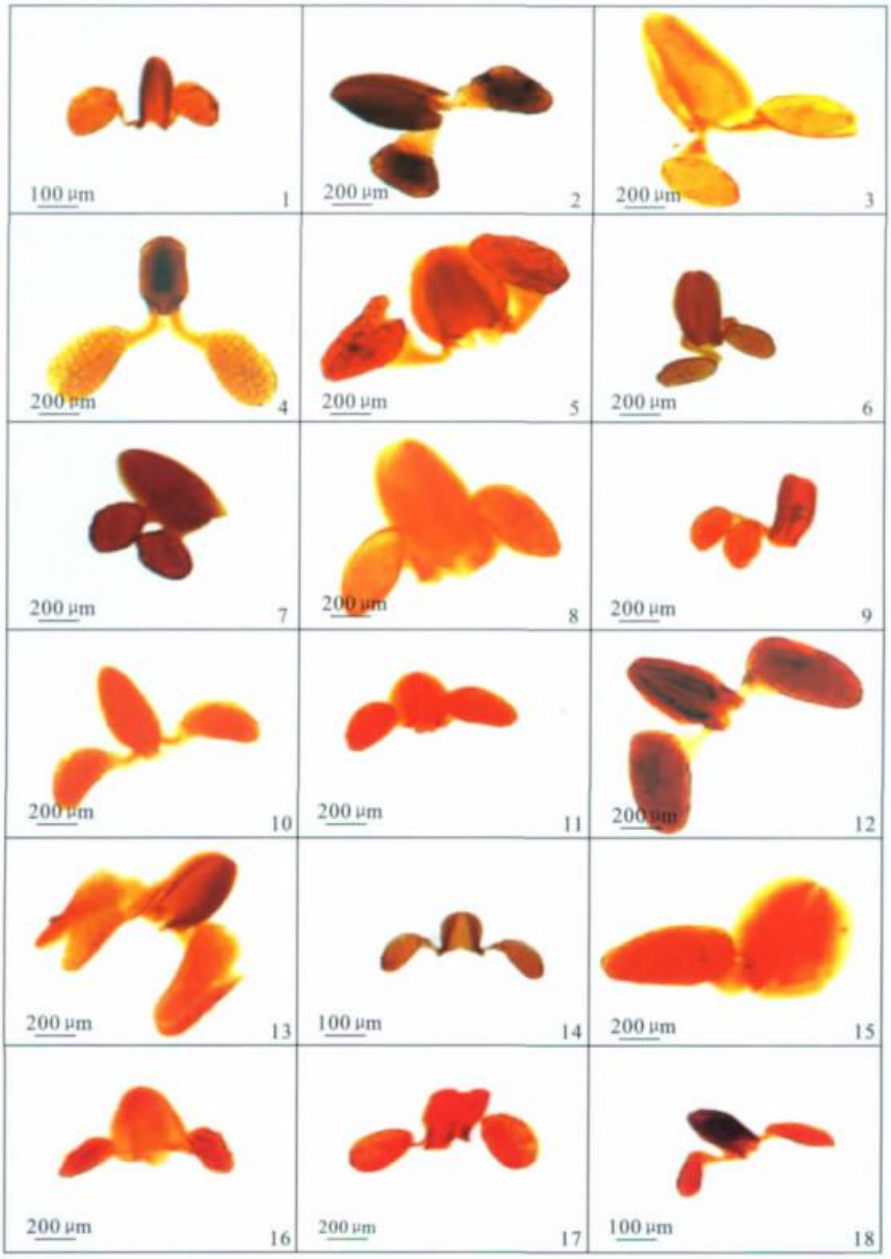
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1. **粉绿白前**;2. **广西杯冠藤**;3. **白薇**;4. **刺瓜**;5. **豹药藤**;6. **大理白前**;7. **白前**;8. **太行白前**;9. **华北白前**;10. **朱砂藤**;11. **四川鹅绒藤**;12. **戟叶鹅绒藤**;13. **翅果杯冠藤**;14. **合掌消**;15. **美翼杯冠藤**;16. **镇江白前**;17. **变色白前**;18. **轮叶白前**

Plate Ⅰ Pollinarium of *Cynanchum* L.

Fig. 1. *C. canescens*; Fig. 2. *C. kwangsiense*; Fig. 3. *C. atratum*; Fig. 4. *C. corymbosum*; Fig. 5. *C. decipiens*; Fig. 6. *C. forrestii*; Fig. 7. *C. glaucescens*; Fig. 8. *C. taihangense*; Fig. 9. *C. mongolicum*; Fig. 10. *C. officinale*; Fig. 11. *C. szechuanense*; Fig. 12. *C. acutum* subsp. *sibiricum*; Fig. 13. *C. alatum*; Fig. 14. *C. amplexicaule*; Fig. 15. *C. callialatum*; Fig. 16. *C. sublanceolatum*; Fig. 17. *C. versicolor*; Fig. 18. *C. verticillatum*.

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- 第二届国家期刊奖百种重点期刊
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- 中国核心期刊（遴选）数据库核心期刊
- 中国学术期刊综合评价数据库统计源期刊

执行主编　南红梅　　英 文 编 辑　张文俊(美)
责任编辑　潘新社　　拉丁文编辑　吴振海

西北植物学报
XIBEI ZHIWU XUEBAO
月刊　（1980年创刊）
第32卷 第9期　2012年9月

ACTA BOTANICA
BOREALI-OCCIDENTALIA SINICA
Monthly　（Started in 1980）
Vol.32 No.9　Sep. 2012

主管单位　中华人民共和国教育部
主　　办　西北农林科技大学
　　陕西省植物学会
编　　辑　《西北植物学报》编辑部
　　陕西杨陵邰城路3号西北农林科技大学
　　邮政编码：712100 电话：029-87082936
　　E-mail:xbzwxb@vip.163.com
主　　编　赵 忠
出　　版　科 学 出 版 社
　　（北京东黄城根北街16号，邮编：100717）
印刷装订　陕西龙源印务有限公司
订 购 处　全国各地邮局
国内发行　杨凌示范区邮政局
国外发行　中国国际图书贸易总公司
　　（北京399信箱　邮政编码：100044）
网　　址　http://www.xbzwxb.com

Administrated by : Ministry of Education of P. R. C
Sponsored by : Northwest A & F University
　　Botanical Society of Shaanxi Province
Edited by : Editorial Department of Acta Botanica
　　Boreali-Occidentalia Sinica
　　（3 Taicheng Road, Yangling, Shaanxi, 712100, China）
Editor in Chief : ZHAO Zhong
Published by : Science Press
　　（16 Donghuangchenggen North Street,Beijing 100717,China）
Printed by : Shaanxi Longyuan Printing Co., Ltd.
Domestic : All Local Post Offices in China
Domestic Distributor : Yangling Post Offices
International Distributor : China International Book Trading Corporation
　　（P.O.Box 399, Beijing 100044,China）

国内外公开发行
广告经营许可证 6104031000014
刊　号：ISSN1000-4025 / CN61-1091/Q
国内邮发代号：52-73
国外发行代号：M5897
定价：35.00元

ISSN 1000-4025
CN61-1091/Q

西北植物学报

ACTA BOTANICA BOREALI-OCCIDENTALIA SINICA

第32卷 第4期
Vol.32 No.4



4

2012

西北农林科技大学 主办
科学出版社出版

9 771000 402125 04>

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西北植物学报

(Xibei Zhiwu Xuebao,1980 年创刊)

2012 年 4 月　第 32 卷　第 4 期

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[期刊基本参数] CN 61—1091/Q * 1980 * m * A4 * 214 * zh * P * ¥35.00 * 1500 * 34 * 2012-04

ACTA BOTANICA BOREALI-OCCIDENTALIA SINICA
April 2012 Vol. 32 No. 4
(Started publication in 1980)

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西北植物学报，2012，32(4)：0709－0715
Acta Bot. Boreal.-Occident. Sin.

文章编号：1000-4025(2012)04-0709-07

石灰岩特有植物圆叶乌桕叶表皮形态特征及其生态适应性研究

何敏宜[1,2]，袁锡强[1]，秦新生[1*]

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摘　要：采用扫描电子显微镜和光学显微镜，对石灰岩特有植物圆叶乌桕与同属的乌桕、山乌桕的叶表皮微形态进行观察，比较3个种的叶表皮形态特征，分析圆叶乌桕在石灰岩地区生长的环境适应特点。结果表明：圆叶乌桕叶下表皮细胞小且呈无规则型，细胞排列紧密；气孔集中分布于下表皮，气孔密度和气孔指数相对最小；气孔类型是无规则型，无副卫细胞；圆叶乌桕上下叶表皮有厚角质层和蜡质层，蜡被呈片状和网状。圆叶乌桕的叶表皮微形态特征反映了它对石灰岩生境的适应性较强。

关键词：圆叶乌桕；石灰岩；叶表皮；气孔参数；适应性

中图分类号：Q944.56；Q945.79　　**文献标志码**：A

Characteristics of Leaf Epidemic and the Association with Their Environmental Adaptation of *Triadica rotundifolia*, a Limestone Endemic Species

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Abstract: The leaf epidermis of *Triadica rotundifolia* (Hemsley) Esser-endemic plants in limestone region, and of *Triadica sebifera*, *Triadica cochinchinensis* were examined through scanning electron microscope (SEM) and light microscope (LM). By comparing the three species, we analyse *T. rotundifolia*'s environmental adaptive mechanisms based on its leaf epidermic morphological characteristics. The results showed that: abaxial cells of *T. rotundifolia* were small size reversely, with irregular type and closly arranged. The stomatas could only be seen on abaxial epidermis. The stomatal density and index of *T. rotundifolia* were lower than that of other two species. Stomatal type was anomocytic without subsidisry cells. Horny layer and wax layer thickly covered on the epidermism, with its waxy coat lamellar and reticulation. All of these implied that *T. rotundifolia* can adapt to limestone habitats condition.

Key words: *Triadica rotundifolia*; limestone; leaf epidemic; stomatal parameters; adaptability

石灰岩地区(也称岩溶地区或喀斯特地区)广泛分布于中国贵州、广西、云南等省份。由于石灰岩区域发育的土壤土层浅薄，蓄水能力弱，因而地表环境干燥，生长在其上的植物大多具耐旱的特性。圆叶

＊ 收稿日期：2011-12-29；修改稿收到日期：2012-02-20

基金项目：国家高等学校本科特色专业建设点—林学(教高函[201015]号)；广东省自然科学基金(8451064201001149)；广东省大学生创新实验计划(1056411009)；广东省林业科技创新专项资金(2009KJCX014)

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乌桕[*Triadica rotundifolia* (Hemsley) Esser]隶属于大戟科乌桕属(*Triadica*)[1],是石灰岩特有植物,在中国主要分布于南部和西南喀斯特集中地区。圆叶乌桕多见于石灰岩缝隙和洞口等向阳处,是钙质土的指示植物,李荣峰等通过研究圆叶乌桕叶和茎的横切面解剖结构后提出,发达的角质层、栅栏组织和海绵组织、明显的乳突、发达的维管系统等结构有助于提高圆叶乌桕抗旱、喜钙及耐瘠等性能[2]。由于叶片是植物进化过程中对环境变化较敏感且可塑性较大的器官,其结构特征能体现环境因子的影响或植物对环境的适应,因此本试验通过研究圆叶乌桕的叶表皮结构特征,并与同属非石灰岩特有种类乌桕(*Triadica sebifera*)、山乌桕(*Triadica cochinchinensis*)进行比较,探究它对石灰岩生境适应的内在结构特性。

1 材料和方法

1.1 材料与取样

以圆叶乌桕、乌桕和山乌桕为研究对象,所有新鲜叶片材料均取自野生植株。腊叶材料凭证标本存于中国科学院华南植物园标本馆(IBSC)。材料具体信息见表 1。

1.2 方 法

1.2.1 叶片解剖结构观察 选取新鲜成熟叶片靠近中脉的脉间区域,剪取面积约 1 cm×0.5 cm 的样品保存到 FAA 固定液。实验前取出样品,冲洗干净表面的 FAA 固定液。把材料浸在等量混合的一定浓度的过氧化氢和冰醋酸离析液中,放在 60℃烘箱内 5～12 h。待材料变白,取出分离。腊叶标本则在剪取样品后沸水煮 30 min,转入 20%次氯酸钠溶液中离析至材料变白。分离方法与新鲜材料一致。

用系列酒精脱水(50%-75%-85%-95%)、固绿染色,二甲苯冲洗,中性树胶封片,在光学显微镜下观察表皮细胞形态,测表皮细胞大小,气孔大小以及气孔密度等参数,部分特征描述参照相关文献所用术语[3-5]。

1.2.2 叶片扫描电镜观察 选取成熟叶片靠近中脉的脉间区域,用毛笔蘸取 95%的酒精轻刷表面,自然干燥后,切取面积约 1 cm×0.5 cm 的样品,将上、下表皮分别粘在样品台上,真空喷金镀膜后在 FEI-XL30 环境扫描电子显微镜下观察、测量、拍照。

1.2.3 数据采集和统计分析 选取圆叶乌桕、乌桕、山乌桕的上、下表皮标本各 5 片,每个标本中随机选取 20 个细胞,在显微镜下放大,测量,录入 Excel 表格求平均值(表 2)。同时测量所取标本中的所有气孔大小,取平均值(表 3)。

2 结果与分析

2.1 叶表皮细胞特征

由表 2 可以看出,圆叶乌桕、乌桕和山乌桕的叶片上表皮细胞大小差别不明显,其中乌桕的表皮细胞

表 1 材料来源

Table 1 Source of materials

种名 Species	新鲜叶片采集地 Sample collecting area	腊叶标本及其馆藏地 Voucher specimen
圆叶乌桕 *Triadica rotundifolia*	广州市从化吕田镇石灰岩山 Limestone Mountains in Lütian Town, Conghua, Guangzhou	邓良(L. Tang) 0305524(IBSC)
乌桕 1 *Triadica sebifera* 1	广州市从化吕田镇石灰岩山 Limestone Mountains in Lütian Town, Conghua, Guangzhou	李淑玉(S. Y. Li)0305657(IBSC)
乌桕 2 *Triadica sebifera* 2	华南农业大学树木园 The Arboretum of South China Agricultural University	李淑玉(S. Y. Li)0305657(IBSC)
山乌桕 *Triadica cochinchinensis*	华南农业大学树木园 The Arboretum of South China Agricultural University	邓良(L. Tang) 0274963(IBSC)

表 2 光学显微镜下 3 种乌桕属植物叶表皮细胞特征

Table 2 Characteristics of leaf epidermal cells of 3 species of *Triadica* under light microscope

	种名 Species	细胞形状 Cell Shape	细胞周长 Cell perimeter/μm	细胞面积 Cell area/μm²	气孔有无 Stomata	图版Ⅰ Plate Ⅰ
下表皮 Lower epidermis	圆叶乌桕 *T. rotundifolia*	无规则型 Irregular	75.930	296.061	有 Have	1A,1B
	乌桕 1 *T. sebifera* 1	无规则型 Irregular	81.293	391.334	有 Have	2A,2B
	山乌桕 *T. cochinchinensis*	无规则型 Irregular	116.629	685.494	有 Have	3A,3B
上表皮 Upper epidermis	圆叶乌桕 *T. rotundifolia*	无规则型 Irregular	113.444	724.617	无 None	1C,1D
	乌桕 1 *T. sebifera* 1	多边形 Polygonal	121.083	776.233	有 Have	2C,2D
	山乌桕 *T. cochinchinensis*	无规则型 Irregular	111.970	641.459	无 None	3C,3D

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表3 光学显微镜下3种乌桕属植物气孔特征

Table 3 Characteristics of stomata in 3 species of *Triadica* under light microscope

种 Species	位置 Location	大小 Size /μm²	长宽比 Length-width ratio	气孔指数 Stomatal index	气孔密度 Stomatal density /(个·mm⁻²)	气孔形状 Stomatal shape	气孔器类型 Stomatal type	副卫细胞大小 Subsidisry size /μm²	图版Ⅰ Plate Ⅰ
圆叶乌桕 *T. rotundifolia*	下表皮 Lower epidermis	20,328×11,672	1.736	9.149	324.77	椭圆形 Oval	无规则型 Anomocytic	无 None	1A,1B
乌桕1 *T. sebifera* 1	下表皮 Lower epidermis	20,944×10,631	1.975	16.308	347.83	椭圆形 Oval	平列型 Paracytic	35,161×29,391	2A,2B
乌桕2 *T. sebifera* 2	上表皮 Upper epidermis	19,362×10,008	1.940	5.971	90.69	椭圆形 Oval	平列型 Paracytic	36,859×44,800	2C,2D
山乌桕 *T. cochinchinensis*	下表皮 Lower epidermis	18,116×7,266	2.501	14.387	397.70	椭圆形 Oval	平列型 Paracytic	24,775×19,391	3A,3B

表4 3种乌桕属植物的叶表皮在扫描电镜下的特点

Table 4 Characteristics of leaf abaxial epidermis of 3 species of *Triadica* under SEM

种类 Species	位置 Location	气孔器 Stomatal apparatus	气孔外拱盖纹饰 Ornamentation of outer stomatal ledge	气孔外拱盖内缘 Inner margin of outer stomatal ledge	蜡质纹饰 Wax ornamentation	蜡被 Waxy coating	图版Ⅱ Plate Ⅱ
圆叶乌桕 *T. rotundifolia*	上表皮 Upper epidermis	无 None	无 None	无 None	厚,条状隆起成网 Thick,strip hunch to retiform	片状,网状 Lamellar,reticulate	1C
	下表皮 Lower epidermis	气孔水平,椭圆形 Flat,oval	环状外缘,鳞片状突起,颗粒状 Ring edge,scalelike,granular	近平滑 Nearly smooth	厚,海星状排列 Thick,starfishlike	近圆球状,片状 Near globular,lamellar	1A,1B
乌桕1 *T. sebifera* 1	上表皮 Upper epidermis	无 None	无 None	无 None	较厚,条状突起成网状 Thicker,strip hunch to retiform	小颗粒状,片状 Small grainy,lamellar	2C
	下表皮 Lower epidermis	气孔微凸,椭圆形 Extrude,oval	环状外缘,条状隆起,颗粒状 Ring edge,strip hunch,granular	近平滑 Nearly smooth	厚,鳞片状覆盖 Thick,scalelike cover	小颗粒状,片状 Small grainy,lamellar	2A,2B
乌桕2 *T. sebifera* 2	上表皮 Upper epidermis	无 None	无 None	无 None	薄,近平滑 Thin,nearly smooth	小鳞片状 Small scalelike	3C
	下表皮 Lower epidermis	气孔微凸,椭圆形 Extrude,oval	环状外缘,条状隆起,颗粒状 Ring edge,strip hunch,granular	近平滑 Nearly smooth	较厚,鳞片状覆盖 Thicker,scalelike cover	鳞片状,网状 Scalelike,reticulate	3A,3B
山乌桕 *T. cochinchinensis*	上表皮 Upper epidermis	无 None	无 None	无 None	薄,条状微突 Thin,strip hunch	鳞片状,片状 Scalelike,lamellar	4C
	下表皮 Lower epidermis	气孔突出,椭圆形 Extrude,oval	环状外缘,波纹条状隆起,较光滑 Ring edge,wave strip hunch,smooth	波状 Undulate	较厚,条状排列成网 Striation to retiform	鳞片状,片状 Scalelike,lamellar	4A,4B

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最大(776.233 μm^2)。叶片下表皮细胞大小则有明显的差异,圆叶乌桕下表皮细胞最小(296.061 μm^2),石灰岩地区生长的乌桕,其下表皮细胞也较小(391.334 μm^2),说明石灰岩生境对圆叶乌桕细胞大小的形成产生影响。3 种乌桕属植物的细胞形状可分为无规则型和多边形两类,其中乌桕上表皮细胞为多边形,圆叶乌桕和山乌桕上表皮形状相似,细胞壁呈光滑迂回的曲线,细胞之间相互镶嵌,排列紧密。下表皮细胞则均为无规则型。根据光镜的观察结果,圆叶乌桕和山乌桕气孔器集中在下表皮,乌桕上下表皮均有气孔器分布(表 2、图版Ⅰ)。

2.2 叶表皮气孔参数特征

由表 3 可知,圆叶乌桕、乌桕和山乌桕气孔长轴的变化范围在 18.1～21.0 μm 之间,其中圆叶乌桕叶片表皮气孔长轴为 20.328 μm;圆叶乌桕气孔大小为 20.328 $\mu m \times 11.672$ μm,在 3 个种中最大,山乌桕的气孔最小;圆叶乌桕的气孔长宽比最小,反映其气孔器更接近圆形;气孔指数和气孔密度均是反映气孔分布的指标,圆叶乌桕下表皮气孔指数为 9.149,气孔密度为 324.77 个 · mm^{-2};根据李焜章对气孔器类型的分类[6],圆叶乌桕的气孔器为无规则型,没有副卫细胞。乌桕和山乌桕的气孔器为平列型,有 2 个副卫细胞;3 个种的气孔形状均为椭圆形(表 3、图版Ⅰ)。

2.3 叶表皮附属物特征

表 4 显示,圆叶乌桕、乌桕和山乌桕的叶片表面均有蜡质。圆叶乌桕和生长在石灰岩地区的乌桕,其上下表皮有较厚的角质层和蜡质层,蜡质层和角质层在细胞表面形成蜡质纹饰;气孔外拱盖均有环状外缘,圆叶乌桕气孔外拱盖有密密的鳞片状突起,山乌桕和乌桕均为条状隆起,山乌桕气孔外拱盖较光滑,呈波纹条状。乌桕外拱盖密布颗粒状蜡质体;而气孔外拱盖内缘,除了山乌桕为波状以外,另外两种均接近平滑(表 4、图版Ⅱ)。

3 讨 论

植物在某一生境中的叶片形态特征能够反映该物种的环境可塑性,而叶片是营养器官中对环境变化最为敏感的器官[7],环境的影响主要体现在表皮细胞的大小和形状,气孔大小和密度,表皮的蜡质纹饰等方面。圆叶乌桕叶片面积较乌桕属的其他种大,叶片厚,革质,仅从外部形态推测,圆叶乌桕叶片的能量利用效率和保水能力相对较高。

3.1 圆叶乌桕叶表皮细胞与石灰岩生境适应关联

叶片表皮细胞大小与植物的代谢活动有关,生理活跃的细胞常常较小,而代谢活动弱的细胞则往往较大[8]。本试验观测结果表明,常年生长在石灰岩地区的圆叶乌桕下表皮细胞明显小于乌桕和山乌桕,而非石灰岩特有的乌桕,当其生长在石灰岩地区时,其下表皮细胞也较小,这说明植物表皮细胞因为环境因子的变化能发生适应性改变,即在高温干旱胁迫下,表皮细胞体积将变小。细胞体积小而数量多,相对表面积就会增大,这对物质的迅速交换和转运十分有利[2]。圆叶乌桕表皮细胞的这一特征,初步反映了圆叶乌桕在长期高温、干旱的石灰岩地区具有较强的环境适应性。

3.2 圆叶乌桕叶表皮气孔特征与石灰岩生境适应的关联

气孔是植物进行水分和气体交换的主要通道,气孔调节是植物抵御逆境胁迫,适应环境的有效策略[9]。Sam 等认为气孔的分布特征、密度和面积等受环境中水分状况的影响[10]。圆叶乌桕的气孔器特征体现在以下两方面:1)集中分布在下表皮,在石灰岩地区缺水的情况下,这一分布模式促进植物与外界气体交换的同时,又避免了多数气孔由于其他蒸腾散失水分,同时避免了很多对气孔的机械伤害;2)下表皮气孔外空隙口不像乌桕和山乌桕被有厚蜡质,只在离气孔器一定半径距离围绕气孔分布;并且圆叶乌桕的气孔并没有像乌桕和山乌桕那样突起,而是水平。上述特征能够保证圆叶乌桕叶片 CO_2 吸收通道畅通;气孔器附近的蜡质比叶片其他地方薄,是其适应石灰岩生境的体现。另外,圆叶乌桕的气孔指数和气孔密度较另外两个种小,在高温缺水的环境下能有效减少气孔的蒸腾作用;圆叶乌桕保卫细胞饱满,气孔长宽比低,使其对环境应答更为敏感快捷。圆叶乌桕的气孔器类型属于无规则型,没有副卫细胞,因此区别于另外两个种,副卫细胞的缺乏是否与石灰岩生境有关仍有待进一步深入研究。

3.3 圆叶乌桕叶表皮蜡质与石灰岩生境适应关联

圆叶乌桕的上下叶表皮均有较厚的蜡质层,这些蜡质纹饰是由表皮细胞经过分泌作用形成的[11]。蜡质层连同角质层一起覆盖在叶表皮形成保护层,从而使表皮具有一定的保水性,减少体内水分蒸腾,并能够防止病菌侵入[12]。据在广东省连州、从化等石灰岩地区考察显示,圆叶乌桕种群生长状况良好,枝叶繁茂,极少发生病虫害,这与蜡质的保护应有一定关系。在阳光充沛,高温干旱的石灰岩地区,蜡质层还起到反射强光辐射的作用[13]。生长在广州市

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从化吕田石灰岩地区的乌桕样品同样具有较厚的蜡质，反映出对石灰岩环境的适应。生长在石灰岩地区的乌桕和圆叶乌桕叶表皮蜡质表现出相同的趋向，丰富的叶表蜡质层可以减少水分散失，增强对强光和干旱的适应性。

上述研究表明，圆叶乌桕的叶表皮形态具有典型的旱生结构特征：叶表皮细胞小，排列紧密，气孔集中分布下表皮，表皮气孔大，保卫细胞饱满，叶表皮被有厚角质层和蜡质层。这些特征保证了圆叶乌桕在高温干旱的石灰岩地区具有较强的保水能力和吸收养分的能力，适应在石灰岩地区生长。

致谢：衷心感谢华南农业大学公共基础实验中学植物学实验室的俞新华、羊海军老师和林学院 2007 级何敏贤、刘锡辉、林森同学，以及中科院华南植物园标本馆曾飞燕工程师对实验取样给予的大力支持。

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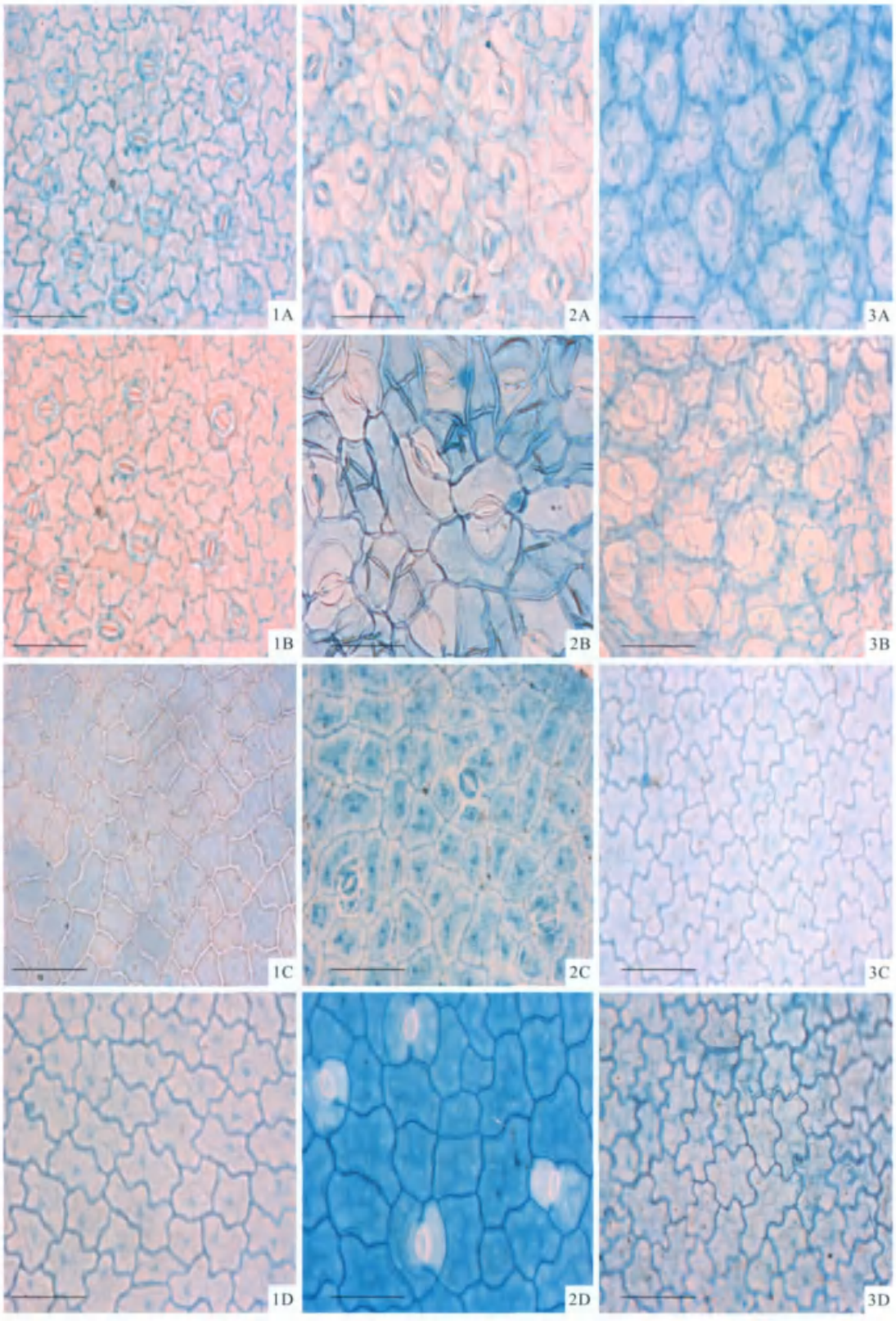
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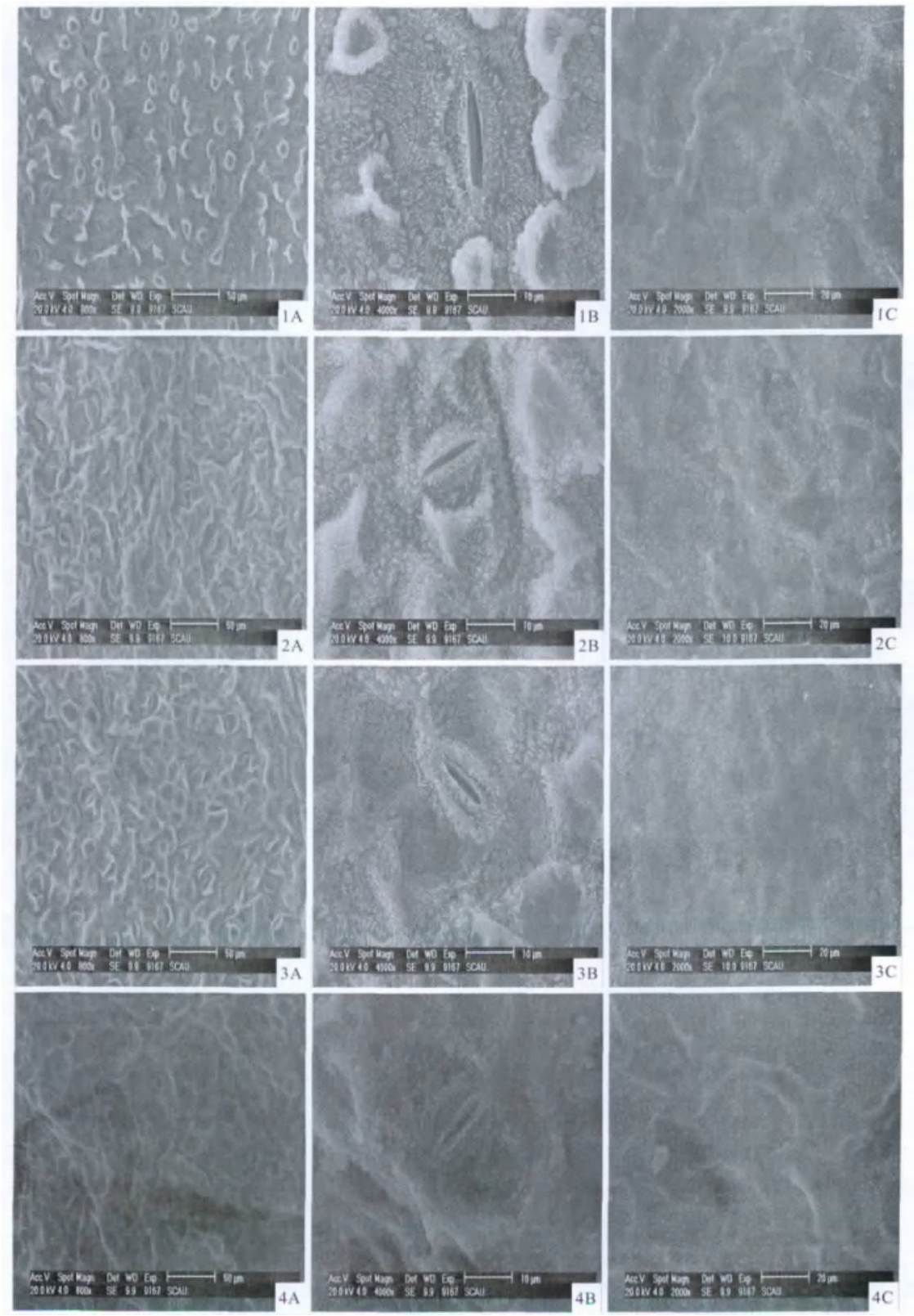
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图版 Ⅰ 1A～1D. **圆叶乌桕**；2A～2D. **乌桕**；3A～3D. **山乌桕**。A、B **为下表皮细胞**，C、D **为上表皮细胞**。**标尺**＝50 μm。

Plate Ⅰ Fig. 1A～1D. *T. rotundifolia*; Fig. 2A～2D. *T. sebifera*; Fig. 3A～3D. *T. cochinchinensis*. A and B represents the cells of upper epidermis, C and D represent the cells of lower epidermis. Bar＝50 μm.

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图版 Ⅱ　1A～1C. **圆叶乌桕**；2A～2C. **乌桕** 1；3A～3C. **乌桕** 2；4A～4C. **山乌桕**。A、B **代表叶下表皮细胞**：A，×800；B，×4 000；C **为叶上表皮细胞**，×2 000。

Plate Ⅱ　Fig. 1A～1C. *T. rotundifolia*；Fig. 2A～2C. *T. sebifera*（sample 1）；Fig. 3A～3C. *T. sebifera*（sample 2）；Fig. 4A～4C. *T. cochinchinensis*. A and B represent the cells of lower epidermis：A，×800；B，×4 000；C represents the cells of upper epidermis，×2 000.

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- 中国期刊方阵“双效”期刊
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- 中国核心期刊（遴选）数据库核心期刊
- 中国学术期刊综合评价数据库统计源期刊

执行主编 南红梅　　英 文 编 辑 张文俊(美)
责任编辑 裴阿卫　　拉丁文编辑 吴振海

西北植物学报
XIBEI ZHIWU XUEBAO
月刊 （1980年创刊）
第32卷 第4期 2012年4月

ACTA BOTANICA
BOREALI-OCCIDENTALIA SINICA
Monthly （Started in 1980）
Vol.32 No.4 Apr. 2012

主管单位 中华人民共和国教育部
主　　办 西北农林科技大学
陕西省植物学会
编　　辑 《西北植物学报》编辑部
陕西杨陵邰城路3号西北农林科技大学
邮政编码：712100 电话：029-87082936
E-mail:xbzwxb@vip.163.com
主　　编 赵 忠
出　　版 科学出版社
（北京东黄城根北街16号，邮编：100717）
印刷装订 陕西龙源印务有限公司
订 购 处 全国各地邮局
国内发行 杨凌示范区邮政局
国外发行 中国国际图书贸易总公司
（北京399信箱 邮政编码：100044）
网　　址 http://www.xbzwxb.com

Administrated by : Ministry of Education of P. R. C
Sponsored by : Northwest A & F University
Botanical Society of Shaanxi Province
Edited by : Editorial Department of Acta Botanica Boreali-Occidentalia Sinica
（3 Taicheng Road, Yangling, Shaanxi, 712100, China）
Editor in Chief : ZHAO Zhong
Published by : Science Press
（16 Donghuangchenggen North Street,Beijing 100717,China）
Printed by : Shaanxi Longyuan Printing Co., Ltd.
Domestic : All Local Post Offices in China
Domestic Distributor : Yangling Post Offices
International Distributor : China International Book Trading Corporation
（P.O.Box 399, Beijing 100044,China）

国内外公开发行
广告经营许可证 6104031000014
刊　号：ISSN1000-4025 / CN61-1091/Q
国内邮发代号：52-73
国外发行代号：M5897
定价：35.00元

中文核心期刊
中国科技核心期刊
BBR

ISSN 1673-5102
CN 23-1480/S

植物研究

Bulletin of Botanical Research

第32卷 第2期
2012年3月

Vol.32 No.2
March, 2012

东北林业大学 主办
Sponsored by Northeast Forestry University

科学出版社 出版
Published by Science Press

科学出版社

植 物 研 究

Zhiwuyanjiu

（双月刊）

第32卷 第2期（总第146期） 2012年3月

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〔期刊基本参数〕CN 23-1480/S＊1959＊b＊A4＊128＊zh＋en＊P＊￥14.00＊900＊22＊2012－03＊n

植物研究 2012,32(2):137~142
Bulletin of Botanical Research

12 种鹅绒藤属(萝藦科)植物花粉器形态学研究

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摘 要 用光学显微镜对萝藦科(Asclepiadaceae)鹅绒藤属(*Cynanchum*)12 种植物花粉器形态进行了观察。结果表明:花粉块的形态有 3 种类型:球形、长球形和超长球形。着粉腺的形态有 6 种类型:长圆形、方形、近方形、三角形、正三角形和近三角形。花粉器形态学结果对青羊参(*Cynanchum otophyllum*)在鹅绒藤属中的分类具有较大意义;支持《中国植物志》第 63 卷中对催吐白前组(Sect. *Vincetoxicum*)的分组处理;结合鹅绒藤属花粉块下垂,娃儿藤属(*Tylophora*)花粉块平展的特点,支持将娃儿藤属作为一个独特类群的观点。

关键词 鹅绒藤属;花粉器;萝藦科;分类

中图分类号: Q949.776.6 **文献标识码:** A **文章编号:** 1673-5102(2012)02-0137-06

Pollinarium Morphology of 12 Species of *Cynanchum*(Asclepiadaceae)

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Abstract The pollinarium morphology of 12 species of *Cynanchum* Linn. were observed under light microscope (LM). Three types of pollinia (spheroidal, prolate and perprolate) and six types of retinaculum (oblong, square, near square, regular triangle and near triangle) were observed. This is important for the classification of *Cynanchum otophyllum* and supports the treatment of *Cynanchum* Sect. *Vincetoxicum* in *Flora of China* (Vol. 63). As the pollinarium in *Cynanchum* is saggy while that of *Tylophora* R. Br. is horizontal, it supports that *Tylophora* should be a unique group.

Key words *Cynanchum*; pollinarium; Asclepiadaceae; Taxonomy

鹅绒藤属(*Cynanchum* Linn.)隶属于萝藦科(Asclepiadaceae),是一个具有重要经济价值和学术价值的类群。该属自建立以来属下分类群已发表的合法名称有 300 多个,由于地理分布广,形态变异大,属及属下类群的分立和归并问题一直是萝藦科分类争论的焦点之一,至今仍存在很大争议,以至于给其资源保护与利用造成混乱,中药材误用事故屡见不鲜。

为了探讨花粉器形态在鹅绒藤属植物中的分类学意义,本研究通过查阅华南农业大学植物标本馆馆藏的鹅绒藤属标本,对 12 种鹅绒藤属植物的花粉器进行光学显微镜观察,比较分析花粉器形态特征,以期为该属植物分类研究及可持续利用提供科学依据。

1 材料和方法

1.1 试验材料

试验材料均取自华南农业大学植物标本馆(CANT)的腊叶标本,材料具体信息见表 1 和图版Ⅰ。

1.2 试验方法

从腊叶标本上取花,用 10% 的 KOH 复水 10 min 后,取出置于载玻片上,在解剖镜下用解剖针轻轻拔下花粉器。在体视镜下观察,并用 Image-pro Express 5 对花粉器进行拍照,对着粉腺、花粉

基金项目:国家自然科学基金(31000095)、国家高等学校本科特色专业建设点——林学(教高函[201015]号)和广东省大学生创新实验项目(1056411009,LX005)

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收稿日期:2011-09-28

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块的高度和直径进行测量，并对花粉块柄的长度进行测量。每次测量 3 个花粉器，取平均值。

花粉器、着粉腺和花粉块等特征类型术语参考中国科学院中国植物志编委会[1]、王伏雄[2]、Hesse M.[3]等资料。

表 1 鹅绒藤属植物花粉器研究的试验材料及凭证标本

Table 1 Materials and voucher specimens of pollinarium of *Cynanchum*

种名 Species	采集地 Locality	凭证标本 Voucher specimen
鹅绒藤 *C. chinense*	河南新乡 Xinxiang, Henan	钟观光 K. K. Tsoong 3633
牛皮消 *C. auriculatum*	四川峨眉山 Emeishan, Sichuan	熊济华等 J. H. Xiong et al. 32382
生马牛皮消 *C. maximoviczii*	台湾 Taiwan	采集人不详 Anonymous 21300
催吐白前 *C. vincetoxicum*	台湾 Taiwan	G. Masamune 4432
柳叶白前 *C. stauntonii*	江西星子 Xingzi, Jiangxi	梁国贤 G. X. Liang 2648
蔓白前 *C. volubile*	台湾 Taiwan	G. Masamune 3677
毛白前 *C. mooreanum*	湖北武昌 Wuchang, Hubei	钱重海 Z. H. Qian 272
山白前 *C. fordii*	福建南靖 Nanjing, Fujian	陈恒彬 H. B. Chen 902
竹灵消 *C. inamoenum*	不详 Without detailed location	Y. Kudo 3090
昆明杯冠藤 *C. wallichii*	不详 Without detailed location	E. Bodinier 1998
青羊参 *C. otophyllum*	四川峨眉山 Emeishan, Sichuan	张纲 G. Zhang 1237
台湾杯冠藤 *C. formosanum*	台湾 Taiwan	采集人不详 Anonymous 21284

2 结果与分析

2.1 花粉块的特征

在所观察的 12 种鹅绒藤属植物中，花粉块在每个药室内藏 1 个，下垂，每个花粉器有花粉块 2 个。依据观察结果，可以将花粉块的形态分为 3 类：(A) 球形，包括竹灵消和台湾杯冠藤；(B) 长球形，包括昆明杯冠藤、蔓白前、生马牛皮消、青羊参、毛白前和山白前；(C) 超长球形，包括柳叶白前、催吐白前、牛皮消和鹅绒藤。花粉块的平均大小为 305.6 μm × 172.0 μm，其中柳叶白前的花粉块最小，为 186.3 μm × 86.7 μm；台湾杯冠藤的花粉块最大，为 460.0 μm × 387.0 μm。花粉块的长度与直径之比介于 1.19(台湾杯冠藤) 到 2.58(催吐白前) 之间(表 2)。

2.2 着粉腺的特征

着粉腺的形态有呈近圆形，如昆明杯冠藤(图版Ⅱ:10)；有呈长圆形，如鹅绒藤(图版Ⅱ:1)、竹灵消(图版Ⅱ:9)、毛白前(图版Ⅱ:7)、柳叶白前(图版Ⅱ:5) 和催吐白前(图版Ⅱ:4)；有呈方形，如台湾杯冠藤(图版Ⅱ:12)；有呈近方形，如牛皮消(图版Ⅱ:2)；有呈三角形，如蔓白前(图版Ⅱ:6)、青羊参(图版Ⅱ:11)；有呈正三角形，如生马牛皮消(图版Ⅱ:3)；有呈近三角形，如山白前(图版Ⅱ:8)。在所观察的 12 种鹅绒藤属植物中，着粉腺的背面有一条竖直的腺缝，将着粉腺平分；着粉腺与花粉块的长轴平行，大部分种的着粉腺 2 个侧壁均宽且厚，仅竹灵消的着粉腺侧壁较薄。着粉腺的下端(与着粉块柄相连的一段) 向内凹陷，形成一缺刻，上端钝圆(如昆明杯冠藤)，锐尖(如蔓白前)，开裂(如催吐白前)。着粉腺的高度和直径在各个种之间变异很大，其中柳叶白前的着粉腺高度与直径均最小，为 178.7 μm × 115.8 μm，而台湾杯冠藤的着粉腺高度和直径最大，为 507.2 μm × 510.6 μm。着粉腺的高度和直径的比值介于 0.99(台湾杯冠藤) 和 1.73(毛白前) 之间。

2.3 着粉块柄的特征

鹅绒藤属植物着粉块柄一端均系于着粉腺的基侧，另一端膨大，与花粉块顶部相连，着粉块柄平展。着粉块柄的长短不一，其长度介于 94.7 μm (山白前) 和 203.2 μm(牛皮消) 之间。着粉块柄与花粉块的长度比值可用于评价着粉块柄的发达程度[4]。研究结果表明山白前和台湾杯冠藤的着粉块柄最不发达，昆明杯冠藤和生马牛皮消次之，而竹灵消和蔓白前的着粉块柄最发达(表 2)。

3 讨论

鹅绒藤属植物腊叶标本的花粉器与复水后形态不会发生很大的改变，可以作为分类的主要依据。前人对鹅绒藤属植物的研究集中在对其药理作用和化学成分的研究，而有关鹅绒藤属花粉器的研究鲜见报道。作者对鹅绒藤属的花粉块、着粉腺及花粉块柄研究结果表明鹅绒藤属植物的花粉块、着粉腺的形态大小和着粉块柄的长度变异比较大。根据 Hesse M 等[3]对花粉形状的划分，可以将所观

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表 2 鹅绒藤属 12 种植物花粉器形态

Table 2 Pollinarium morphology of 12 species of *Cynanchum*

种名 Species	花粉块 Pollinia				着粉腺 Retinaculum				着粉块柄 Caudicle	柄长度/块长度 Length of caudicle/pollinia
	形态 Shape	高 Height(μm)	直径 Diameter(μm)	高度/直径 Height/Diameter	形态 Shape	高 Height(μm)	直径 Diameter(μm)	高度/直径 Height/Diameter	长 Length(μm)	
鹅绒藤 *C. chinense*	超长球形 Perprolate	246.4	119.9	2.06	长圆形,顶端钝圆 Oblong with blunt end	298.6	211.0	1.42	101.6	0.41
牛皮消 *C. auriculatum*	超长球形 Perprolate	421.4	178.8	2.36	近方形,顶端钝圆 Near square with blunt end	395.5	302.4	1.31	203.2	0.48
生马牛皮消 *C. maximowiczii*	长球形 Prolate	405.4	209.2	1.94	正三角形,顶端尖 Regular triangle with pointed end	405.3	295.5	1.37	157.7	0.39
催吐白前 *C. vincetoxicum*	超长球形 Perprolate	331.0	128.2	2.58	长圆形,顶端开裂 Oblong with dissilient end	334.2	230.9	1.45	171.4	0.52
柳叶白前 *C. stauntonii*	超长球形 Perprolate	186.3	86.7	2.15	长圆形,顶端圆 Oblong with blunt end	178.7	115.8	1.54	118.9	0.64
蔓白前 *C. volubile*	长球形 Prolate	240.5	141.1	1.70	三角形,顶端锐尖 Triangle with pointed end	445.8	287.6	1.55	165.6	0.69
毛白前 *C. mooreanum*	长球形 Prolate	215.6	141.1	1.53	长圆形,顶端钝圆 Oblong with blunt end	332.6	192.7	1.73	106	0.49
山白前 *C. fordii*	长球形 Prolate	300.7	164.9	1.82	近三角形,顶端钝圆 Near triangle with blunt end	290.4	202.6	1.43	94.7	0.31
竹灵消 *C. inamoenum*	球形 Spheroidal	212.9	142.5	1.49	长圆形,顶端急尖 Oblong with pointed end	386.5	242.9	1.59	168.6	0.79
昆明杯冠藤 *C. wallichii*	长球形 Prolate	338.1	169.1	2.00	近圆形,顶端钝圆 Near roundness with blunt end	306.6	232.7	1.32	113.2	0.33
青羊参 *C. otophyllum*	长球形 Prolate	378.7	204.7	1.85	三角形,顶端尖 Triangle with pointed end	358.4	332.8	1.08	159.9	0.42
台湾杯冠藤 *C. formosanum*	球形 Spheroidal	460.0	387.0	1.19	方形,顶端凹缺 Square with concave blunt	507.2	510.6	0.99	142.4	0.31

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察的 12 个种的花粉块分为 3 种类型: 花粉块球形【高度: 直径) ≤1.5】、长球形【1.5 <(高度: 直径) ≤2】和超长球形【(高度: 直径) >2】。根据着粉腺的形态特征则可分为 6 种类型: 长圆形、方形、近方形、三角形、正三角形和近三角形。但综合考虑花粉块和着粉腺的形态大小、花粉块柄的长度以及花粉块柄与花粉块长度的比值,对这些分类群进行完整的归纳还是较为困难。

3.1 鹅绒藤属内的分类讨论

《中国植物志》第 63 卷[1] 把鹅绒藤属分为七个组,其中青羊参、昆明杯冠藤、台湾杯冠藤同属于青羊参组,牛皮消和生马牛皮消同属于牛皮消组。然而,根据花粉器观测结果可以看出,青羊参与台湾杯冠藤以及昆明杯冠藤无论是在花粉块的形态大小、着粉腺的形态大小、着粉块柄的长度和发达程度等均存在着较大差异。而青羊参与生马牛皮消的花粉块、着粉腺的形态大小更为相近: 两者的花粉块均为长球形且大小相近(青羊参 378.7 μm × 204.7 μm,生马牛皮消 405.4 μm × 209.2 μm) ; 青羊参的着粉腺为三角形,大小为 358.4 μm × 332.8 μm; 生马牛皮消的着粉腺为正三角形,大小为 405.3 μm × 295.5 μm; 两者的花粉块柄接近等长(青羊参 159.9 μm,生马牛皮消 157.7 μm) 且花粉块柄与花粉块长度的比值一样(均为 0.42) ,表明两者花粉块柄的发达程度一样。青羊参和生马牛皮消两者花粉器的相似性,可以为青羊参在鹅绒藤属中的分类问题提供一定的参考依据,但仍有待更多实验证据的支持。

花粉块柄与花粉块的长度比值不仅可用于评价花粉块柄的发达程度,而且花粉块柄在判断类群间的进化关系上也具有重要意义,因为发达的花粉块柄更有利于花粉块翻转,能更好地适应萝藦科植物特殊的传粉机制[5] 。实验观测的 12 种鹅绒藤属植物花粉块柄与花粉块的长度比值由大到小排列为: 竹灵消 > 蔓白前 > 柳叶白前 > 催吐白前 > 毛白前 > 牛皮消 > 青羊参 > 鹅绒藤 > 生马牛皮消 > 昆明杯冠藤 > 山白前 = 台湾杯冠藤,变化范围从 0.79(竹灵消) 到 0.31(山白前和台湾杯冠藤) ,其中除山白前以外,竹灵消、蔓白前、柳叶白前、催吐白前和毛白前的花粉块柄都较本研究中观察的其它种类的花粉块柄发达。可见,《中国植物志》第 63 卷[1] 中对催吐白前组的分类是较为自然的处理。

3.2 鹅绒藤属与其近缘亲属的分类讨论

花粉器上花粉块数量的多寡、有无花粉块柄是分亚科的唯一特征,而花粉块的方向和位置则是马利筋亚科分族的主要依据之一。花粉块按其方向和位置,可以分为下垂、直立和平展 3 种类型。花粉块下垂的类型包括马利筋族等,花粉块直立的类型包括牛奶菜族的大部分属等; 花粉块平展的类型包括娃儿藤属和箭药藤属(Belostemma Wall ex Wight) 等[1] 。Endress 等[6] 发表的夹竹桃科(包括萝藦科) 的分类系统中,把娃儿藤属归入了马利筋族。研究所观察的 12 种鹅绒藤属植物中,花粉块均下垂,而李丽文[7] 对娃儿藤属 13 种植物的花粉器形态研究表明娃儿藤属的花粉块为平展。因此,实验研究结果不赞成把娃儿藤属归入马利筋族,并支持莫罗坚[4] 将娃儿藤属作为一个独特类群的观点。

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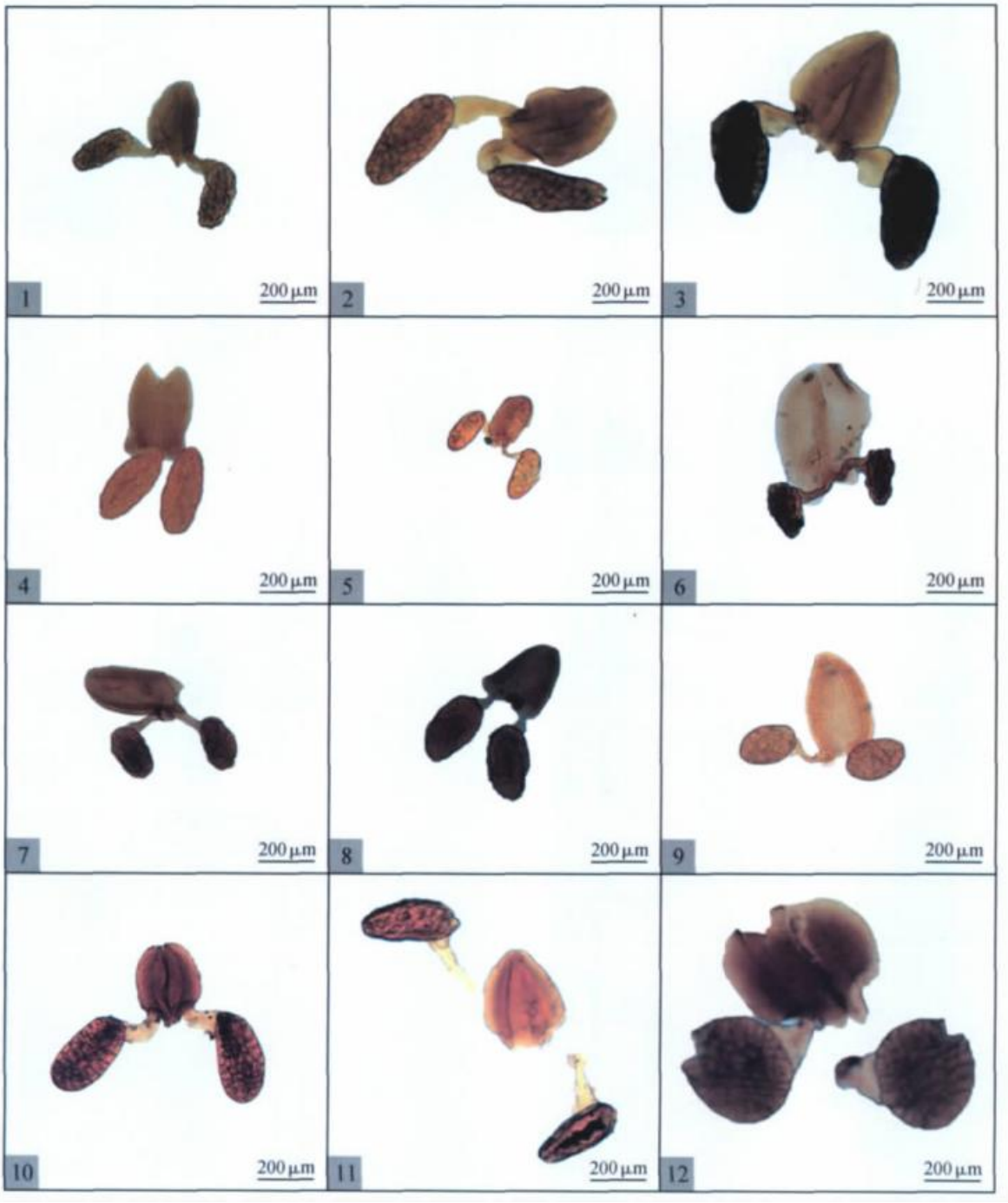
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图版 I　鹅绒藤属植物凭证标本　1A、1B. **鹅绒藤**; 2A、2B. **牛皮消**; 3A、3B. **生马牛皮消**; 4A、4B. **催吐白前**; 5A、5B. **柳叶白前**; 6A、6B. **蔓白前**; 7A、7B. **毛白前**; 8A、8B. **山白前**; 9A、9B. **竹灵消**; 10A、10B. **昆明杯冠藤**; 11A、11B. **青羊参**; 12A、12B. **台湾杯冠藤**

Plate I　Voucher specimens of *Cynanchum*　1A, 1B. *C. chinense*; 2A, 2B. *C. auriculatum*; 3A, 3B. *C. maximoviczii*; 4A, 4B. *C. vincetoxicum*; 5A, 5B. *C. stauntonii*; 6A, 6B. *C. volubile*; 7A, 7B. *C. mooreanum*; 8A, 8B. *C. fordii*; 9A, 9B. *C. inamoenum*; 10A, 10B. *C. wallichii*; 11A, 11B. *C. otophyllum*; 12A, 12B. *C. formosanum*

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图版 Ⅱ 鹅绒藤属植物花粉器 1. 鹅绒藤; 2. 牛皮消; 3. 生马牛皮消; 4. 催吐白前; 5. 柳叶白前; 6. 蔓白前; 7. 毛白前; 8. 山白前; 9. 竹灵消; 10. 昆明杯冠藤; 11. 青羊参; 12. 台湾杯冠藤

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国内统一刊号：CN 23-1480/S，国际标准刊号：ISSN 1673-5102，双月刊，每期128页。

邮发代号：国内邮发代号14-77。全国各地邮局(所)均可订阅。错过订期者可直接向本刊编辑部邮购(加收邮资：平寄2.00元/本，挂号寄4.00元/本)，并注明订阅年份、期数、册数。

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植 物 研 究

(双月刊 1959年创刊)

2012年3月 第32卷 第2期

Bulletin of Botanical Research

(Bimonthly Started in 1959)

Vol. 32 No.2 Mar., 2012

编　　辑　《植物研究》编辑部
哈尔滨市和兴路26号东北林业大学,150040
电子信箱：zhiwuyanjiu@vip.163.com
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主管单位　中华人民共和国教育部

主办单位　东北林业大学

主　　编　祖元刚

出　　版　科学出版社
北京东黄城根北街16号
邮政编码：100717

印　　刷　哈尔滨工业大学印刷厂

总发行处　哈尔滨市邮政局

订 购 处　全国各地邮局

国外发行　中国国际图书贸易总公司
(北京399信箱 100044)

广告经营许可证 2301070000008

Edited by Editorial Office of《Bull. Bot. Res.》
Northeast Forestry University, No. 26 Hexing Road, Harbin 150040, China
E-mail: zhiwuyanjiu@vip.163.com
Tel:0451-82190611
URL: http://bbr.nefu.edu.cn

Administrated by Ministry of Education of the People's Republic of China

Sponsored by Northeast Forestry University

Editor-in-Chief: ZU Yuan-Gang

Published by Science Press
(16 Donghuangchenggen North Street, Beijing 100717, China)

Printed by Harbin Institute of Technology Printing House

Distributed by Harbin Post Office

Domestic: All Local Post Offices in China

Foreign: China International Book Trading Corporation
(P.O. Box 399, Beijing 100044, China)

国内邮发代号：14-77

国外发行代号：BM562

定价：14.00元

ISSN 1673-5102



ISSN 1673-923X
CODEN ZLKDA5

中南林业科技大学学报

Journal of Central South University of Forestry & Technology

第31卷 Volume 31 | 第9期 Number 9

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[期刊基本参数] CN43-1470/S*1981*m*A4*171*zh*P*¥20.00*1200*35*2011-9*p

第 31 卷 第 9 期(总第 123 期) 2011 年 9 月出版

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本期编辑:谢荣秀 吴 毅 欧阳钦 英文编辑:谢荣秀 吴 毅 欧阳钦

中南林业科技大学学报

ZHONGNAN LINYE KEJI DAXUE XUEBAO

（月刊，1981年创刊）
第31卷第9期（总第123期） 2011年9月出版

主管单位 湖南省教育厅
主办单位 中南林业科技大学
主　　编 吴晓芙
社　　长 伍　谦
编辑出版 《中南林业科技大学学报》编辑部
湖南长沙市韶山南路498号 邮政编码：410004
电话：0731-85623395
E-mail：xb-csfu@163.com
印　　刷 湖南和成彩印有限公司
国外总发行 中国出版对外贸易总公司
（北京782信箱，邮编：10011）
国内发行 中南林业科技大学期刊社

JOURNAL OF CENTRAL SOUTH UNIVERSITY OF FORESTRY & TECHNOLOGY

(Monthly, Started in 1981)
Vol. 31 No. 9(Sum123) Sep. 2011

Administered by Education Department of Hunan Province

Sponsored by Central South University of Forestry & Technology

Chief Editor WU Xiao-fu

Periodicals Press Director WU Qian

Edited & Published by Ed.Dept.of Journ.of CSUFT
(Changsha 410004, Hunan, China)
E-mail：xb-csfu@163.com

Printed by Hunan Hecheng Color Printing Co.Ltd.

Distributed abroad by China National Publishing Industry Trading Corporation
(P.O.BOX 782, Beijing, 100011, China)

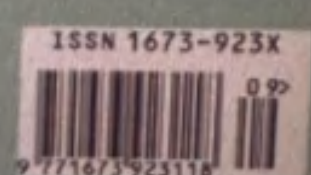
Distributed domestically by Periodicals Press of CSUFT

刊　　号：ISSN 1673-923X
CN43-1470/S

订阅网址：www.kankan.com.cn

国内定价：20.00元/本

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DOI:10.14067/j.cnki.1673-923x.2011.09.035

海南浆纸林林下维管植物区系研究

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摘 要: 根据实地调查与标本采集,现记录到海南浆纸林基地林下维管植物538种及种下单位,隶属于122科359属,其中蕨类植物26科44属85种1亚种,裸子植物2科2属2种,被子植物94科313属439种,9变种,2亚种,1栽培变种。该区系大型科少,没有大型属,主要为含1个种的小型属,区系优势科分别为大戟科、蝶形花科、茜草科、禾本科、锦葵科和菊科。种子植物区系成分较为复杂,主要表现在科地理成分的广泛性和属的地理成分的多样性。在科的分布区类型中,热带、亚热带的地理分布成分占优势;属的地理成分可划分为12个分布型和4个变型,其中以泛热带分布为主,占区系总数的42%。

关键词: 海南;浆纸林;地理成分;植物区系
中图分类号: Q948.5 **文献标志码:** A **文章编号:** 1673-923X(2011)09-0091-05

Study on the vascular plants flora under pulp-paper forest in Hainan

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Abstract: The floristic compositions, characteristics, rare and endangered plants in the pulp-paper Forest in Hainan were studied on the basis of field investigation, literatures checked and specimens collected. The main results are as follows. There are 538 vascular plant species, belonging to 359 genera in 122 families, recorded in pulp-paper forest in Hainan. Among them, 85 species and 4 varieties of pteridophytes, 2 species of gymnosperms, 439 species of angiosperms belong to 44 genera in 26 families, 2 genera in 2 families and 313 genera in 94 families, respectively. The tropical and subtropical distribution elements, especially these tropical Asia ones, are dominant in pulp-paper forest in Hainan. The tropical and subtropical distribution general of seed plants cover 42% of the total seed plants. However, there are still a few temperate distribution elements.

Key words: Hainan; pulp-paper forest; geographical element; flora

收稿日期: 2011-01-10
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海南人工林主要是种植橡胶、槟榔、椰子、桉树、木麻黄、相思类、松类等经济树种。桉树是桃金娘科 Myrtaceae 桉属 *Eucalyptus* 树种的总称，生长迅速，用途广泛，经济价值大，生态和社会效益显著，是全球三大著名速生树种（松、杨、桉）之一，也是海南岛浆纸林的主要树种之一。

海南浆纸林中的另一重要树种是相思类植物，隶属于含羞草科 Mimosaceae 金合欢属 *Acacia*。林下植被是人工林生态系统的一个重要组成部分，在促进人工林养分循环和维护林地地力中起着不可忽视的作用。海南人工林面积较大，然而对人工林下植物缺少系统调查研究。作者于 2007～2008 年对海南岛浆纸林林下植物进行调查研究，旨在弄清浆纸林林下植物区系特征，为浆纸林的合理栽培和可持续经营以及林下植被的保护提供理论依据与基础资料。

1 研究区概况

海南岛（18°10′～20°10′ N，108°37′～111°03′ E）位于中国最南端，面积约 3.4 万 km^2，是中国仅次于台湾的第二大岛。全岛气候温和，年平均气温 22～26 ℃，终年无霜雪，雨量充沛，年平均降雨量为 1 500～2 000 mm，具有我国最为典型的热带季风气候[1]。

海南浆纸林在海南各大县市均有分布，以西部和中部最为集中，多种植在海岸沙地和低海拔山地。

2 研究方法

2.1 文献收集

全面收集和利用已发表和未发表的有关浆纸林、人工林、海南岛植物研究等文献资料，包括论文、专著、植物志、采集记录等。在资料收集的基础上，采用典型取样与随机普查相结合，既照顾全面，又突出重点的方法。

2.2 野外实地调查

2007 年 10 月～2008 年 10 月实地调查了海南 18 个市县，路线分东线、中线和西线。选取桉树林、相思林、木麻黄林等不同的浆纸林品种类型，以及公司经营、公司加农户等不同的管理方式经营下的浆纸林区进行调查。调查时还将考虑到不同的生境条件及其不同的营林阶段。

2.3 植物区系统计分析

植物区系科的分析主要根据科的地理分布特征，并参照前人的观点[2-6]。属的分布区类型主要根据吴征镒对中国种子植物属的分布区类型划分[7]。通过对海南浆纸林林下植物科、属、种的数目统计以及地理成分，优势科和表征科的属种组成特点、区系性质的分析，揭示该地区植物区系的特点和性质。

3 结果与分析

3.1 海南浆纸林林下植物区系数量特征

根据在海南浆纸林的实地调查，共记录到维管植物 538 种及种下单位，隶属于 122 科 359 属，其中蕨类植物 26 科 44 属 85 种 1 亚种，裸子植物 2 科 2 属 2 种，被子植物 94 科 313 属 439 种，9 变种，2 亚种，1 栽培变种。

海南浆纸林中蕨类植物区系以凤尾蕨科、金星蕨科、里白科、鳞毛蕨科、水龙骨科所含属种为主，多为热带性质较强类群，并且很多都是常见种类。含种数最多的金星蕨科是以泛热带为分布中心的世界性大科，在海南浆纸林中毛蕨属 *Cyclosorus* 具有较多的种类，其他如新月蕨属 *Pronephrium*、假毛蕨属 *Pseudocyclosorus* 等也有少数代表，金星蕨科植物多生长在浆纸林向阳、开阔处，如渐尖毛蕨 *Cyclosorus acuminatus*、华南毛蕨 *C. parasiticu* 等仅分布在路边或山脚林缘，新月蕨 *Pronephrium asperum*、溪边假毛蕨 *Pseudocyclosorus ciliate* 则分布在潮湿的山谷中或水沟旁。

海南浆纸林中中国蕨科的种类有 2 种，即碎米蕨 *Cheilosoria mysurensis* 和薄叶碎米蕨 *C. tenuifolia* 等均为适应桉树林下干旱生境的蕨类植物种类。卷柏科在系统演化上是最古老的科之一，本科仅卷柏属 *Selaginella* 分布于全球，海南浆纸林地区有 1 属 5 种。卷柏科也有许多喜生长在浆纸林边缘或林下的种类如海南卷柏 *Selaginella rolandi-principis*、深绿卷柏 *S. doederleinii* 等。

鳞毛蕨科广布于全世界温带和亚热带高山，在海南浆纸林样地中仅有复叶耳蕨属 *Arachniodes*、

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拟贯众属 *Cyclopeltis* 等 4 属 4 种的分布。

海南浆纸林样地中裸子植物种类较为贫乏，仅有 2 种，即海南苏铁 *Cycas hainanensis* 和买麻藤 *Gnetum montanum*。海南苏铁仅见 3 株，分布在琼中上安马场和保亭六弓迈帮桉树林下次生林中。

海南浆纸林中被子植物 94 科 313 属 439 种，9 变种，2 亚种，1 栽培变种，占该地区维管植物种类总数的 83.0%，是该地区植物区系的主要组成部分。

海南浆纸林林下种子植物科的统计见表 1，可见海南浆纸林林下植物区系以单种科和寡种科为主，两者占总数的比例分别为 29%和 61%。

表 1　海南浆纸林林下种子植物科的类型统计

Table 1　Statistics of families types of seed plants under-growth pulp-paper forest in Hainan

科的类型 类群	单种科	寡种科 (2～10 种)	中等科 (11～20 种)	较大科 (21～50 种)
裸子植物	2	0	0	0
被子植物	25	57	4	4
合　计	27	57	4	4

3.2　海南浆纸林林下种子植物区系优势科

通过对海南浆纸林林下种子植物各科所含种数的统计可知，所含种类 10 种以上的只有 8 科(见表 2)，单属单种科则有 27 科。旋花科、莎草科、锦葵科、菊科、大戟科、禾本科等所含种类均在 10 种以上(含 10 种)，且在群落中也占优势。而桑科、茜草科、蝶形花科等虽然所含种类也在 10 种以上，但是这些科的种类在样方内数量并不多，因此这些科所含的种类在该地区的植物区系中不具代表性。

表 2　海南浆纸林林下种子植物含 10 种以上科的大小排列

Table 2　The families(≥10 species) of seed plants under-growth pulp-paper forest in Hainan

科名	属数	种数
大戟科 Euphorbiaceae	22	42
蝶形花科 Papilionaceae	23	32
茜草科 Rubiaceae	16	28
禾本科 Poaceae	26	28
锦葵科 Malvaceae	9	18
菊科 Compositae	17	18
桑科 Moraceae	6	15
莎草科 Cyperaceae	7	11
旋花科 Convolvulaceae	6	10

苦木科、山矾科、萝摩科、漆树科、野牡丹科、无患子科、梧桐科、白花菜科、桃金娘科、芸香科等科所含种类虽然在 10 种以下，但这些种类在群落中出现的频率相对较大，是群落中的优势种。

海南浆纸林林下植物含 10 种以上的科中，以泛热带分布的科为主，有 5 科，占含 10 种以上的总科数 55%，如桑科、锦葵科、茜草科、大戟科、蝶形花科等；其余 4 科均为世界分布科，占含 10 种以上的总科数 44%，分别是旋花科、莎草科、菊科、禾本科。

可见，海南浆纸林林下植物区系的具有较强的热带性质。

3.3　海南浆纸林林下种子植物区系属的大小统计

海南浆纸林林下种子植物含 4 种以上的属有 14 属(见表 3)，占该地区种子植物总属数的 4%；该地区主要由单种属组成，有 233 属，占总属数的 82%。

表 3　海南浆纸林林下种子植物的含 4 种以上的属的大小排列

Table 3　The genera(≥4 species) of seed plants under-growth pulp-paper forest in Hainan

属 名		属含种数	占总种数的百分比/%
榕属	*Ficus*	9	1.99
黄花稔属	*Sida*	8	1.77
耳草属	*Hedyotis*	6	1.32
槌果藤属	*Capparis*	5	1.10
叶下珠属	*Phyllanthus*	5	1.10
悬钩子属	*Rubus*	5	1.10
巴豆属	*Croton*	4	0.88
算盘子属	*Glochidion*	4	0.88
野桐属	*Mallotus*	4	0.88
决明属	*Cassia*	4	0.88
山绿豆属	*Desmodium*	4	0.88
素馨属	*Jasminum*	4	0.88
茄属	*Solanum*	4	0.88
母草属	*Lindernia*	4	0.88

海南浆纸林林下种子植物中以榕属(9 种)所含种类最多，榕属植物中的对叶榕、大果榕、斜叶榕等均为比较常见的种类；其次是黄花稔属(14 种)，多分布在林下灌丛和林缘，常见的有黄花稔、苘叶黄花稔、中华黄花稔、长梗黄花稔、心叶黄花稔、白背黄花稔等；耳草属所含种类在海南浆纸林林下较为常见，有些种类是群落的优势种，如耳草、牛白藤等；槌果藤属所含种类如曲枝槌果藤、小刺槌果藤、

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桃叶槌果藤等在桉树林下灌草从中常见;叶下珠属植物多见于草本层,如叶下珠、珠子草、黄珠子草等;悬钩子属为林缘、路边常见种类,如越南悬钩子、白花悬钩子等;巴豆属植物以鸡骨香、光叶巴豆、银叶巴豆等较为常见;野桐属以白背叶、白楸、粗糠柴等为主。

海南浆纸林林下植物上层灌木以榕属、野桐属、算盘子属等所含种类较多;中、下层灌木以黄花稔属、巴豆属等种类为主;草本层则以耳草属、叶下珠属、山绿豆属等种类为主;攀援灌木和藤本以槌果藤属、悬钩子属、素馨属等居多。

3.4 海南浆纸林林下种子植物区系植物区系性质

3.4.1 科的分布区类型与地理成分分析

海南浆纸林林下植物世界分布科 19 科,占总科数 20%。其中菊科、旋花科、玄参科、唇形科、禾本科、莎草科等所含种类常见于灌丛木下、林缘、荒坡等,堇菜科、远志科、藜科、瑞香科、百合科所含种类多见于林下稍隐蔽处,而蔷薇科、鼠李科所含种类则多生于林缘或林内向阳处。

海南浆纸林林下植物以热带、亚热带成分为主,有 68 科,占除世界分布科数外总科数的 89.47%。其中泛热带分布 61 科,占 80.26%。该地区中包括典型的热带科,如五桠果科、钩枝藤科及金虎尾科等。桃金娘科、野牡丹科、大戟科、蝶形花科、桑科、夹竹桃科、茜草科、葫芦科、无患子科、漆树科、马鞭草科、梧桐科、锦葵科及紫金牛科等所含种类较多,且所含属种都是以热带、亚热带分布为主。

温带性科有 8 科,占除世界分布科数外总科数的 10.53%,温带性科在海南浆纸林林下所含属种数较少,单种单属科有 3 个,即毛茛科、柳叶菜科、胡桃科,蓼科、金缕梅科、报春花科含 1 属 2 种,紫金牛科、紫草科含 2 属 4 种,这些成分在林下分布范围较窄,且数量较少。

3.4.2 属的分布区类型与地理成分分析

根据吴征镒(1991)对中国种子植物属的分布区类型划分,海南浆纸林林下种子植物所含的 290 属可以划分为 12 个分布区类型和 4 个变型,其中热带、亚热带成分有 258 属,占该地区非世界属总数的 93.82%;温带分布的属有 17 属,占非世界属总数的 6.18%。

世界分布的属有 15 属,如铁线莲属 *Clemati*、堇菜属 *Viola*、蓼属 *Polygonum*、远志属 *Polygala*、悬钩子属 *Rubus*、茄属 *Solanum*、莎草属 *Cyperus*、马唐属 *Digitaria* 等,这些属所含种类多为草本或藤本,多生长在荒坡、田野、路旁或林下向阳处,具有体型小,种子易于传播,环境适应能力强等共同特点。

泛热带及其亚型分布的属共有 117 属,占海南浆纸林林下种子植物中非世界属数的 42%,是该地区所占比例最大的分布类型,这些属所含的种类在植物群落中起着重要的作用,有的是群落中的优势类群。如牡荆属 *Vitex*、柞木属 *Xylosma*、黄花稔属 *Sida*、梵天花属 *Urena*、山矾属 *Symplocos*、鹅掌柴属 *Schefflera* 等在灌木至小乔木层中起重要作用。而牛膝属 *Achyranthes*、黄细心属 *Boerhavia*、决明属 *Cassia*、耳草属 *Hedyotis*、鱼黄草属 *Merremia*、狗尾草 *Setaria*、鼠尾粟属 *Sporobolus* 等则在林下草本层中占重要地位。藤本植物中常见的有槌果藤属 *Capparis*、盒果藤属 *Operculina*、巴戟天属 *Morinda*、崖豆藤属 *Millettia* 以及菝葜属 *Smilax* 等。

热带亚洲和热带美洲间断分布的属有 9 属,占海南浆纸林林下种子植物中非世界属数的 3.27%。多为藤本或灌木,其中一些是浆纸林林下或路旁常见种类,如山芝麻属 *Helicteres*、泡果茼属 *Herissantia*、雀梅藤属 *Sageretia*、泡花树属 *Meliosma* 等。

旧世界热带及其亚型分布的属有 48 属,占海南浆纸林林下种子植物中非世界属数的 17.45%,是该地区所占比例仅次于泛热带及其亚型的分布类型。多为灌木至小乔木层种类,也有少数草本种类。分布较广的有暗罗属 *Polyalthia*、蒲桃属 *Syzygium*、谷木属 *Memecylon*、扁担杆属 *Grewia*、五月茶属 *Antidesma*、血桐属 *Macaranga*、野桐属 *Mallotus*、合欢属 *Albizia*、倒吊笔属 *Wrightia*、鱼骨木属 *Canthium* 等。草本和藤本植物主要有黄葵属 *Abelmoschus*、狸尾草属 *Uraria*、老鸦嘴属 *Thunbergia*、杜若属 *Pollia* 等。

热带亚洲至热带大洋洲分布的属有 28 属,占海南浆纸林林下种子植物中非世界属数的 10.18%。小乔木层起重要作用的有樟属 *Cinnamomum*、第伦桃属 *Dillenia*、黑面神属 *Breynia*、赤

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才属 *Erioglossum*、水锦树属 *Wendlandia* 等，灌木层以荛花属 *Wikstroemia*、桃金娘属 *Rhodomyrtus*、野牡丹属 *Melastoma*、假木豆属 *Dendrolobium* 等为主，草本和藤本则以假鹰爪属 *Desmos*、轮环藤属 *Cyclea*、蝙蝠草属 *Christia*、山柑属 *Cansjera*、广防风属 *Epimeredi*、山菅兰属 *Dianella*、鹧鸪草属 *Eriachne* 等为主。

热带亚洲至热带非洲分布的属有 19 属，占海南浆纸林林下种子植物中非世界属数的 6.91%。多为灌木或草本，见于林下或林缘，如灌木常见的有肖槿属 *Thespesia*、小盘木属 *Microdesmis*、厚皮树属 *Lannea*、狗骨柴属 *Diplospora* 等，草本常见的有莠竹属 *Microstegium*、菅属 *Themeda* 等，藤本常见的有钩枝藤属 *Ancistrocladus*、土密树属 *Bridelia* 等。

热带亚洲及其变型分布共有 36 属，占海南浆纸林林下种子植物中非世界属数的 13%。黄肉楠属 *Actinodaphne*、润楠属 *Machilus*、黄牛木属 *Cratoxylum*、银柴属 *Aporosa* 等在小乔木层占据重要地位。灌木中常见的有破布叶属 *Microcos*、留萼木属 *Blachia*、排钱树属 *Phyllodium*、叶被木属 *Phyllochlamys*、鹊肾树属 *Streblus* 等。草本层中葫芦茶属 *Tadehagi*、棕叶芦属 *Thysanolaena*、芋属 *Colocasia* 较为常见。藤本植物则金瓜属 *Gymnopetalum*、茅瓜属 *Solena*、风车藤属 *Hiptage*、葛属 *Pueraria*、鸡矢藤属 *Paederia* 较为常见。

北温带及其亚型分布的属有 4 属，占海南浆纸林林下种子植物中非世界属数的 1.45%。海南浆纸林林下种子植物区系以热带、亚热带为主，但仍有一定比例的温带分布属，如李属 *Prunus*、茜草属 *Rubia*、苦苣菜属 *Sonchus*、画眉草属 *Eragrostis* 等。

东亚和北美洲间断分布有 9 属，占海南浆纸林林下种子植物中非世界属数的 3.27%。林下常见的有山绿豆属 *Desmodium*、柯属 *Lithocarpus*、勾儿茶属 *Berchemia*、楤木属 *Aralia* 等。

东亚东喜马拉雅—日本分布的有 3 属，占海南浆纸林林下种子植物中非世界属数的 1.09%。蓬莱葛属 *Gardneria*、黄猄草属 *Championella*、金发草属 *Pogonatherum* 等东亚分布属所含种类在海南浆纸林多见于林下灌丛或林缘。

由以上分析可以看出，海南浆纸林林下种子植物区系地理成分以热带、亚热带成分为主，其中又以旧世界热带和泛热带分布为主，表现出强烈的热带特色。同时温带成分在海南浆纸林林下也有一定分布，但在植物群落中所占的比例较小。

3.5　海南浆纸林基地林下植物中的珍稀濒危植物

海南浆纸林林下植物中，调查到 4 种珍稀濒危植物（见表 4）。七指蕨野外数量较少，且分布区狭窄，仅零星分布在琼中浆纸林灌木林和木薯地。海南苏铁仅见 3 株，分布在琼中浆纸林中。

表 4　海南浆纸林林下珍稀濒危植物†

Table 4　The distribution and status of rare and endangered plants undergrowth pulp-paper forest in Hainan

序号	种名	科名	分布	保护级别
1	七指蕨 *Helminthostachys zeylanica*	七指蕨科	琼中	Ⅱ
2	海南苏铁 *Cycas hainanensis*	苏铁科	琼中	Ⅰ
3	两列虾脊兰 *Calanthe formosana*	兰科	儋州	Ⅱ
4	美冠兰 *Eulophia graminea*	兰科	琼中	Ⅱ

† 表中用阿拉伯数字表示的保护级别取自于国家重点保护野生植物名录（第一批）[8]，用罗马数字表示的保护级别来自于国家重点保护野生植物名录（第二批 征求意见稿）[9]。

对于浆纸林下的珍稀濒危植物，建议采取就地保护，不仅要保护好珍稀濒危植物本身，也要保护好其生长的环境，包括其伴生植物等，在林内以珍稀濒危植物分布点为中心划定一定范围（以 20 m×20 m 为最小面积）作为保护区，林缘竖立警示教育牌。在从事林业工作人员内部特别是对林业生产一线员工要进行珍稀植物识别与保护的宣传教育，可以采取现场实物和照片、壁报相结合的形式，并指派护林员对林下珍稀濒危植物进行定期观察、记录。营林抚育中也应注意不要采取全部砍光的形式，应该保留一些乡土灌木和草本，这将有利于水土保持和林内小环境的营造，为更多植物的生长提供条件。浆纸林砍伐时宜以间伐方式进行，不宜以重型机械大规模作业，对非材用部位也应注意集中处理，以免造成土壤和水源污染。造林前的植物普查工作对珍稀濒危植物的及时保护尤为重要，发现林地有珍稀濒危植物后，应及时上报相关管理部门，保护周围生境，尽量避免继续在其中造林。另外，也可根据当地情况对部分珍稀濒危植物进行人工繁殖、野外放归实验，为珍稀濒危植物的保护与种群扩大做好前期科研工作。

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[本文编校：吴　毅]

（上接第 68 页）

从以上计算分析可知，对于给定水质目标及污染物汇入量的湖泊，采用换水周期法 2 进行计算，可充分考虑到水质目标及纳污能力对水体自净交换的制约性，从而能更精确的推求换水周期及最小生态流量。文章利用湘阴县东湖对生态需水流量及换水周期计算方法进行了讨论，揭示了湖泊水体水质目标及纳污能力等制约因素对生态需水流量及换水周期计算的影响，推导出了常规计算公式，为开展水体交换周期的分析和研究及水资源合理利用提供了依据及参考。

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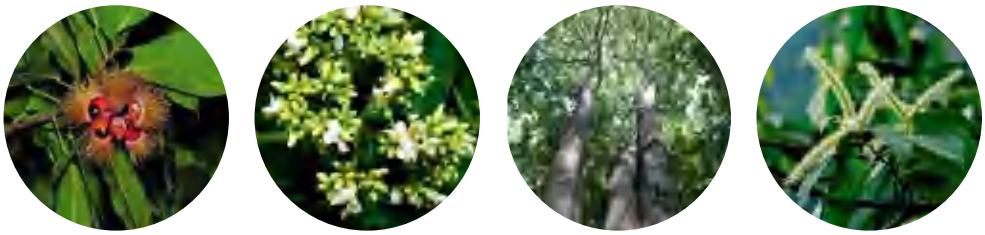
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广东大径材树种

Large-diameter Timber Tree Species in Guangdong



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中国林业出版社
China Forestry Publishing House

内容简介

本书共收录广东省野生和栽培大径材植物108种3变种，主要是AHP评分靠前的树种，也包括部分未推广利用但有培育潜力的树种。每种植物介绍其所隶属的科名及属名、中文通用名、中文别名、学名、简要形态特征、产地、生境、木材特性，其他主要是简述其研究进展。植物名称采用APG（IV）分类系统。每种植物选择一至数张照片展示其生境及形态识别特征，全书共有彩色照片457幅，均为野外实地拍摄。为便于读者查阅，树种（目录）采用中文名拼音排序，并配有学名索引。

图书在版编目(CIP)数据

广东大径材树种 / 秦新生等著. -- 北京 : 中国林业出版社，2024. 12. -- ISBN 978-7-5219-2882-2

Ⅰ. S79

中国国家版本馆CIP数据核字第2024Q944L8号

责任编辑：于界芬　张健

出版发行：中国林业出版社

（100009，北京市西城区刘海胡同7号，电话010-83143542）

电子邮箱：cfphzbs@163.com

网址：https://www.cfph.net

印刷：北京博海升彩色印刷有限公司

版次：2024年12月第1版

印次：2024年12月第1次印刷

开本：880mm×1230mm　1/16

印张：13

字数：350千字

定价：168.00元

广东大径材树种

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本书野外调查和编研出版得到以下项目的支持

广东省林业局林业科技创新重大项目 (2022KJCX015)

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中国中药资源大典

国家出版基金项目
NATIONAL PUBLICATION FOUNDATION

中国中药资源大典

“十三五”国家重点出版物出版规划项目



广东卷 ⑦

黄璐琦/总主编
晁志 严寒静/主编

北京科学技术出版社

图书在版编目（CIP）数据

中国中药资源大典. 广东卷. 7 / 晁志, 严寒静主编. 北京 : 北京科学技术出版社, 2024. 6. -- ISBN 978-7-5714-4009-1

Ⅰ. R281.4

中国国家版本馆CIP数据核字第2024SS4158号

责任编辑：侍　伟　李兆弟　王治华　庞璐璐　吕　慧
责任校对：贾　荣
图文制作：樊润琴
责任印制：李　茗
出 版 人：曾庆宇
出版发行：北京科学技术出版社
社　　址：北京西直门南大街16号
邮政编码：100035
电　　话：0086-10-66135495（总编室）　0086-10-66113227（发行部）
网　　址：www.bkydw.cn
印　　刷：北京博海升彩色印刷有限公司
开　　本：889 mm × 1 194 mm　1/16
字　　数：848千字
印　　张：38.25
版　　次：2024年6月第1版
印　　次：2024年6月第1次印刷
审 图 号：GS京（2023）1758号
ISBN 978-7-5714-4009-1

定　　价：490.00元

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中国科学院华南植物园
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广东翁源青云山省级自然保护区植物区系与植被

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CFPH

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深圳市兰科植物保护研究中心

广东翁源青云山省级自然保护区植物区系与植被

Flora and Vegetation of Qingyunshan Provincial Nature Reserve, Wengyuan, Guangdong

王发国　杨新东　邢福武　谢冲林　主编

中国林业出版社
China Forestry Publishing House

图书在版编目（CIP）数据

广东翁源青云山省级自然保护区植物区系与植被 /王发国等主编. --北京：中国林业出版社，2022.12

ISBN 978-7-5219-1631-7

Ⅰ. ①广… Ⅱ. ①王… Ⅲ. ①自然保护区—植物区系—研究—翁源县 ②自然保护区—植被—研究—翁源县 Ⅳ. ①Q948.526.54

中国版本图书馆CIP数据核字（2022）第057667号

内容简介

广东翁源青云山省级自然保护区位于韶关市翁源县东南部，属森林生态系统类型自然保护区，其植被类型多样，植物种类丰富，区系成分复杂。本书是编者在对广东翁源青云山省级自然保护区植物区系和植被进行了多年野外调查的基础上，查阅相关资料，经标本鉴定、样方资料整理分析，提出了青云山自然保护区植被分类系统；对保护区的植物区系、群落生态学、物种多样性、珍稀濒危植物、植物资源等进行了比较深入的研究，并提出了保护与利用建议。本书将为我国亚热带地区植物区系、资源与植被的研究，当地生态环境的保护，以及生物多样性的保护和可持续利用提供基础资料，可供植物学、生态学、林学、农学工作者、大专院校师生和植物爱好者参考使用。

广东翁源青云山省级自然保护区植物区系与植被　　王发国 杨新东 邢福武 谢冲林 主编

出版发行：中国林业出版社

地　　址：北京西城区德胜门内大街刘海胡同7号

策划编辑：王　斌

责任编辑：张　健　刘开运　吴文静　　装帧设计：柏桐文化传播公司

印　　刷：北京雅昌艺术印刷有限公司

开　　本：889 mm × 1194 mm　1/16

印　　张：13.25（其中彩插1.75）

字　　数：405千字

版　　次：2022年12月第1版　第1次印刷

定　　价：98.00元

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项目资助

广东翁源青云山省级自然保护区管理处

翁源青云山自然保护区植物综合调查研究项目（WYCGF2016003）

广东省重点领域研发计划项目（2020B1111530004）

粤北生态屏障生态系统服务功能提升技术

韶关市野生动植物和自然保护区管理办公室

韶关市陆生野生珍稀植物资源调查

广东省野生动植物保护管理项目、广东省野生动植物保护管理及湿地保护专项资金

韶关市第二次全国重点保护野生植物资源调查、广东省第二次全国重点保护野生动植物资源调查（蕨类植物）

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国家出版基金项目
中国中草药志
叶华谷 李楚源 叶文才 曾飞燕 主编
1
化学工业出版社

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内容简介

本书以图文结合的形式，收录我国野生及栽培的药物共419种，主要从药物资源的利用角度，介绍了每种药物的科名、中文名、中药拉丁名、别名、动植物拉丁名、基原、形态特征、生长环境、地理分布、采集加工、药材性状、性味归经、功能主治、用法用量等，有些种类还有附方和附注。为了安全起见，在一些有毒植物的性味功能后面标明“有大毒”“有小毒”“有毒”等字样，提醒读者慎用。

本书可供药物研究、教育、资源开发利用、植物分类及科普等领域人员参考使用。

图书在版编目（CIP）数据

中国中草药志. 1/ 叶华谷等主编. —北京：化学工业出版社，2022.3

ISBN 978-7-122-40411-4

Ⅰ. ①中… Ⅱ. ①叶… Ⅲ. ①中药志 Ⅳ. ① R281.4

中国版本图书馆 CIP 数据核字（2021）第 251566 号

责任编辑：李 丽 刘 军
文字编辑：赵爱萍
责任校对：王 静
装帧设计：关 飞

出版发行：化学工业出版社
（北京市东城区青年湖南街 13 号 邮政编码 100011）
印 装：中煤（北京）印务有限公司
787mm × 1092mm 1/16 印张 37½ 字数 932 千字
2022 年 9 月北京第 1 版第 1 次印刷

购书咨询：010-64518888 售后服务：010-64518899
网 址：http://www.cip.com.cn
凡购买本书，如有缺损质量问题，本社销售中心负责调换。

定 价：298.00 元

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FLORA OF CANARY ISLANDS

（加那利群岛植物志）

Volume I

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Xing Fuwu Wang Faguo Zhou Jinsong John Tenhunen

SCIENCE PRESS
Beijing

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扫描全能王 创建

FLORA OF CANARY ISLANDS (Volume I)

Editors in Chief: Xing Fuwu Wang Faguo Zhou Jinsong John Tenhunen

This book systematically introduces the plant resources of Canary Islands. The contents include: natural general situation of nature in Canary Islands, the name, scientific name, synonymous name, morphological characteristic, geographical distribution, habitat, elevation, cultivation of plants in Canary Islands, and relevant literatures. The use of part plants were also included.

This book is published in English, consisting of two volumes. The volume I contains 21 families, 30 genera and 63 species of Lycophytes and Ferns, 3 families, 4 genera, 8 species and 1 subspecies of Gymnosperms, and 71 families, 275 genera and 854 species (including varieties and subspecies) of Angiosperms; volume II continually contains 58 families, 346 genera and 955 species (including varieties and subspecies) of Angiosperms. It is rich in content and pictures, complete in data and has certain popular science and practical guiding values. It can be used as a reference book for researchers in botany, ecology, forestry, landscape gardening, natural conservation and environmental protection, for teachers and students in colleges and universities, and for government officials. It can also be used as a reference material for tourists in Canary Islands.

ISBN 978-7-03-070363-7
Published by Science Press (Beijing)

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Responsible Editors(Press): Ma Jun Hao Chenyang

扫描全能王 创建

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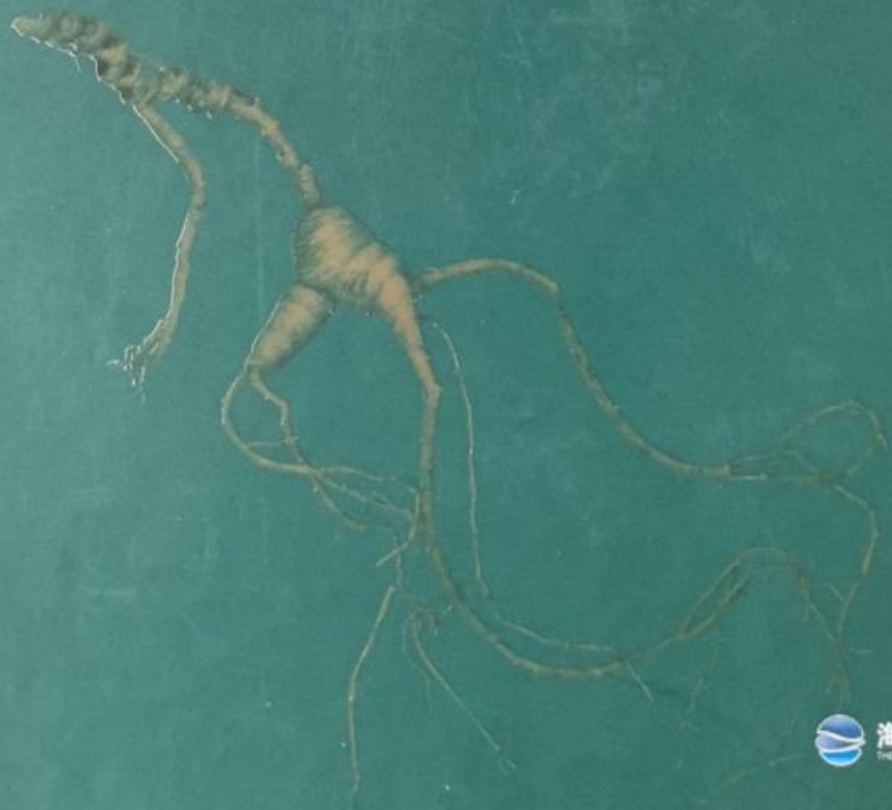
“十三五”国家重点图书出版规划项目
国家新闻出版改革发展项目
国家出版基金项目

国家出版基金项目

CHINESE MEDICINAL PLANTS: AN ILLUSTRATED APPROACH

中药原植物鉴定图典





主编

陈虎彪 赵中振

海峡出版发行集团 | 福建科学技术出版社
THE STRAITS PUBLISHING & DISTRIBUTING GROUP | FUJIAN SCIENCE & TECHNOLOGY PUBLISHING HOUSE

图书在版编目(CIP)数据

中药原植物鉴定图典 / 陈虎彪，赵中振主编 . —福州：福建科学技术出版社，2020. 11
ISBN 978-7-5335-6203-8

Ⅰ . ①中… Ⅱ . ①陈… ②赵… Ⅲ . ①中药鉴定学－图集 Ⅳ . ① R282.5-64

中国版本图书馆 CIP 数据核字（2020）第 130674 号

书　　名	**中药原植物鉴定图典**
主　　编	陈虎彪　赵中振
出版发行	福建科学技术出版社
社　　址	福州市东水路76号（邮编350001）
网　　址	www.fjstp.com
经　　销	福建新华发行（集团）有限责任公司
印　　刷	福州德安彩色印刷有限公司
开　　本	889毫米×1194毫米　1/16
印　　张	56
插　　页	4
字　　数	1363千字
版　　次	2020年11月第1版
印　　次	2020年11月第1次印刷
书　　号	ISBN 978-7-5335-6203-8
定　　价	598.00元

书中如有印装质量问题，可直接向本社调换

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连山森林康养植物

连山壮族瑶族自治县林业局
广州岭南森林康养科学研究所 编

中山大學出版社
SUN YAT-SEN UNIVERSITY PRESS

《连山森林康养植物》
编委会

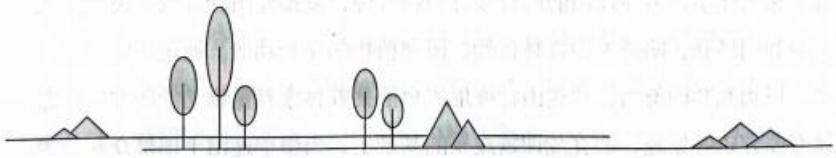
名誉主编　李杰辉

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图书在版编目（CIP）数据

连山森林康养植物 / 连山壮族瑶族自治县林业局，广州岭南森林康养科学研究所编 . —广州：中山大学出版社，2020.10

ISBN 978 - 7 -306 - 07015 - 9

Ⅰ. ① 连…　Ⅱ. ①连…　②广…　Ⅲ. ① 森林生态系统—关系—健康—研究—连山壮族瑶族自治县　②森林植物—研究—连山壮族瑶族自治县　Ⅳ. ① S718.55　② R161　③ Q948.526.54

中国版本图书馆 CIP 数据核字（2020）第 207659 号

LianShan Senlin Kangyang Zhiwu

出 版 人：王天琪
策划编辑：曾育林
责任编辑：曾育林
封面设计：曾　斌
责任校对：梁嘉璐
责任技编：何雅涛
出版发行：中山大学出版社
电　　话：编辑部 020 - 84110283，84111996，84111997，84113349
　　发行部 020 - 84111998，84111981，84111160
地　　址：广州市新港西路 135 号
邮　　编：510275　　传　真：020 - 84036565
网　　址：http://www.zsup.com.cn　　E-mail:zdcbs@mail.sysu.edu.cn
印 刷 者：广州市友盛彩印有限公司
规　　格：787mm × 1092mm　1/16　15.5印张　500千字
版次印次：2020年10月第 1 版　　2020 年10月第 1 次印刷
定　　价：168.00 元

如发现本书因印装质量影响阅读，请与出版社发行部联系调换

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深圳市园林绿化计价标准

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ILLUSTRATED HANDBOOK OF LANDSCAPING PLANTS FOR VALUATION STANDARD IN SHENZHEN, CHINA

上　册

深圳市建设工程造价管理站　编

中国计划出版社

中国计划出版社
网址：www.jhpress.com
电话：400-670-9365
进入官方微信

图书在版编目（CIP）数据

深圳市园林绿化计价标准苗木图鉴 ：全2册 / 深圳市建设工程造价管理站编. -- 北京 ：中国计划出版社，2019.11
ISBN 978-7-5182-0920-0

Ⅰ. ①深… Ⅱ. ①深… Ⅲ. ①园林植物－深圳－图集 Ⅳ. ①S68-64

中国版本图书馆CIP数据核字(2018)第201485号

深圳市园林绿化计价标准苗木图鉴（上、下册）
深圳市建设工程造价管理站 编

中国计划出版社出版发行
网址：www.jhpress.com
地址：北京市西城区木樨地北里甲11号国宏大厦C座3层
邮政编码：100038 电话：（010）63906433（发行部）
北京汇瑞嘉合文化发展有限公司印刷

889mm×1197mm 1/12 84印张 2212千字
2019年11月第1版 2019年11月第1次印刷

ISBN 978-7-5182-0920-0
定价：680.00元（上、下册）

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本书野外调查和编研出版得到以下项目的支持：

坪山区古树资源普查服务项目（PSCG20160233-LY018）　国家自然科学基金（31870699）

图书在版编目（CIP）数据

深圳坪山古树 / 冯志坚，秦新生主编 . -- 北京 : 中国林业出版社，2018.5
ISBN 978-7-5038-9506-7

Ⅰ . ①深… Ⅱ . ①冯… ②秦… Ⅲ . ①树木－介绍－深圳 Ⅳ . ① S717.265.4

中国版本图书馆 CIP 数据核字 (2018) 第 064175 号

深圳坪山古树　　冯志坚　秦新生　主编

出版发行：中国林业出版社
地　　址：北京西城区德胜门内大街刘海胡同 7 号

策划编辑：王　斌（342855430@qq.com）
责任编辑：刘开运　张　健　吴文静　李　楠　　装帧设计：百彤文化传播公司

印　　刷：北京雅昌艺术印刷有限公司
开　　本：889 mm × 1194 mm　1/16
印　　张：16
字　　数：350 千字
版　　次：2019 年 5 月第 1 版 第 1 次印刷
定　　价：248.00 元（USD 49.99）

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“十二五”国家重点图书出版规划项目



中国非粮生物柴油植物

NON-FOOD BIODIESEL PLANTS OF CHINA

主编：邢福武



中国林业出版社

图书在版编目（CIP）数据

中国非粮生物柴油植物 / 邢福武主编. -- 北京 :中国林业出版社, 2018.8

ISBN 978-7-5038-9698-9

Ⅰ. ①中… Ⅱ. ①邢… Ⅲ. ①生物能源—柴油—植物—介绍—中国 Ⅳ. ①Q949.93

中国版本图书馆CIP数据核字(2018)第182394号

中国非粮生物柴油植物

Non-food Biodiesel Plants of China

邢福武 主编

出版项目负责人：刘开运

出版发行：中国林业出版社

地　　址：北京西城区德胜门内大街刘海胡同7号　　电话：13901070021　　Email: 377406220

策划编辑：王　斌

责任编辑：刘开运　李春艳　张　健　吴文静　李　楠　　装帧设计：广州百彤文化传播有

印　　刷：北京雅昌艺术印刷有限公司

开　　本：635mm × 965mm　1/8

印　　张：131

字　　数：3600千字

版　　次：2019年3月第1版　第1次印刷

定　　价：1280.00元　（USD 256.99）

《中国非粮生物柴油植物》

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Checklist of Seed Plants in the Karst Regions in China

Yu-Min Shui, Wen-Hong Chen, Xin-Sheng Qin

中国喀斯特地区种子植物名录

税玉民　陈文红　秦新生　编著

科学出版社

扫描全能王 创建

中国喀斯特地区种子植物名录

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资助单位

中国科学院昆明植物研究所
中国科学院东亚植物多样性与生物地理学重点实验室
云南省喀斯特地区生物多样性保护研究会

项目资助

国家自然科学基金
西南边境董棕林调查和研究，兼论河流与山脉的阻隔效应（31370228）
广义马铃苣苔属（苦苣苔科）的分类学研究，兼谈花色分化的意义（31470306）
秋海棠属特有类群——侧膜组的分类学研究（30270109）

中国科学院“西部之光”人才项目
滇东南喀斯特地区植物多样性调查和研究（200431131100100）

云南省科学基础研究计划
滇东南石灰岩山典型地段种子植物多样性调查和研究（2001C0022Q）

科学出版社

北京

扫描全能王 创建

内 容 简 介

本名录共收载中国喀斯特地区种子植物 134 科 696 属 2622 种（包括种下等级）。其中裸子植物 6 科 13 属 31 种，被子植物 128 科 683 属 2591 种；被子植物包括双子叶植物 114 科 558 属 2155 种，单子叶植物 14 科 125 属 436 种。本名录中裸子植物按郑万钧系统（1979）编排，被子植物按哈钦松（Hutchinson）系统（1959）排列；种则按拉丁字母顺序排列。

本名录包括科、种的中文名和学名，以及产地、群落地位、用途、保护等级等信息，可供生物、林业及环境学科的工作者和爱好者参考。

图书在版编目（CIP）数据

中国喀斯特地区种子植物名录 / 税玉民，陈文红，秦新生编著. —北京：科学出版社, 2017.6

ISBN 978-7-03-053595-5

Ⅰ.①中… Ⅱ.①税… ②陈… ③秦… Ⅲ. ①种子植物–中国–名录 Ⅳ.①Q949.408-62

中国版本图书馆 CIP 数据核字(2017)第 131974 号

责任编辑：马 俊 / 责任校对：刘亚琦
责任印制：张 伟 / 封面设计：刘新新

科学出版社出版
北京东黄城根北街 16 号
邮政编码: 100717
http://www.sciencep.com

北京教图印刷有限公司 印刷
科学出版社发行 各地新华书店经销
*
2017 年 6 月第 一 版 开本：720×1000 B5
2017 年 6 月第一次印刷 印张：17 3/4
字数：358 000

定价：128.00 元

(如有印装质量问题，我社负责调换)

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中国热带雨林地区植物图鉴

Illustrated Handbook of Plants in Tropical Rainforest Area of China

海南植物 1

Plants of Hainan



中国科学院华南植物园
主编：邢福武 陈红锋 秦新生 张荣京 周劲松

华中科技大学出版社
http://www.hustp.com

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图书在版编目（CIP）数据

中国热带雨林地区植物图鉴——海南植物 / 邢福武等主编 . -- 武汉 : 华中科技大学出版社 , 2013.12

ISBN 978-7-5609-9307-2

Ⅰ . ①中… Ⅱ . 邢… Ⅲ . ①热带雨林－植物－海南省－图集 Ⅳ . ① Q948.52-64

中国版本图书馆 CIP 数据核字（2013）第 193788 号

中国热带雨林地区植物图鉴——**海南植物（第1册）** 主编：邢福武 陈红锋 秦新生 张荣京 周劲松

出版发行：华中科技大学出版社（中国·武汉）

地　　址：武汉市武昌珞喻路 1037 号（邮编：430074）

出 版 人：阮海洪

策划编辑：王　斌　　责任监印：张贵君

责任编辑：狄　英　吴文静　　装帧设计：百彤文化

印　　刷：深圳市建融印刷包装有限公司

开　　本：965 mm×715 mm　1/16

印　　张：47.75

字　　数：750 千字

版　　次：2014 年 4 月第 1 版 第 1 次印刷

定　　价：998.00 元（USD 199.99）（全三册）

投稿热线：（020）66636689　　342855430@qq.com

本书若有印装质量问题，请向出版社营销中心调换

全国免费服务热线：400-6679-118 竭诚为您服务

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广东省林业调查规划院

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FOREST PLANTS IN GUANGDONG

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華中科技大學出版社
http://www.hustp.com

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图书在版编目（CIP）数据

广东森林植物 / 刘凯昌，庄雪影等主编. -- 武汉：华中科技大学出版社，2013.12
ISBN 978-7-5609-9554-0
Ⅰ. ①广… Ⅱ. ①刘… ②庄… Ⅲ. ①森林植物－广东省 Ⅳ. ① Q948.526.5

中国版本图书馆 CIP 数据核字（2013）第 299924 号

广东森林植物

刘凯昌 庄雪影 薛春泉 李镇魁 主 编
冯志坚 肖智慧 黄久香 李清湖 副主编

出版发行：华中科技大学出版社（中国 · 武汉）
地　　址：武汉市武昌珞喻路1037号（邮编：430074）
出 版 人：阮海洪

策划编辑：王　斌　　责任监印：张贵君
责任编辑：章丹娜　　装帧设计：百彤文化

印　　刷：深圳市建融印刷包装有限公司
开　　本：965 mm×715 mm　1/16
印　　张：28.75
字　　数：110千字
版　　次：2013年12月第1版 第1次印刷
定　　价：158.00元（USD 31.99）

华中出版

投稿热线：（020）66636689　342855430@qq.com
本书若有印装质量问题，请向出版社营销中心调换
全国免费服务热线：400-6679-118 竭诚为您服务
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海南吊罗山野生植物

彩色图鉴

COLOURED ILLUSTRATIVE PLATES OF WILD PLANTS
IN DIAOLUOSHAN HAINAN CHINA

秦新生等 编著



中国林业出版社

扫描全能王 创建

本书野外调查和编研出版得到以下项目支持

国家财政部 2012 年林业国家级自然保护区补助资金【财农（2012）134 号】

国家科技部科技基础性工作专项重点项目—海南专题（2008FY110400-1-12）

国家自然科学基金（31000095）

广东省大学生创新实验项目（1056412096）

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扫描全能王 创建

图书在版编目（CIP）数据

海南吊罗山野生植物彩色图鉴 / 秦新生等编著 . -- 北京 : 中国林业出版社 , 2013.5

ISBN 978-7-5038-7046-0

Ⅰ . ①海… Ⅱ . ①秦… Ⅲ . ①山 - 野生植物 - 海南省 - 图谱 Ⅳ . ① Q948.526.6-64

中国版本图书馆 CIP 数据核字（2013）第 101209 号

海南吊罗山野生植物彩色图鉴

秦新生 等 编著

出　　版：中国林业出版社

地　　址：北京西城区德胜门内大街刘海胡同 7 号

策划编辑：王　斌

责任编辑：刘开运　李春艳　狄　英

装帧设计：百彤文化传播公司

印　　刷：广州市人杰彩印厂

开　　本：889mm × 1194mm　1/16

印　　张：22.25

字　　数：580 千字

版　　次：2013 年 5 月第 1 版 第 1 次

定　　价：398.00 元（USD 89.99）

扫描全能王 创建

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乐昌植物

邹滨 曾繁助
叶育石 主编










華中科技大學出版社
http://www.hustp.com

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图书在版编目（CIP）数据

乐昌植物 / 邹滨，曾繁助，叶育石 主编. – 武汉：华中科技大学出版社，2012.11

ISBN 978-7-5609-8476-6

Ⅰ. ①乐… Ⅱ. ①邹… ②曾… ③叶… Ⅲ. ①植物 – 介绍 – 乐昌市 Ⅳ. ① Q948.526.53

中国版本图书馆 CIP 数据核字（2012）第 258354 号

乐昌植物　　邹滨 曾繁助 叶育石 主编

出版发行：华中科技大学出版社（中国·武汉）

地　　址：武汉市武昌珞喻路 1037 号（邮编：430074）

出 版 人：阮海洪

策划编辑：王斌　　责任监印：张贵君

责任编辑：熊纯 卢平　　装帧设计：百彤文化

印　　刷：深圳市彩美印刷有限公司

开　　本：965 mm × 1270 mm 1/16

印　　张：47.5

字　　数：1520 千字

版　　次：2013 年 3 月第 1 版 第 1 次印刷

定　　价：498.00 元（USD 100.00）

华中出版

投稿热线：（020）66638820　　1275336759@qq.com

本书若有印装质量问题，请向出版社营销中心调换

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拉丁名索引

中国科学院华南植物园

海南
植物物种多样性编目

Inventory of Plant Species Diversity of Hainan

主编：
邢福武　周劲松
王发国　曾庆文
易绮斐　刘东明

华中科技大学出版社
http://www.hustp.com

图书在版编目（CIP）数据

海南植物物种多样性编目 / 邢福武等 主编. – 武汉: 华中科技大学出版社, 2012.4

ISBN 978-7-5609-7854-3

Ⅰ. ①海… Ⅱ. ①邢… Ⅲ. ①植物 – 生物多样性 – 目录 – 海南省 Ⅳ. ①Q948.526.6

中国版本图书馆CIP数据核字(2012)第068858号

海南植物物种多样性编目

邢福武等 主编

出版发行：华中科技大学出版社（中国·武汉）

地　　址：武汉市武昌珞喻路1037号（邮编430074）

出 版 人：阮海洪

策划编辑：王　斌

责任编辑：黎若君

责任校对：段园园

责任监印：秦英

装帧设计：百彤文化

印　　刷：利丰雅高印刷（深圳）有限公司

开　　本：889 mm × 1194 mm　1/16

印　　张：41

字　　数：1200千字

版　　次：2012年4月第1版 第1次印刷

定　　价：198.00元（USD 39.99）

投稿热线：（020）66638820　　1275336759@qq.com

本书若有印装质量问题，请向出版社营销中心调换

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广东省农业技术推广奖

获奖证书

为表彰在农业技术推广工作中做出贡献的单位和个人，特颁发此证书，以资鼓励。

获奖项目：广东省石灰岩山区造林树种选择和造林技术推广

奖励等级：二等奖

获 奖 者：秦新生

奖励日期：2017年1月5日

证 书 号：2015-2-L04-R14

广东省农业技术推广奖

评审委员会

2017年1月5日

广东省科学技术奖励

证　书

为表彰广东省科学技术奖获得者，

特颁发此证书。

项目名称：中国南海岛屿植物多样性研究及产业化

奖励等级：一等奖

获 奖 者：秦新生

粤府证：〔2016〕4868号

项目编号：B012-1-01-R06

广东省人民政府

二〇一七年一月

广东省科学技术奖励

证　书

为表彰广东省科学技术奖获得者，

特颁发此证书。

项目名称：中国南海岛屿植物多样性研究及产业化

奖励等级：一等奖

获 奖 者：华南农业大学

粤 府 证：〔2016〕3123 号

项目编号：B012-1-01-D04

二〇一七年二月

ICS 65.020.40
B 64

DB44

广　东　省　地　方　标　准

DB44/T 2186—2019

黄花风铃木栽培技术规程

Technical regulations on cultivation of *Handroanthus chrysanthus*

地方标准信息服务平台

2019－09－09 发布　　2019－12－01 实施

广东省市场监督管理局　发布

地方标准信息服务平台

前　言

本标准按照 GB/T 1.1-2009 给出的规则起草。

本标准由广东省林业局提出并归口。

本标准起草单位：华南农业大学。

本标准主要起草人：冯志坚、张波、翁殊斐、李镇魁、秦新生、卢艺菲、徐茵、袁森、丁释丰、黄稚清、吴林源。

地方标准信息服务平台

荣誉证书

华南农业大学：

你校提交的论文《中国鹅绒藤属植物叶表皮微形态扫描电镜研究》（作者：洪文君，阙青敏，秦新生；指导教师：秦新生），被评为首届全国植物生产类大学生实践创新论坛优秀论文二等奖。特发此证，以资鼓励。

首届全国植物生产类大学生实践创新论坛

（承办单位：南京农业大学代章）

二〇一三年十二月三十日



首届全国植物生产类大学生实践创新论坛在我校举行

时间:2013-12-25 来源: 作者: 点击数: 1060

12月21日，首届全国植物生产类大学生实践创新论坛在我校举行。本次论坛由我校承办，中国农业大学等18所农林高校联办，来自全国18所拥有国家级植物生产类实验教学中心的高校近100名师生参加了此次论坛。我校副校长胡锋教授、江苏省教育厅高教处处长徐子敏出席开幕式并讲话，开幕式由我校教务处处长王恬教授主持。

会场

论坛开幕式上，胡锋代表学校对江苏省教育厅给予我校的支持表示感谢，对参会代表表示欢迎。胡锋指出，教育部、农业部、国家林业局最近出台的《关于推进高等农林教育综合改革的若干意见》中明确指出，要加强创新创业能力培养，深入推进农林院校科技创新。新的历史时期，社会对农业人才提出了更高的要求，创新人才培养面临很大的挑战，本次论坛的召开，对探索创新人才培养模式改革，加强农林院校学生在实践创新方面的交流提供了平台，有利于进一步推进卓越农林人才培养计划，全面提升农林院校学生创新能力。

徐子敏在讲话中指出，创新是一个民族进步的灵魂，是一个国家兴旺发达的不竭动力。大学承担着培养创新人才、创新知识体系的任务。南京农业大学举办首届植物生产类大学生实践创新论坛，为学生进行学术交流提供了一个高起点、大范围、宽领域的舞台，有利于开拓学生的视野，希望参会学生珍惜机会，聆听指导，充分交流，发展友谊。

与会代表参观学生创新项目成果展

论坛展出了来自各个参会单位的学生实践创新项目成果123份，参会学生自主投票，选出“学生最喜欢的实践创新项目”14项。论坛期间还对学生论文投稿进行了评审，我校获“学生最喜欢的实践创新项目”1项，论文一等奖1篇、二等奖2篇，三等奖3篇，优秀奖2篇。

本次论坛特别邀请了我校盖钧镒院士做专题报告。

王恬在闭幕式上总结讲话中指出，此次论坛为农林院校探索创新实践人才培养模式改革提供了很好的参考，为农林院校学生走出校园、开拓视野提供了机会，论坛将进一步探索可持续发展机制，为更多学生提供实践创新交流学习平台。

上一条：沈其新教授团队获中国草学会草业科学技术奖二等奖

关于第九届全国植物生产类大学生实践创新论坛的参赛通知

发布者：植物生物学基础国家级实验教学示范中心（华南农业大学） 发布时间：2023-08-03 浏览次数： 183



关于组织参加第九届全国植物生产类大学生实践创新论坛
暨大学生创新创业训练计划成果展的通知

各相关学院：

为深入学习贯彻党的二十大精神及新时代人才强国战略，发挥国家级实验教学示范中心实践育人作用，提高人才培养质量，为全国植物生产类大学生搭建实践创新项目成果交流和展示平台，同时促进植物生产类国家级实验教学示范中心各相关单位的联系与合作，高等学校国家级实验教学示范中心联席会拟定于 2023 年 10 月在广西大学（广西南宁）举办第九届全国植物生产类大学生实践创新论坛暨大学生创新创业训练计划项目成果展，本次论坛将组织相关专家对各校推荐的论文进行评审，根据评审意见遴选出优秀论文（设置一、…、三等奖）。同时，优秀论文将编制成论文集，作为第九届植物生产类大学生实践创新论坛的成果。根据组委会的工作部署，现将有关事宜通知如下：

1. 我校拟择优推荐 10 篇植物生产类大学生实践创新项目论文，并提交相应的展板信息。论文字数不超过 5000 字（含图表），内容主要反映项目研究情况（包括研究目的、方法、主要观点及结论等）；展板内容不超过 500 字（含图表）。论文格式及展板要求（详见附件 1、2）。如论文已在出版物上正式发表，推荐时请标明发表的刊物名称等信息。未发表论文请附中国知网查重报告简洁版。

2. 请参赛者于 2023 年 9 月 5 日前将参赛文稿和展板内容以 word 文档形式发送到邮箱 hjyang@scau.edu.cn。

3. 2023 年 9 月 10 日前，学校由植物生物学基础国家级实验教学示范中心（华南农业大学）组织校内评议，参赛者通过 PPT 形式进行作品汇报，每项作品答

辩 5 分钟，按评分高低择优向组委会推荐参赛作品。

4. 参赛工作联系人：羊海军，13928549834，hjyang@scau.edu.cn

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邮编：510642

荣誉证书

华南农业大学“9 种鹅绒藤属(萝藦科)植物种子微形态特征研究”论文获第二届全国植物生产类大学生实践创新论坛暨成果展**二等奖**

论文作者：洪文君　郭成龙　郑明轩

指导老师：秦新生

第二届全国植物生产类大学生实践创新论坛暨成果展

西北农林科技大学教务处（代章）

二〇一四年十一月二十二日

荣誉证书

华南农业大学：

你校提交的项目展板《中国鹅绒藤属（萝藦科）分类学研究》（完成人：洪文君，冯乙晴，阙青敏，郭成龙，黄健乐；指导教师：秦新生），被评为首届全国植物生产类大学生实践创新论坛学生最喜欢的实践创新项目作品。特发此证，以资鼓励。

首届全国植物生产类大学生实践创新论坛

（承办单位：南京农业大学代章）

二〇一三年十二月三十日

荣誉证书

华南农业大学“中国鹅绒藤属（萝藦科）分类学研究”被评为第二届全国植物生产类大学生实践创新论坛暨成果展“学生最喜欢的实践创新项目作品（展板）”。

作者：洪文君（在读研究生）　郭成龙　郑明轩

第二届全国植物生产类大学生实践创新论坛暨成果展
西北农林科技大学教务处（代章）
二〇一四年十一月二十二日

庆祝广东园林学会成立60周年

荣誉证书

广东园林学会

二〇二二年十一月

证 书

高筱钰、秦新生、冯志坚同志：

您的论文《朱槿品种资源与分类探讨》获得广东园林学会2022年优秀论文征集评选活动一等奖。

特发此证，以资鼓励。

广东园林学会

2022年11月18日

中国教育工会华南农业大学委员会文件

华农工字〔2022〕2 号

关于表彰 2019-2021 年部门工会先进集体和个人的决定

各部门工会、各单位:

为弘扬先进，树立榜样，推进工会各项工作整体水平的提高，促进工会工作的创新发展，根据《华南农业大学部门工会工作考核办法》（华农工字〔2014〕4 号）和《华南农业大学工会工作先进集体（个人）评选办法》（华农工字〔2015〕6 号）精神，经各部门工会推荐、校工会委员会评审，决定授予工程学院工会等 5 个部门工会“先进集体”荣誉称号、授予习欠云等 10 人“优秀工会干部”荣誉称号、授予王敏等 71 人“工会工作积极分子”荣誉称号，并对以上获奖者予以表彰和奖励。

希望受表彰的部门工会和个人发扬成绩，开拓进取，继续积极参与和支持工会工作，推进工会工作向更高层次发展。希望各部门工会和广大会员以先进为榜样，以习近平新时代中国特色社

会主义思想为指导，深入学习贯彻党的十九大、十九届历次全会和中央群团工作会议精神，紧密围绕学校中心工作，以师为本、服务大局、凝心聚力、担当作为，为推进学校高质量内涵式发展和“双一流”建设做出更大的贡献。

附件：2019-2021年部门工会先进集体和个人名单

中国教育工会华南农业大学委员会

2022年4月20日

公开方式：主动公开

中国教育工会华南农业大学委员会　　2022年4月20日印发

附件:

2019-2021年部门工会先进集体和个人名单

一、部门工会先进集体名单（5个）

工程学院工会

动科学院工会

数学与信息学院、软件学院工会

机关一部门工会

总务部部门工会

二、优秀工会干部名单（按姓氏笔画顺序排序）（10名）

习欠云　石　睿　牟英辉　巫光宏　罗鸿辉　罗粤舟　姜　峥

高锐涛　郭剑英　唐军梅

三、工会工作积极分子名单（按姓氏笔画顺序排序）（71名）

王　敏　王　琴　王　琳　王伟峰　王向方　王敏虹　方育阗

邓　铭　邓平宇　邓懿祯　卢　菁　叶晓燕　冯　悦　宁丽军

朱孝扬　伏广农　刘小锋　刘志鹏　刘效东　刘楚生　孙理超

李　凤　李　培　李玉玲　李曼华　杨德惠　肖好章　岑伊静

邱少健　余少虹　张　宇　张　芳　张　彬　张文彬　张亚莉

张晓佳　张雪莲　陈　洋　陈志华　陈健文　陈婷婷　邵爱琴

苗秋瑾　林慷祺　罗小珍　罗学柳　周云开　周文英　施　煜

骆芙蓉　秦新生　袁　兰　莫嘉嗣　钱春梅　徐　雨　徐聪聪

高　琴　郭　萍　黄小云　黄志雄　黄承红　龚淑华　章劲柳
程蔚新　温刘发　谢　辉　靳　珍　潘璐怡　薛晓丽　戴占海
魏剑波

证　书

秦新生 同志：

　　您的论文“粤港澳大湾区高速公路生态修复探索与实践”荣获粤港澳大湾区生态保护与生态系统治理高端学术研讨会优秀论文二等奖。

　　特发此证

中国林学会

2021 年 11 月

聘书

兹聘请 秦新生 为华南农业大学第八届本科教学督导委员会委员。聘期：2018 年 4 月至 2020 年 3 月。

此聘

华南农业大学

二〇一八年四月