

基于叶绿体全基因组序列中的物种特有变异位点的木樨科植物资源遗传多样性的分子鉴定新方法

刘美辰¹, 左云娟^{2,3}, 李 斌^{4,5*}, 严志宏^{6*}, 靳晓白⁷, 杨志荣⁸, 韩宜彤⁹, 郭明星¹⁰, 索志立^{11*}

¹北京市食品检验研究院(北京市食品安全监控和风险评估中心), 北京

²中国科学院东南亚生物多样性研究中心, 云南 勐腊

³中国科学院西双版纳热带植物园综合保护中心, 云南 勐腊

⁴中国林业科学研究院林业研究所, 北京

⁵中国林业科学研究院林木遗传和育种国家重点实验室, 北京

⁶江西中医药大学实验室服务中心, 江西 南昌

⁷国家植物园, 北京

⁸中国科学院植物研究所国家植物标本馆, 北京

⁹河北师范大学生命科学学院, 河北 石家庄

¹⁰汉中市茶业发展中心, 陕西 汉中

¹¹中国科学院植物研究所系统与进化植物学国家重点实验室, 北京

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摘 要

准确鉴定植物的遗传多样性是资源保护与可持续利用的基础。木樨科植物具有极高的食用、药用、观赏价值, 同时在经济与生态保护方面也发挥着重要作用。由于植物的表型特征会受到发育阶段和环境条件的影响, 不同学者对表型特征的理解和判断存在差异, 导致基于表型特征的木樨科植物鉴定存在困难。本研究利用木樨科17个样品的叶绿体全基因组序列, 从中筛选出物种特有的1114个核苷酸变异位点作为分子性状, 并以此编制分子鉴定检索表, 成功鉴定了供试样品。研究发现, 物种特有的变异位点数量以及核苷酸构成, 在属/种/亚种之间存在明显差异。结果显示, 叶绿体全基因组DNA序列中的单核苷酸变异位点信息, 能够用于木樨科植物资源遗传多样性的分子鉴定。本研究对于推动木樨科植物的分类修订、资源保护和利用具有重要意义。

关键词

木樨科, 植物资源多样性, 叶绿体基因组, 物种特有的核苷酸变异位点, 分子鉴定

*通讯作者。

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A Novel Molecular Identification Method for Assessing Genetic Diversity of Oleaceae Plant Resources Based on Taxon-Specific Variable Nucleotide Sites in Chloroplast Genome Sequences

Meichen Liu¹, Yunjuan Zuo^{2,3}, Bin Li^{4,5*}, Zhihong Yan^{6*}, Xiaobai Jin⁶, Zhirong Yang⁷, Yitong Han⁸, Mingxing Guo⁹, Zhili Suo^{10*}

¹Beijing Institute of Food Inspection and Research (Beijing Municipal Center for Food Safety Monitoring and Risk Assessment), Beijing

²Southeast Asia Biodiversity Research Institute, Chinese Academy of Sciences, Mengla Yunnan

³Center for Integrative Conservation, Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, Mengla Yunnan

⁴Research Institute of Forestry, Chinese Academy of Forestry, Beijing

⁵State Key Laboratory of Tree Genetics and Breeding, Research Institute of Forestry, Chinese Academy of Forestry, Beijing

⁶Laboratory Service Center, Jiangxi University of Chinese Medicine, Nanchang Jiangxi

⁷China National Botanical Garden, Beijing

⁸National Herbarium (PE), Institute of Botany, Chinese Academy of Sciences, Beijing

⁹College of Life Sciences, Hebei Normal University, Shijiazhuang Hebei

¹⁰Hanzhong Tea Industry Development Center, Hanzhong Shaanxi

¹¹State Key Laboratory of Systematic and Evolutionary Botany, Institute of Botany, Chinese Academy of Sciences, Beijing

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Abstract

Accurate identification of plant genetic diversity is the foundation for resource conservation and sustainable utilization. Oleaceae plants possess extremely high edible, medicinal, and ornamental values, while also playing significant roles in economic and ecological protection. As plant phenotypic traits are influenced by developmental stages and environmental conditions, differences in understanding and judgment among scholars regarding these traits lead to challenges in identifying Oleaceae plants based on phenotypic characteristics. This study utilized the chloroplast genome sequences of 17 Oleaceae samples to screen 1114 taxon-specific nucleotide variation sites as molecular characters, based on which a molecular identification key was developed, successfully identifying the tested samples. The study found that both the number of taxon-specific variation sites and nucleotide composition exhibited significant differences among genera, species, and subspecies. The results showed that single nucleotide variation site information in chloroplast whole-genome DNA sequences can be used for molecular identification of genetic diversity in Oleaceae plant resources. This study holds significant importance for advancing taxonomic revision, resource conservation, and utilization of Oleaceae plants.

Keywords

Oleaceae, Plant Resources Diversity, Chloroplast Whole-Genome Sequence, Taxon-Specific Variable Nucleotide Sites, Molecular Identification

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1. 引言

木樨科 Oleaceae 是真双子叶植物, 隶属于唇形目, 在全球分布广泛, 涵盖温带至亚热带地区, 全球约有 29 个属, 包含约 400 种植物。木樨科植物具有多方面的价值, 包括食用、观赏、药用、木材利用以及环境保护[1]-[3]。例如, 桂花 *Osmanthus fragrans* 多蜜, 含有 β -紫罗兰酮、萜品醇、乙酸-3-己烯酯、罗勒烯以及芳樟醇等多种芳香化合物。这些成分赋予了桂花浓郁而持久的独特香味。桂花的香料提取物可用于制作桂花糕、桂花元宵等传统食品, 增添独特的桂花香气, 改善或增强食品的香味; 桂花的香料提取物也广泛用于化妆品中, 如香水、护肤品等, 还可用于制作空气清新剂、香薰蜡烛等日化产品[1][2][4][5]。茉莉花 *Jasminum sambac* 是提升品质的天然素材, 通过花香吸附工艺, 将茉莉花与绿茶窈制, 可制成中国十大名茶之一的茉莉花茶, 其香气浓郁持久, 茶汤黄绿明亮, 具有提神醒脑、消食解腻的功效。茉莉花可制成花酱、香包、扩香石、护肤品等。桂花和茉莉花都是著名的观赏植物, 它们的香料资源在食品、日化、医药等多个领域展现出显著的经济效益[1][2][6]。茉莉花象征着忠贞、清纯和友谊。在文学、音乐、绘画等领域, 茉莉花都有广泛的体现, 歌曲《茉莉花》闻名世界。木樨榄(木犀榄、油橄榄) *Olea europaea* 的果实经过压榨可以得到橄榄油, 其油脂成分天然且稳定, 不需要复杂的加工就可以直接食用, 营养价值高, 而且容易被人体吸收, 被誉为“植物油皇后”和“地中海甘露”[1][2][7]。

木樨科植物的叶、根、花、果实等都是重要的中药材[1][2][8]。例如, 连翘 *Forsythia suspensa* 的果实是中成药银翘解毒丸的主要成分之一, 具有清热解毒的功效[1][2][8]。油橄榄的药用历史非常悠久, 地中海地区的民间医疗利用油橄榄叶治疗发烧以及疟疾等多种疾病[1][2][7][8]。木樨科植物广泛用于城乡景观绿化和环境修复[1][2]。例如, 丁香具有抗旱、耐寒、耐盐碱的特性。丁香的花很繁盛, 香气芬芳[1][2]。女贞 *Ligustrum lucidum* 能够抗二氧化硫、氯气, 具有净化空气的作用; 女贞的果实是鸟类的食物, 对于维持生物多样性具有生态价值[1][2]。木樨科有些植物种类的木材质量优良[1][2]。例如, 白蜡树 *Fraxinus chinensis* 的木材可以用来制作家具、工具柄、枕木等[1][2]。油橄榄的木材坚硬, 纹理细致, 是制作器具和手工艺品的优良材料[1][2][7]。

木樨科植物经历了多次多倍体化事件, 例如, 约 5300 万年前至 6100 万年前期间发生了六倍体化事件, 约 1800 万年前至 2100 万年前期间发生了四倍体化事件。这些事件为物种的多样化提供了遗传基础[9]。通过对木樨科的 298 个物种的代表样品进行系统发育树的重建, 发现木樨科的起源时间可以追溯到约 8600 万年前, 亚洲的热带地区是木樨科物种扩散的主要来源地[10]。

木樨科植物的分类采用的表型性状包括: 叶的着生方式(例如, 对生方式)、叶形(例如, 单叶、三出复叶或者羽状复叶等)、叶边缘特征(例如, 叶缘是全缘还是具齿)、叶柄、托叶、花的特征(例如, 花的颜色、辐射对称性、花冠裂片数、雄蕊数目、花序类型等)、果实的特征(例如, 是核果、蒴果、浆果、翅果, 还是浆果状核果, 不同属的果实形态差异比较显著)、子房结构以及花期等。由于表型特征在种/亚种/属之间存在一定的相似性, 而且性状的表现会受到植物生长发育阶段、季节或者环境条件的影响, 仅依据表型特征来鉴定木樨科植物资源的多样性存在难度[1][2][11]-[14]。

木樨科植物的分类研究经历了多种方法的探索, 包括形态学、细胞学、孢粉学、化学成分、RAPD、AFLP、ISSR、SSR 标记、DNA 条形码技术等[1][2][11]-[19]。引入新技术、增加信息量、提高物种分

辨力仍然是研究的重要方向[20]-[37]。近年来,叶绿体全基因组序列数据已经广泛应用于植物的物种鉴定和系统发生学研究,这种数据信息量大,能够提升物种的分辨率[20]-[37]。为了促进木樨科植物资源的保护、可持续利用以及相关产业的发展,本文报道一种在分子水平上鉴定木樨科植物资源遗传多样性的新方法。

2. 材料与方法

17 份样品代表木樨科的 4 个物种,每个物种重复取样 3~7 个植株。供试样品名称及其叶绿体全基因组的序列号如表 1 (<https://www.ncbi.nlm.nih.gov>)。根据本团队研发的方法[27]-[37]编制分子鉴定检索表。利用 MAFFT v7.055b 软件[38]获得比对序列矩阵。比对后的序列矩阵的长度为 157,737 个核苷酸,由左向右,左端(5'-端)起的第 1 个核苷酸字母的位置编号为 1,最右端的核苷酸字母的位置编号为 157,737。用 MEGA 7.0 [39]和 DnaSP v6 软件[40]检测核苷酸变异位点(图 1, 表 2)。每个物种的特有核苷酸变异位点作为分子性状,用于编写供试样品的分子鉴定检索表(见图 1)。利用马鞭草科 Verbenaceae 海榄雌属 *Avicennia* L. 的海榄雌 *Avicennia marina* (Forssk.) Vierh. 以及胡麻科 Pedaliaceae 芝麻属 *Sesamum* L. 的芝麻 *Sesamum indicum* L. 作为外类群(表 1 和图 1)。用 MEGA 7.0 软件的 Tamura 3-parameter model 参数模型推断系统发生关系(图 2)。分子鉴定检索表(图 1)的运算基于每个物种的全部供试样品的基因组序列数据(表 1)。为节约篇幅,图 2 中,每个物种仅展示 3 个代表样品。

Table 1. Samples and GenBank accession numbers for the chloroplast genome sequences used in this study

表 1. 供试样品及叶绿体基因组序列号

	拉丁学名 Latin name	中文名称 Chinese name	序列号 GenBank accession No.
1	<i>Abeliophyllum distichum</i> Nakai	翅果连翘	MK616470.1, MN116559.1, MN127986.1
2	<i>Forsythia suspensa</i> (Thunb.) Vahl	连翘	PV567297.1 (isolate ENC868427), PV567298.1 (isolate ENC868428), PV567302.1 (isolate ENC870086), PV567303.1 (isolate ENC870087), PV567304.1 (isolate ENC870088), PV567305.1 (isolate ENC870089), MF579702.1
3	<i>Olea europaea</i> subsp. <i>cuspidata</i> (Wall. & G. Don) Cif.	锈鳞木樨榄	MT560021.1 (voucher Hengduan team 1114), MT560022.1 (voucher BOP215910), MT560023.1 (voucher Tibetan team 13384), MT560024.1 (voucher Tibetan team 12907)
4	<i>Tetrapilus caudatilimbus</i> (L.C. Chia) de Juana	尾叶滨木樨榄	MT560027.1 (voucher BOP215905), MT560029.1 (voucher Cunyu Yang et al 4670), MT560030.1 (voucher POC544614)
5	* <i>Avicennia marina</i> (Forssk.) Vierh.	海榄雌	MN307164.1
6	* <i>Sesamum indicum</i> L.	芝麻	KC569603.1

注: *Olea caudatilimba* L.C. Chia 是尾叶滨木樨榄 *Tetrapilus caudatilimbus* 的异名。*外类群。

1a. Type C₉₃A₂₉₅T₃₇₈G₃₈₅T₅₂₈G₅₄₀G₂₁₆₂G₂₃₈₀T₄₂₆₅T₄₄₈₀A₄₅₈₃A₄₇₁₅T₅₂₇₅T₅₃₁₅G₅₈₂₀A₅₈₄₄T₆₈₄₂A₇₃₆₃G₇₄₈₇
 A₈₃₁₆T₈₃₉₀G₉₁₅₃G₁₁₈₄₉A₁₄₆₄₀C₁₄₉₃₃G₁₆₂₄₄T₁₆₆₃₉A₁₈₉₃₇T₁₉₂₂₁C₂₀₀₄₇C₂₀₁₉₆T₂₀₂₃₄T₂₂₀₀₀T₂₂₇₆₇T₂₇₆₁₃G₂₇₇₇₁G₂₇₇₉₀
 C₂₈₇₁₇A₃₀₂₁₅A₃₀₈₉₁G₃₁₁₃₄T₃₁₉₉₅A₃₃₄₇₅A₃₃₄₉₈G₃₃₅₆₅A₃₆₉₂₅T₃₈₉₅₅T₃₉₃₅₅G₄₁₈₀₄T₄₇₁₄₂C₄₇₉₂₈A₄₇₉₇₇C₄₇₉₇₈A₄₇₉₈₀
 T₄₈₄₇₀T₄₉₄₂₁T₄₉₅₀₅T₄₉₈₁₉A₅₀₂₁₅G₅₁₈₄₃T₅₃₈₁₅T₅₄₁₄₀T₅₄₆₄₇T₅₄₆₇₉A₅₄₇₂₉G₅₄₈₀₁A₅₅₅₄₂G₅₆₁₂₀G₅₇₂₃₅T₅₈₁₅₅T₆₀₆₀₁
 T₆₃₀₆₃T₆₃₀₈₄A₆₃₈₂₂C₆₄₈₇₁T₆₇₁₂₆A₆₉₂₆₂A₆₉₂₆₃C₇₀₀₆₆A₇₁₂₃₈T₇₁₄₃₁A₇₂₇₅₄G₇₃₁₈₈G₇₃₃₁₃G₇₃₆₄₉A₇₅₃₃₅A₇₆₃₀₁T₇₉₁₁₈
 A₇₉₃₄₃G₈₀₈₄₉C₈₂₁₂₀C₈₂₁₅₉G₈₂₃₃₇G₈₅₁₅₂A₈₅₈₄₄C₈₆₀₅₆C₈₆₄₃₉T₈₇₀₉₂T₈₇₃₅₀G₈₇₇₉₆A₈₇₉₃₉G₈₇₉₄₂T₈₈₀₇₄G₈₈₀₉₂A₈₈₁₂₂
 C₉₀₅₅₇C₉₃₁₇₆G₉₆₀₃₇T₉₇₉₂₀G₉₇₉₂₁A₉₇₉₂₂T₉₇₉₂₃C₁₀₄₁₃₄C₁₁₃₀₀₅T₁₁₃₉₁₇G₁₁₄₀₉₀T₁₁₄₂₇₂C₁₁₄₄₉₆T₁₁₄₅₆₁A₁₁₄₅₆₉T₁₁₄₆₆₀
 T₁₁₄₆₈₅C₁₁₄₉₂₂G₁₁₅₂₃₃T₁₁₆₀₈₈A₁₁₆₃₃₄G₁₁₆₄₀₇C₁₁₆₅₃₅T₁₁₆₅₆₇C₁₁₆₅₆₈C₁₁₆₅₇₅A₁₁₆₅₇₇T₁₁₆₅₉₄T₁₁₆₉₉₄T₁₁₇₀₂₅T₁₁₇₈₈₄
 A₁₁₈₁₈₃T₁₁₈₉₈₄T₁₁₉₂₄₄A₁₁₉₅₂₃G₁₁₉₇₆₆C₁₂₁₁₃₄A₁₂₁₇₅₇T₁₂₂₇₂₉G₁₂₃₀₂₀T₁₂₃₂₄₆A₁₂₅₃₃₄A₁₂₅₃₅₂A₁₂₅₇₅₈G₁₂₆₅₄₁A₁₂₆₅₅₃
 T₁₂₆₉₆₄T₁₂₇₁₀₃T₁₂₇₁₂₅A₁₂₇₅₃₆A₁₂₈₂₂₈T₁₂₈₃₄₂T₁₂₈₃₄₈T₁₂₈₃₆₀A₁₂₈₃₈₈C₁₂₈₅₀₄T₁₂₈₆₇₄G₁₂₈₉₁₆C₁₂₉₁₃₃T₁₂₉₁₅₈A₁₂₉₃₀₆
 A₁₂₉₃₄₆T₁₂₉₄₇₉A₁₂₉₈₄₄C₁₃₀₂₉₃C₁₃₀₆₂₁T₁₃₀₇₃₅G₁₃₀₇₇₇A₁₃₀₇₇₈G₁₃₀₇₈₄C₁₃₀₉₄₀C₁₃₀₉₅₅C₁₃₁₀₄₈T₁₃₁₁₃₃T₁₃₁₂₈₅C₁₃₁₄₀₀
 C₁₃₁₅₉₉T₁₃₁₆₈₄T₁₃₁₉₂₈A₁₃₂₀₆₆G₁₃₂₉₇₈G₁₄₁₈₄₉A₁₄₈₀₆₀T₁₄₈₀₆₁C₁₄₈₀₆₂A₁₄₈₀₆₃C₁₄₉₉₄₆G₁₅₂₈₀₇G₁₅₅₄₂₆

..... 连翘 *Forsythia suspensa*

1b. Type T₉₃G₂₉₅C₃₇₈T₃₈₅C₅₂₈T₅₄₀C₂₁₆₂A₂₃₈₀C₄₂₆₅A₄₄₈₀G₄₅₈₃G₄₇₁₅C₅₂₇₅G₅₃₁₅C₅₈₂₀G₅₈₄₄C₆₈₄₂G₇₃₆₃C₇₄₈₇
 G₈₃₁₆C₈₃₉₀C₉₁₅₃T₁₁₈₄₉G₁₄₆₄₀T₁₄₉₃₃A₁₆₂₄₄C₁₆₆₃₉G₁₈₉₃₇C₁₉₂₂₁T₂₀₀₄₇T₂₀₁₉₆C₂₀₂₃₄A₂₂₀₀₀C₂₂₇₆₇C₂₇₆₁₃T₂₇₇₇₁A₂₇₇₉₀
 A₂₈₇₁₇T₃₀₂₁₅G₃₀₈₉₁T₃₁₁₃₄C₃₁₉₉₅G₃₃₄₇₅G₃₃₄₉₈T₃₃₅₆₅G₃₆₉₂₅A₃₈₉₅₅C₃₉₃₅₅A₄₁₈₀₄C₄₇₁₄₂A₄₇₉₂₈C₄₇₉₇₇A₄₇₉₇₈T₄₇₉₈₀
 C₄₈₄₇₀G₄₉₄₂₁G₄₉₅₀₅C₄₉₈₁₉G₅₀₂₁₅A₅₁₈₄₃C₅₃₈₁₅C₅₄₁₄₀C₅₄₆₄₇C₅₄₆₇₉C₅₄₇₂₉T₅₄₈₀₁C₅₅₅₄₂A₅₆₁₂₀A₅₇₂₃₅G₅₈₁₅₅C₆₀₆₀₁
 C₆₃₀₆₃C₆₃₀₈₄G₆₃₈₂₂T₆₄₈₇₁C₆₇₁₂₆C₆₉₂₆₂C₆₉₂₆₃T₇₀₀₆₆G₇₁₂₃₈G₇₁₄₃₁C₇₂₇₅₄A₇₃₁₈₈T₇₃₃₁₃T₇₃₆₄₉G₇₅₃₃₅G₇₆₃₀₁A₇₉₁₁₈
 G₇₉₃₄₃A₈₀₈₄₉T₈₂₁₂₀T₈₂₁₅₉C₈₂₃₃₇A₈₅₁₅₂G₈₅₈₄₄T₈₆₀₅₆G₈₆₄₃₉C₈₇₀₉₂C₈₇₃₅₀C₈₇₇₉₆C₈₇₉₃₉T₈₇₉₄₂C₈₈₀₇₄A₈₈₀₉₂G₈₈₁₂₂
 A₉₀₅₅₇A₉₃₁₇₆A₉₆₀₃₇A₉₇₉₂₀T₉₇₉₂₁C₉₇₉₂₂A₉₇₉₂₃T₁₀₄₁₃₄G₁₁₃₀₀₅C₁₁₃₉₁₇A₁₁₄₀₉₀G₁₁₄₂₇₂G₁₁₄₄₉₆C₁₁₄₅₆₁G₁₁₄₅₆₉C₁₁₄₆₆₀
 C₁₁₄₆₈₅G₁₁₄₉₂₂A₁₁₅₂₃₃C₁₁₆₀₈₈C₁₁₆₃₃₄A₁₁₆₄₀₇T₁₁₆₅₃₅A₁₁₆₅₆₇T₁₁₆₅₆₈T₁₁₆₅₇₅C₁₁₆₅₇₇A₁₁₆₅₉₄C₁₁₆₉₉₄C₁₁₇₀₂₅G₁₁₇₈₈₄
 G₁₁₈₁₈₃C₁₁₈₉₈₄G₁₁₉₂₄₄G₁₁₉₅₂₃A₁₁₉₇₆₆T₁₂₁₁₃₄T₁₂₁₇₅₇C₁₂₂₇₂₉T₁₂₃₀₂₀C₁₂₃₂₄₆G₁₂₅₃₃₄C₁₂₅₃₅₂G₁₂₅₇₅₈A₁₂₆₅₄₁G₁₂₆₅₅₃
 C₁₂₆₉₆₄C₁₂₇₁₀₃C₁₂₇₁₂₅C₁₂₇₅₃₆C₁₂₈₂₂₈G₁₂₈₃₄₂C₁₂₈₃₄₈G₁₂₈₃₆₀T₁₂₈₃₈₈G₁₂₈₅₀₄G₁₂₈₆₇₄A₁₂₈₉₁₆T₁₂₉₁₃₃C₁₂₉₁₅₈T₁₂₉₃₀₆
 T₁₂₉₃₄₆G₁₂₉₄₇₉G₁₂₉₈₄₄G₁₃₀₂₉₃T₁₃₀₆₂₁C₁₃₀₇₃₅A₁₃₀₇₇₇G₁₃₀₇₇₈A₁₃₀₇₈₄T₁₃₀₉₄₀T₁₃₀₉₅₅G₁₃₁₀₄₈C₁₃₁₁₃₃C₁₃₁₂₈₅G₁₃₁₄₀₀
 A₁₃₁₅₉₉C₁₃₁₆₈₄C₁₃₁₉₂₈G₁₃₂₀₆₆C₁₃₂₉₇₈A₁₄₁₈₄₉T₁₄₈₀₆₀G₁₄₈₀₆₁A₁₄₈₀₆₂T₁₄₈₀₆₃T₁₄₉₉₄₆T₁₅₂₈₀₇T₁₅₅₄₂₆

..... 连翘之外的 3 个种 The three species other than *Forsythia suspensa*

2a. Type T₁₅₉G₁₇₁₀G₃₇₁₅G₃₇₃₆C₄₀₅₃G₄₄₁₆T₄₅₀₃A₄₅₂₃G₄₅₃₉A₄₇₀₃T₄₇₁₁T₄₇₁₃A₅₁₁₂G₅₈₇₇G₆₂₁₁T₇₁₂₈T₇₆₉₄A₇₈₆₅
 T₇₈₈₀G₈₄₅₉A₈₆₀₃T₈₈₆₅T₉₁₆₆G₉₈₀₁A₉₉₀₀G₉₉₅₆T₁₀₀₈₁C₁₀₄₃₀A₁₀₄₃₂C₁₁₁₇₄A₁₂₅₇₅C₁₃₀₃₇A₁₃₀₄₀G₁₃₈₈₃A₁₄₁₁₃A₁₄₁₄₁
 C₁₄₁₅₂C₁₅₀₃₉A₁₅₂₀₁G₁₅₅₄₀A₁₅₅₆₂T₁₅₈₀₆G₁₆₀₅₉A₁₆₅₀₅A₁₇₀₃₉G₁₉₁₉₄T₁₉₉₃₆T₂₀₃₉₀T₂₂₂₈₃G₂₂₄₈₀T₂₃₆₂₃T₂₄₂₀₇T₂₄₅₃₇

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 T31730 A32073 T32202 G32383 A33458 T34049 T34079 G34247 C34425 A34426 T34427 G34863 A34878 T34984 G35003 G35847 G36871
 T37402 T38398 A38899 C38948 A39410 A39411 A39412 A39413 A39414 T39452 C41387 C41558 A42642 A43170 T44517 T45273 G45617
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 C86946 G87824 C87930 G88298 T90669 G91484 A97693 T98247 G101237 C102589 T107715 A112103 A113926 G113938 G114165 A114210
 G114512 A114558 T115046 G115683 T116003 A116094 G116178 T116383 G116395 C117123 G117487 C117567 A117584 A117683 A118204
 T118474 C118930 T119049 T119280 G119310 G119434 G119478 A119517 C119967 T121239 G121466 T122531 T122619 C122684 T123017
 G123232 A123234 A123339 T124202 G124265 T124312 T125575 G125635 G126190 G126191 G126271 T126630 A127262 T127362 G127628
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 G131537 T131603 G131635 A131729 C132045 T132057 T133880 A138268 G143394 C144746 A147736 T148290 C154499 A155314 C157685

..... 翅果连翘 *Abeliophyllum distichum*

2b. Type C159 T1710 T3715 A3736 A4053 T4416 A4503 G4523 C4539 T4703 G4711 G4713 G5112 T5877 C6211 C7128 G7694 G7865
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 G24538 A24539 A24540 T26036 C26315 G26411 A27003 G27160 T29158 G29987 G30079 A30086 A30202 C30248 C30675 C31071 A31369
 A31730 G32073 C32202 T32383 G33458 C34049 C34079 A34247 A34425 T34426 G34427 A34863 C34878 G34984 C35003 T35847 A36871
 C37402 C38398 C38899 A38948 T39410 T39411 T39412 T39413 T39414 C39452 T41387 A41558 G42642 G43170 C44517 G45273 T45617
 G45816 A46073 A46124 A47126 C47135 T47984 C47985 G47986 C48333 G49455 C50006 G50245 C51138 C51821 T51904 T53893 T53986
 A54045 A54097 A54728 G54771 C55375 G58390 T59631 C59855 A59994 G59995 G61371 C63712 C63804 A64976 C65343 C65527 G65787
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 C127637 C127965 A128564 C128676 A128977 T128999 C129063 A129338 T129699 G129913 G130305 T130443 A131349 C131412 C131502

T131537A131603T131635G131729A132045A132057G133880G138268A143394T144746G147736C148290A154499C155314A157685

..... 翅果连翘之外的 3 个种 The three species other than *Abeliophyllum distichum*

3a. Type C₁₄₄T₃₇₇C₉₀₅C₉₇₀T₁₆₅₆A₁₈₂₂C₁₈₄₇G₂₀₄₄G₂₁₁₄T₂₂₆₈C₂₃₄₂T₂₃₆₃A₂₇₈₀T₃₃₄₆A₃₄₁₁T₃₄₉₅G₃₇₂₇A₄₁₉₃

C₄₄₇₃C₄₅₅₀T₄₅₇₁C₄₅₇₂G₅₁₀₇A₅₁₀₈A₅₁₉₉C₅₂₂₁T₅₂₆₉T₅₅₂₇C₆₁₇₀T₆₂₃₅T₆₂₄₇A₆₆₇₀T₇₀₀₇G₇₂₂₈G₇₇₅₂A₇₈₀₃A₉₄₆₄C₉₄₈₆

A₉₆₈₈G₉₈₁₃T₉₈₁₉G₉₈₂₈C₉₉₃₇A₉₉₅₉A₁₀₁₁₃G₁₀₅₄₅G₁₀₆₂₃A₁₀₈₁₀C₁₁₂₆₄A₁₁₄₆₇A₁₁₆₀₆A₁₂₃₇₀C₁₃₁₂₇G₁₃₅₄₂A₁₄₆₁₆C₁₄₆₃₆

A₁₅₀₇₈T₁₅₇₄₅C₁₅₉₉₀G₁₇₁₉₃T₁₇₆₈₈T₁₇₈₁₉A₁₇₈₄₄C₁₈₀₅₄C₁₈₉₈₂G₁₉₅₇₈C₂₀₂₃₅G₂₀₇₈₂A₂₀₉₈₉C₂₂₃₄₅A₂₂₅₅₀G₂₂₇₀₁T₂₃₀₆₆

G₂₃₄₃₈A₂₃₇₉₇G₂₄₂₆₇G₂₄₂₇₄A₂₅₂₄₉A₂₅₆₈₄C₂₅₉₀₃T₂₆₃₀₀A₂₈₅₀₄A₂₈₅₀₈G₂₈₅₅₁T₂₈₉₁₇T₂₉₀₁₇C₂₉₅₆₇T₂₉₆₀₄G₂₉₇₃₀C₂₉₈₂₇

A₃₀₀₁₈C₃₀₈₃₄T₃₁₇₅₀G₃₁₇₉₀A₃₂₃₇₇A₃₂₄₂₅C₃₂₄₂₆C₃₂₄₃₉T₃₂₉₇₃C₃₃₁₀₉T₃₃₁₆₇T₃₃₉₁₉T₃₃₉₂₄C₃₄₁₇₄C₃₄₃₉₇T₃₄₆₁₅G₃₄₈₇₁

C₃₅₀₈₉C₃₇₄₄₆T₃₈₄₂₇G₃₈₄₇₅C₃₈₅₃₀T₃₈₅₅₃C₃₉₀₉₅A₄₀₀₉₉T₄₀₂₃₂G₄₀₄₂₄C₄₀₅₈₉C₄₀₆₈₂C₄₁₄₁₁C₄₃₀₆₂T₄₃₁₁₉T₄₃₅₇₂T₄₄₆₄₃

C₄₅₁₃₇G₄₅₁₄₅A₄₅₆₂₃G₄₇₄₇₄A₄₇₆₂₅T₄₇₇₅₈C₄₇₈₀₅G₄₇₉₅₅T₄₈₀₆₅A₄₉₂₂₈C₄₉₄₈₂C₄₉₄₈₃C₄₉₄₉₄G₄₉₇₁₉G₄₉₇₄₇C₅₀₀₂₃G₅₀₇₃₈

G₅₀₉₈₀C₅₁₂₄₁G₅₁₃₆₅A₅₁₃₆₆C₅₁₅₃₁T₅₁₇₃₄A₅₁₇₆₉C₅₁₉₂₂T₅₂₄₇₁C₅₃₇₅₈T₅₃₈₆₂G₅₄₅₅₃T₅₄₆₃₆T₅₄₈₀₈A₅₅₅₄₆A₅₅₆₂₉T₅₅₇₆₈

G₅₆₁₃₂A₅₆₂₉₇G₅₈₀₉₄C₅₉₀₀₉T₅₉₀₃₀A₅₉₁₀₂G₅₉₃₀₄G₆₀₀₅₉G₆₀₅₃₃G₆₁₇₇₃A₆₃₃₅₃C₆₃₅₀₄A₆₄₃₆₃A₆₄₈₆₂C₆₅₀₀₈A₆₅₃₅₉A₆₆₀₂₃

A₆₆₆₀₅G₆₇₁₅₉T₆₇₅₃₉G₆₇₅₄₀G₆₇₇₁₁T₆₈₀₆₈G₆₈₁₆₂C₆₈₈₀₀G₆₉₁₂₅T₆₉₂₃₈G₆₉₄₂₁T₆₉₅₆₄A₆₉₇₃₇T₆₉₇₅₅T₇₀₀₂₀G₇₀₅₂₇G₇₁₀₂₁

G₇₁₂₈₅C₇₁₇₂₃C₇₂₀₅₈A₇₂₁₉₁T₇₂₃₄₈C₇₂₅₅₂C₇₃₃₁₅G₇₃₅₁₃T₇₃₈₆₅A₇₃₉₀₂T₇₄₀₆₅A₇₅₁₄₉A₇₅₄₆₇G₇₆₃₆₉A₇₈₄₁₂T₇₉₀₂₈G₇₉₃₃₈

T₈₁₂₁₄T₈₁₂₄₂T₈₁₃₀₅A₈₁₉₁₇C₈₃₀₀₀G₈₃₀₅₄A₈₃₅₄₃G₈₃₈₇₆T₈₄₀₅₀G₈₄₁₄₃A₈₆₀₂₄T₈₆₇₁₁A₈₆₇₉₆G₈₇₀₇₂T₈₇₁₃₅T₈₇₂₄₈A₈₇₇₆₆

T₈₈₂₇₀T₈₈₅₉₉G₉₁₀₀₈C₉₃₀₀₈G₁₀₃₃₃₈G₁₀₈₁₂₈T₁₁₃₇₃₇A₁₁₃₉₈₇A₁₁₃₉₈₈G₁₁₄₂₀₉T₁₁₄₃₂₁G₁₁₄₃₃₀G₁₁₄₃₃₈G₁₁₄₄₃₆G₁₁₅₆₀₀T₁₁₆₀₉₀

G₁₁₆₃₄₃C₁₁₆₃₅₂A₁₁₆₆₃₇C₁₁₆₇₅₇A₁₁₇₂₄₃C₁₁₇₂₉₇C₁₁₇₉₀₂A₁₁₇₉₄₈C₁₁₇₉₅₈A₁₁₈₁₈₉G₁₁₈₁₉₈A₁₁₈₁₉₉A₁₁₈₅₄₀T₁₁₉₆₀₄G₁₁₉₇₁₁

T₁₂₀₂₄₉G₁₂₂₀₆₁A₁₂₂₂₅₁T₁₂₃₁₀₇T₁₂₃₄₂₅A₁₂₄₆₃₄A₁₂₄₈₃₃G₁₂₅₃₅₅T₁₂₆₃₃₇C₁₂₆₇₉₀C₁₂₇₁₁₀C₁₂₇₁₉₇T₁₂₇₅₇₁A₁₂₇₆₀₂G₁₂₇₆₃₈

C₁₂₇₇₃₇C₁₂₇₇₈₂C₁₂₇₈₃₄T₁₂₈₂₉₆T₁₂₈₈₇₇C₁₂₈₉₉₅T₁₂₉₄₆₅T₁₂₉₄₇₃G₁₂₉₅₃₆G₁₂₉₆₃₅T₁₂₉₆₈₉T₁₂₉₈₆₃C₁₃₀₀₉₄G₁₃₀₁₀₁C₁₃₀₁₇₆

A₁₃₀₂₂₉G₁₃₀₂₅₆T₁₃₀₅₇₅T₁₃₀₇₀₇T₁₃₁₂₄₉T₁₃₁₃₄₈C₁₃₁₃₅₈G₁₃₁₃₉₇G₁₃₁₅₅₀T₁₃₁₆₂₄T₁₃₁₇₀₂C₁₃₁₉₄₉G₁₃₁₉₅₉T₁₃₁₉₉₅T₁₃₁₉₉₆

A₁₃₂₂₄₆C₁₃₇₈₅₅C₁₄₂₆₄₅G₁₅₂₉₇₅C₁₅₄₉₇₅A₁₅₇₃₈₄A₁₅₇₇₁₃

..... 尾叶滨木樨榄 *Tetrapilus caudatilimbus*

3b. Type G₁₄₄C₃₇₇T₉₀₅A₉₇₀C₁₆₅₆G₁₈₂₂A₁₈₄₇T₂₀₄₄T₂₁₁₄A₂₂₆₈T₂₃₄₂G₂₃₆₃T₂₇₈₀C₃₃₄₆C₃₄₁₁G₃₄₉₅A₃₇₂₇G₄₁₉₃

A₄₄₇₃A₄₅₅₀G₄₅₇₁A₄₅₇₂T₅₁₀₇T₅₁₀₈G₅₁₉₉A₅₂₂₁C₅₂₆₉C₅₅₂₇G₆₁₇₀C₆₂₃₅G₆₂₄₇C₆₆₇₀C₇₀₀₇T₇₂₂₈A₇₇₅₂G₇₈₀₃G₉₄₆₄A₉₄₈₆

C₉₆₈₈A₉₈₁₃A₉₈₁₉A₉₈₂₈A₉₉₃₇G₉₉₅₉T₁₀₁₁₃T₁₀₅₄₅T₁₀₆₂₃G₁₀₈₁₀T₁₁₂₆₄T₁₁₄₆₇G₁₁₆₀₆C₁₂₃₇₀T₁₃₁₂₇C₁₃₅₄₂G₁₄₆₁₆A₁₄₆₃₆

C₁₅₀₇₈G₁₅₇₄₅T₁₅₉₉₀C₁₇₁₉₃C₁₇₆₈₈C₁₇₈₁₉G₁₇₈₄₄G₁₈₀₅₄T₁₈₉₈₂C₁₉₅₇₈T₂₀₂₃₅A₂₀₇₈₂T₂₀₉₈₉A₂₂₃₄₅G₂₂₅₅₀T₂₂₇₀₁C₂₃₀₆₆

A₂₃₄₃₈C₂₃₇₉₇T₂₄₂₆₇T₂₄₂₇₄G₂₅₂₄₉C₂₅₆₈₄T₂₅₉₀₃C₂₆₃₀₀T₂₈₅₀₄C₂₈₅₀₈T₂₈₅₅₁A₂₈₉₁₇G₂₉₀₁₇A₂₉₅₆₇C₂₉₆₀₄T₂₉₇₃₀T₂₉₈₂₇

G₃₀₀₁₈A₃₀₈₃₄G₃₁₇₅₀T₃₁₇₉₀C₃₂₃₇₇G₃₂₄₂₅A₃₂₄₂₆A₃₂₄₃₉G₃₂₉₇₃T₃₃₁₀₉A₃₃₁₆₇A₃₃₉₁₉A₃₃₉₂₄A₃₄₁₇₄A₃₄₃₉₇C₃₄₆₁₅A₃₄₈₇₁

A₃₅₀₈₉G₃₇₄₄₆C₃₈₄₂₇T₃₈₄₇₅A₃₈₅₃₀A₃₈₅₅₃T₃₉₀₉₅G₄₀₀₉₉C₄₀₂₃₂T₄₀₄₂₄T₄₀₅₈₉T₄₀₆₈₂T₄₁₄₁₁T₄₃₀₆₂C₄₃₁₁₉C₄₃₅₇₂C₄₄₆₄₃

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 T132246 A137855 T142645 T152975 A154975 G157384 C157713

..... 尾叶滨木樨榄之外的 3 个种 The three species other than *Tetrapilus caudatilimbus*

4a. Type G125 G205 G207 T217 T233 T260 G929 T2125 T2199 G2665 G2854 G2968 T2985 T2988 G3464 T3518 A3652 T3990 T4215
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 锈鳞木樨榄 *Olea europaea* subsp. *cuspidata*
4b. Type T₁₂₅C₂₀₅A₂₀₇G₂₁₇G₂₃₃A₂₆₀T₉₂₉C₂₁₂₅C₂₁₉₉A₂₆₆₅T₂₈₅₄T₂₉₆₈C₂₉₈₅C₂₉₈₈T₃₄₆₄C₃₅₁₈G₃₆₅₂C₃₉₉₀C₄₂₁₅
 G₄₂₃₇A₄₂₆₄T₄₇₀₉T₄₇₃₂A₄₇₇₄A₄₇₇₅A₄₉₁₉C₅₄₀₁C₅₉₃₇C₆₄₄₀T₆₆₅₃G₆₇₈₁T₆₈₇₇G₇₁₉₂A₇₄₇₈C₇₄₇₉T₇₆₈₃C₈₈₁₃A₉₁₃₆A₉₈₁₄
 G₉₉₇₆G₉₉₈₀G₁₀₁₂₂C₁₀₂₅₂C₁₀₅₇₇C₁₁₃₁₁T₁₁₄₇₅G₁₁₄₈₄T₁₁₇₃₄T₁₂₅₃₉C₁₂₇₁₆C₁₂₉₄₃T₁₃₆₉₂C₁₃₇₂₉A₁₃₈₇₂T₁₄₄₁₅G₁₄₅₇₉G₁₅₀₇₃
 A₁₅₈₆₂A₁₆₀₇₁A₁₆₇₁₄A₁₇₀₀₈C₁₇₀₁₀T₁₇₇₃₂T₁₇₈₃₀T₁₈₀₀₂G₁₈₁₄₈G₁₉₃₃₀T₁₉₇₈₄G₂₀₇₄₆G₂₀₉₂₆G₂₁₀₆₇G₂₁₄₁₁A₂₁₅₃₀T₂₁₈₁₀
 T₂₂₃₃₂T₂₂₄₀₂G₂₃₈₃₁A₂₄₁₀₃T₂₄₄₆₇G₂₄₅₄₅G₂₄₇₇₂A₂₅₉₇₅C₂₆₁₆₁C₂₇₀₈₅G₂₇₃₅₉A₂₇₃₇₃T₂₈₀₅₃T₂₈₇₉₁G₂₈₉₇₀T₂₉₀₃₆T₂₉₅₈₂
 A₂₉₈₂₁G₃₀₁₀₅A₃₀₁₀₆G₃₀₈₁₆G₃₁₀₁₈G₃₁₀₂₄G₃₁₀₄₇A₃₁₀₄₈C₃₁₀₄₉C₃₁₂₈₆A₃₁₃₀₅C₃₁₃₁₁A₃₁₆₂₄A₃₁₆₂₅T₃₁₆₂₆G₃₁₆₂₈A₃₁₆₂₉
 G₃₁₆₃₁A₃₂₂₂₃G₃₂₂₂₄T₃₂₂₂₅A₃₂₂₂₆C₃₂₂₄₃A₃₂₂₅₀T₃₃₀₉₄A₃₃₇₄₉G₃₃₉₃₅T₃₄₀₆₈T₃₄₇₇₇A₃₄₈₁₀T₃₄₈₅₆A₃₄₉₄₁G₃₅₀₉₀C₃₅₂₃₀
 C₃₅₂₃₆A₃₅₅₃₀C₃₅₆₇₀T₃₅₇₃₀G₃₆₀₅₃G₃₆₅₄₆A₃₆₇₅₁T₃₆₇₈₄G₃₈₅₁₄T₃₈₆₅₀T₃₉₀₉₂G₃₉₆₅₉A₃₉₇₄₇C₄₀₀₀₆T₄₀₀₅₆T₄₀₈₂₅A₄₃₀₁₄
 A₄₄₁₃₀G₄₄₈₆₆T₄₅₁₀₁T₄₅₂₅₉T₄₅₂₉₅A₄₅₄₁₈G₄₆₆₀₈T₄₆₈₉₂T₄₇₇₁₉A₄₉₁₉₉C₄₉₇₂₇G₅₀₂₁₇C₅₀₉₇₁T₅₁₇₈₁G₅₂₆₇₇A₅₂₆₉₈T₅₂₇₉₄
 A₅₃₇₇₉G₅₃₈₁₉C₅₃₈₂₅A₅₃₉₃₂C₅₄₃₀₃A₅₅₃₁₃G₅₆₀₇₇C₅₆₅₇₈G₅₇₄₇₃A₅₇₆₈₂G₅₈₀₄₅C₅₉₇₇₂G₅₉₇₇₄A₆₀₀₅₈A₆₀₅₇₅C₆₀₅₉₈T₆₀₆₉₅
 G₆₀₉₇₄T₆₁₁₇₆G₆₁₂₁₁G₆₁₂₄₅C₆₁₇₈₂C₆₁₈₄₁T₆₂₉₀₇T₆₃₄₃₀C₆₅₃₈₉G₆₆₀₈₃T₆₆₄₈₈C₆₇₆₇₀C₆₇₇₈₅A₆₇₉₃₅T₆₉₂₄₈A₆₉₄₃₈C₆₉₄₇₆
 T₆₉₅₅₄A₆₉₈₃₁A₇₀₅₁₆C₇₀₉₀₅G₇₁₄₂₀G₇₁₄₈₈G₇₁₈₇₀C₇₁₉₆₃A₇₁₉₉₈T₇₂₈₀₂T₇₃₀₃₃T₇₃₁₂₇C₇₃₁₅₅G₇₃₆₉₈C₇₅₀₈₄A₇₅₄₁₃C₇₆₀₁₆
 A₇₆₅₀₄A₇₆₅₇₄G₇₇₈₂₇C₇₈₃₀₅G₇₈₄₇₆T₇₉₁₇₉T₈₀₄₀₆T₈₀₇₉₀C₈₁₂₁₅A₈₁₂₇₆G₈₁₂₈₀C₈₁₅₆₈C₈₂₀₇₄G₈₂₀₇₅C₈₃₀₀₆C₈₃₁₇₄A₈₃₈₆₉
 A₈₄₅₅₈A₈₄₆₃₀T₈₆₇₃₇C₈₇₂₅₉C₈₇₆₉₈T₈₉₉₃₁T₉₂₃₃₃A₉₅₈₅₉A₉₆₄₅₂G₉₇₂₈₄A₉₇₈₂₁A₉₉₉₃₀A₁₀₂₉₂₈C₁₀₈₇₅₇T₁₁₃₄₆₄C₁₁₃₇₄₂T₁₁₃₉₀₅
 A₁₁₃₉₈₃A₁₁₄₀₄₅C₁₁₄₁₂₀C₁₁₄₄₄₀T₁₁₄₆₂₅A₁₁₄₇₄₇G₁₁₄₇₅₃T₁₁₅₀₃₃C₁₁₅₀₄₁A₁₁₅₀₇₂G₁₁₅₃₈₀C₁₁₅₉₂₃T₁₁₅₉₄₄G₁₁₅₉₅₀G₁₁₆₀₁₇
 A₁₁₆₃₂₂G₁₁₆₄₆₁G₁₁₆₆₃₃T₁₁₆₇₀₁T₁₁₆₇₈₃C₁₁₇₁₉₆G₁₁₇₃₂₆C₁₁₇₈₂₉T₁₁₈₀₀₂C₁₁₈₁₆₂G₁₁₈₂₇₄C₁₁₉₄₇₁C₁₁₉₈₁₄C₁₁₉₈₈₃C₁₁₉₉₉₉
 G₁₂₀₄₀₅G₁₂₀₅₅₈A₁₂₀₆₉₈T₁₂₀₇₁₈G₁₂₀₇₃₆T₁₂₀₇₄₆C₁₂₀₇₄₇A₁₂₀₈₅₂C₁₂₂₁₅₆G₁₂₂₅₀₄A₁₂₂₅₅₀T₁₂₂₆₇₄T₁₂₂₆₉₈G₁₂₃₉₈₈T₁₂₄₁₇₂
 A₁₂₄₂₁₇C₁₂₄₄₂₅T₁₂₄₄₄₃T₁₂₄₅₅₃G₁₂₅₁₅₄T₁₂₅₈₄₄G₁₂₆₁₆₀C₁₂₆₂₅₆C₁₂₆₇₁₆G₁₂₆₇₅₀C₁₂₇₀₇₇T₁₂₇₁₆₂T₁₂₇₁₆₃C₁₂₇₁₆₄G₁₂₇₁₆₉
 C₁₂₇₆₈₉G₁₂₇₇₆₉T₁₂₈₀₄₃C₁₂₈₁₂₈T₁₂₈₆₀₃A₁₂₈₆₁₈T₁₂₈₆₇₇G₁₂₈₈₂₀A₁₂₈₉₉₄T₁₂₉₀₁₃C₁₂₉₀₉₉C₁₂₉₂₁₁T₁₂₉₃₆₀G₁₂₉₆₅₇T₁₂₉₇₄₇
 C₁₂₉₈₅₉C₁₂₉₈₈₇C₁₂₉₉₅₉T₁₃₀₁₂₄G₁₃₀₄₇₅T₁₃₀₅₃₂T₁₃₀₅₃₈A₁₃₀₉₉₈C₁₃₁₁₀₃T₁₃₁₁₂₉T₁₃₁₁₈₃C₁₃₁₂₃₇C₁₃₁₃₉₀C₁₃₁₇₂₀T₁₃₁₈₇₆
 G₁₃₁₈₉₇T₁₃₂₀₀₀A₁₃₂₀₇₈G₁₃₂₂₄₁A₁₃₂₅₁₉G₁₃₇₂₂₆T₁₄₃₀₅₅T₁₄₆₀₅₃T₁₄₈₁₆₂C₁₄₈₆₉₉T₁₄₉₅₃₁T₁₅₀₁₂₄A₁₅₃₆₅₀A₁₅₆₀₅₂
 锈鳞木樨榄之外的 3 个种 The three species other than *Olea europaea* subsp. *cuspidata*

Figure 1. Molecular identification key for four taxa in the Oleaceae based on taxon-specific nucleotide variant sites within chloroplast genome sequences

图 1. 基于叶绿体全基因组序列中的物种特有核苷酸变异位点的木樨科 4 个物种的分子鉴定检索表

Table 2. Base composition of variable nucleotide sites for identification of four taxa in the Oleaceae
表 2. 木樨科 4 种植物的具有分类价值的核苷酸变异位点数目及碱基构成

*	A (%)**	T (%)**	C (%)**	G (%)**	Total*** 合计(%)
1a	50 (25.77)	68 (35.05)	34 (17.53)	42 (21.65)	194 (17.41/)
1b	36 (18.56)	41 (21.13)	67 (34.54)	50 (25.77)	194 (17.41/)
2a	71 (27.00)	82 (31.18)	39 (14.83)	71 (27.00)	263 (23.61/)
2b	59 (22.43)	63 (23.95)	75 (28.52)	66 (25.10)	263 (23.61/)
3a	72 (23.30)	84 (27.18)	76 (24.60)	77 (24.92)	309 (27.74/)
3b	80 (25.89)	82 (26.54)	68 (22.01)	79 (25.57)	309 (27.74/)
4a	80 (22.99)	92 (26.44)	81 (23.28)	95 (27.30)	348 (31.24)
4b	79 (22.70)	98 (28.16)	88 (25.29)	83 (23.85)	348 (31.24)
合计					1114/2584

注: *该列的序号与检索表内的序号对应; 1a 为连翘 *Forsythia suspensa*, 2a 为翅果连翘 *Abeliophyllum distichum*, 3a 为尾叶滨木樨榄 *Tetrapilus caudatilimbus*, 4a 为锈鳞木樨榄 *Olea europaea* subsp. *cuspidata*。 ** 核苷酸变异位点数(在 4 种碱基中的占比); ***此列括号中, 前一个数字是在物种特有变异位点总数(1114)中所占的比例; 后一个数字是在全部核苷酸变异位点总数(2584)中所占的比例。

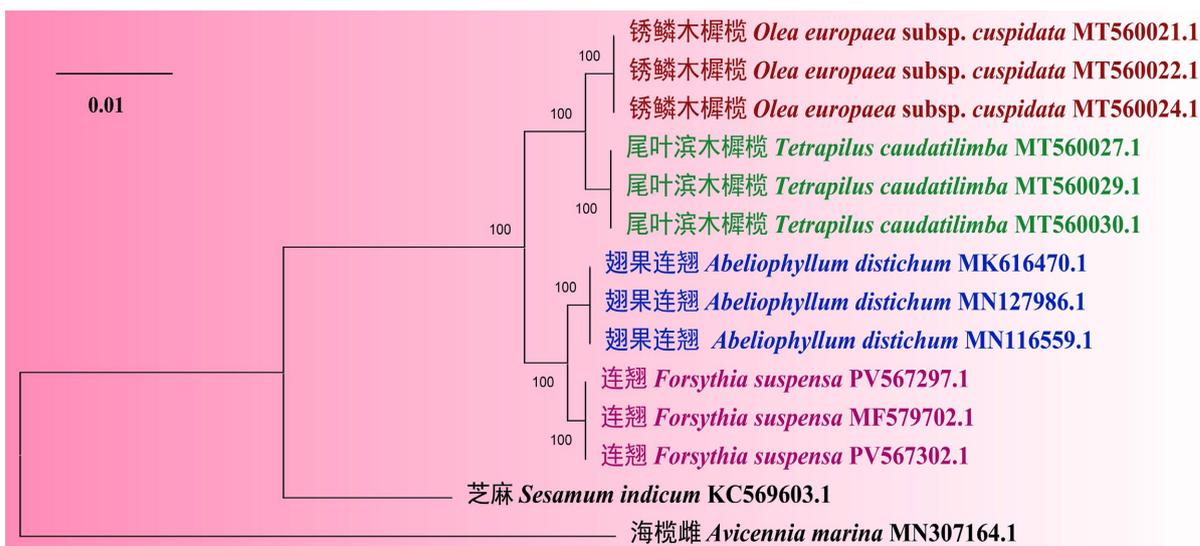


Figure 2. Phylogenetic relationships among four taxa in the Oleaceae based on the chloroplast whole-genome sequences using the neighbour-joining method with the Tamura 3-parameter model. The numbers near the branches are bootstrap support values (%) of 1000 replications

图 2. 基于叶绿体全基因组序列的木樨科 4 个物种的系统发生关系。分支图中的数字为 1000 次重复抽样的自展支持率

3. 结果

木樨科供试样品的叶绿体基因组序列的全长为 155,530 bp (如, MT560022.1, *Olea europaea* subsp. *cuspidata*)~156,405 bp (如, PV567303.1, *Forsythia suspensa*, PV567304.1, *Forsythia suspensa*, PV567298.1, *Forsythia suspensa*)。在比对序列中, 共检测到 2584 个核苷酸变异位点, 占叶绿体基因组序列全长的约 1.66%。

其中,物种的特有核苷酸变异位点数目合计为 1114 个,占变异位点总数的 43.11%。锈鳞木樨榄 *Olea europaea* subsp. *cuspidata* (348)的特有变异位点的数量最多,其次是尾叶滨木樨榄 *Tetrapilus caudatilimbus* (309)、翅果连翘 *Abeliophyllum distichum* (263)、连翘 *Forsythia suspensa* (194)。锈鳞木樨榄的特有变异位点中, G (27.30%)和 T (26.44%)的比例大于 C (23.28%)和 A (22.99%)。尾叶滨木樨榄的特有变异位点中, T (27.18%)的比例高于其它 3 类核苷酸。翅果连翘的特有变异位点中, T 的比例(31.18%)是 C 的比例(14.83%)的 2.1 倍; G (27.00%)和 A (27.00%)的比例是 C 的比例的 1.8 倍, T、A 和 G 的比例之间差异较小。连翘的特有变异位点中, T 的比例(35.05%)是 C 的比例(17.53%)的约 2.0 倍,是 G 的比例(21.65%)的 1.6 倍,是 A 的比例(25.77%)的 1.3 倍以上(表 2)。物种的特有变异位点的数量和核苷酸构成存在属/种/亚种间差异。利用物种的特有核苷酸变异位点,编制分子鉴定检索表,供试样得到精准鉴定(图 1 和图 2)。

4. 讨论

对 21 国 40 个植物标本馆的 4500 份标本的取样调查结果显示,50%以上的热带植物标本存在名称鉴定错误[41]。我们对中国标本馆系统 120 多年来采集、保存的木樨科植物标本的调查显示,中国馆藏的木樨科植物标本总计 74,484 份。利用 TNRS 网站(<https://tnrs.biendata.org/>)查证植物标本的正确名称和异名的结果显示,其中,异名数量(480)占出现名称总数(826)的约 58.11%。仅有属名、没有种名的标本数量占标本总数的 2.10%。此外,虽然标注为木樨科植物的物种名称,但名称无法查证的标本占号称木樨科植物标本总数 74,944 份的 0.61% [42]。植物分类学中,正确名称是指根据《国际藻类、菌物和植物命名法规》(International Code of Nomenclature for algae, fungi, and plants (Madrid Code), 简称 ICN)确认的、当前有效的物种学名。异名(Synonym)是指与正确名称指代同一植物,但未被采用的学名[43]。利用 TNRS 网站的查证结果显示,李榄属 *Linociera* Sw. ex Schreb.是流苏树属 *Chionanthus* Royenden 的异名[44],然而,实际情况要比表面上看起来的复杂,包含在李榄属内的 745 份标本是 4 个属(滨木樨榄属 *Tetrapilus* Lour.、木樨榄属 *Olea* L.、冠花榄属 *Noronhia* Stadman ex Thouars 以及流苏树属)的植物的混合体。基于现有的植物标本记录,结合 DNA 分析等多种技术的研究成果,需要构建高质量的植物标本信息库[42][45][46]。扩大成功精准鉴定的物种数量规模,才能有助于深度信息的挖掘。本研究对于推动木樨科植物的分类修订、资源保护和利用具有重要意义。

地球植物多样性的准确鉴定,对于控制全球气候变暖具有重要作用[47]。叶绿体基因组 DNA 序列的结构与功能之间的关系对于理解和利用光合作用至关重要。例如,德国 Ralph Bock 教授团队利用实验方法探索了叶绿体基因组中反向重复区(a large inverted repeat (IR) region)的功能重要性[48]。全基因组模型认为,复杂性状受到与性状直接相关的特定基因/基因通路的影响,这些基因的数量很少,称为核心基因。核心基因一旦失去功能,会对表型产生巨大影响。核心基因会受到其它基因的调控,调控核心基因的基因称为外围基因。基因之间的调控具有网络特征[49]。叶绿体是半自主细胞器,叶绿体基因组与细胞核基因组以及线粒体基因组之间存在较为复杂的信息交流[50]。深度理解叶绿体基因组 DNA 序列的结构,是重要研究方向之一。

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