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豆科复叶和单叶树种的光合-水分关系分析

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摘要: 以豆科(Fabaceae) 11个复叶树种和6个单叶树种为材料, 测定他们的气孔导度、叶片水力导度、水势、相对含水量等指标, 分析叶型对枝叶光合水分关系的影响。结果显示, 复叶树种正午叶轴水势(−0.91 MPa)与单叶树种正午枝条水势(−0.88 MPa)间无显著差异, 但正午枝条水势(−0.60 MPa)显著高于单叶树种。复叶树种正午气孔导度降低的百分比(55.3%)显著高于单叶树种(34.1%)。叶片、叶轴和枝条正午水势两两之间均显著正相关, 但与正午气孔导度之间均不存在相关性。本研究中, 17个树种的正午叶片水力导度与气孔导度间显著正相关($r = 0.79$, $P < 0.001$), 但他们与气孔导度降低百分比间呈负相关($r = -0.81$, $P < 0.001$), 说明叶片导水率对日间气孔导度的维持具有重要作用。研究结果表明单叶和复叶树种在光合水分关系上存在明显差异, 说明他们对环境条件具有不同的适应策略。

关键词: 叶型; 水力结构; 光合作用; 气孔导度; 豆科

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Analysis of photosynthesis–water relationship between simple– and compound–leafed leguminous trees

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Abstract: To investigate the influence of leaf form on the relationship between water and photosynthesis of leaves and branches, we measured the stomatal conductance, leaf water conductance, water potential, and relative water content of 11 compound-leafed species and six simple-leafed species in Fabaceae. Results showed no significant differences in midday water potential between leaf rachises (−0.91 MPa) of compound-leafed trees and branches of simple-leafed trees (−0.88 MPa). However, the midday water potential of the branches of compound-leafed trees (−0.60 MPa) was significantly higher than that of simple-leafed trees. The percent decrease in midday stomatal conductance of compound–leafed trees was significantly higher than that of simple-leafed trees (55.3% vs. 34.1%). We found significantly

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positive correlations between leaf and stem midday water potentials in all 17 species, and between the rachis and stem midday water potentials in the 11 compound-leaved species. There was no correlation between midday water potential of leaflets, leaf rachises, and branches and midday stomatal conductance. There was a significant positive correlation between leaf hydraulic conductance and midday stomatal conductance across the 17 species ($r = 0.79$, $P < 0.001$), and a significant negative correlation between leaf hydraulic conductance and percent decrease in midday stomatal conductance ($r = -0.81$, $P < 0.001$), indicating the important role of leaf hydraulic conductance in maintaining diurnal stomatal conductance. There were significant differences in the photosynthesis – water relationship among simple- and compound-leaved tree species, reflecting their different adaptive strategies to environmental conditions.

Key words: Leaf form; Hydraulic architecture; Photosynthesis; Stomatal conductance; Fabaceae

叶片是植物进行光合作用的主要器官, 陆生植物吸收和运输的水分主要通过叶片的气孔进行气体交换。水分蒸腾速率过高会导致叶片水势降低, 进而使枝条中的连续水柱进入气泡, 产生断开的危险, 即气穴化^[1,2]。严重的气穴化和栓塞可以导致树木死亡^[3,4]。气穴化的修复是一个耗能过程, 因此枝条和叶片在水分供应和需求上就存在协作的必要性, 以维持水分运输系统的正常运转^[5]。

种子植物的叶片按叶型可分为单叶和复叶两种^[6,7]。单叶仅有一个叶片通过叶柄与枝条直接相连, 是植物中最普遍的叶型, 复叶则有两片至多片分离的小叶片通过叶轴与枝条相连^[8]。叶轴是叶的一部分, 其结构像枝条的延伸部分, 可以像叶片一样脱落, 因而有利于适应干旱生境^[9]。复叶形态上相当于一个大的单叶, 分成了许多小叶, 增加了边界导度, 有利于蒸腾降温 and 气体交换的进行^[10]。在全球气候变化的背景下, 降水格局改变及极端干旱事件频发^[11-13], 复叶植物由于特殊的水分利用策略, 近年来针对其水力结构和光合水分关系的研究已成为科学家关注的热点^[14-17]。

由于水分是大多数生态系统的限制因子, 陆生植物会经常发生气穴化^[18-22]。为了降低气穴化的不利影响, 植物进化出了许多不同的保护机制, 如脆弱性分割(vulnerability segmentation)。同一植株上枝条和叶片在水分状态上存在差异, 二者在应对缺水产生的气穴化的机制上也存在不同, 这一现象被称为脆弱性分割。植物通过这一机制或特定结构可以将栓塞化进程限制在碳投入较少的末端小器

官上^[23,24]。复叶树种胡桃(*Juglans regia* L.) 各器官发生导管气穴化的水势存在显著差异, 最为脆弱的是叶轴^[25]。复叶的水分亏缺状态从小叶传导到最为脆弱的叶轴后, 导致叶轴发生气穴化, 从而避免了进一步扩散到枝条, 起到保护作用^[25]。因此, 相对于单叶树种, 复叶树种由于叶轴的存在, 相当于多了一道水力安全屏障。

气孔调节也是植物保护枝条木质部导管免于气穴化胁迫的一种重要途径^[3,15,26-28]。即使在水分状况良好的情况下, 植物应对正午高温时, 依然有可能因剧烈蒸腾引起的过大张力导致气穴化的发生, 因此对气孔导度的精细调节具有重要的生理作用^[29-31]。植物正午气孔导度的降低通常伴随着叶片水力导度的降低, 可能是由于叶片水分运输系统出现栓塞化导致的^[32]。叶片水力导度的降低可以将叶片和枝条的缺水信号放大, 促使气孔快速响应, 进而控制水分丧失的速度, 减缓枝条木质部水势的进一步下降^[1,32,33]。已有研究表明, 亚热带单叶树种的正午气孔导度与枝条正午水势正相关, 而与叶片正午水势间不相关, 这种现象被认为是保护枝条免受气穴化威胁的一种保护机制^[5]。对于其他类群的植物, 如复叶树种, 是否存在这一机制尚未明确。目前, 从水力结构与枝叶间的光合水分关系的角度, 比较单叶和复叶差异的研究还开展较少。

本研究以豆科(Fabaceae) 17种复叶和单叶树种为材料, 测定他们的光合速率、气孔导度、水势、边材密度和相对含水量等指标, 对(1)复叶树种由于有叶轴的保护, 正午枝条水分状况应高于单

叶树种以及(2)正午气孔导度与枝条正午水势间的正相关关系在复叶树种中同样存在,这两种科学假设进行验证,旨在为深入开展单、复叶树种的功能差异与共性研究奠定理论基础。

1 材料与方法

1.1 研究地点自然概况及实验材料

研究地点位于云南省勐腊县勐仑镇中国科学院西双版纳热带植物园(21°41'N, 101°25'E, 海拔 570 m)。该地区年均温度 21.7℃, 年均降水量 1560 mm。一年分为雨季(5 至 10 月)和旱季(11 月到次年 4 月)两个明显的季节,其中雨季降水量占全年的 80%以上。本实验于 2014 年 6 – 10 月的雨季完成。

豆科为被子植物中最大的 3 个科之一,同一个科内的树种分为单叶和复叶两种叶型^[34, 35]。本研究选取豆科 11 种复叶和 6 种单叶树种为实验材料,所有树种树龄均在 5 年以上(表 1)。通过目测法估算树种的高度,用卷尺测定树种的胸径(胸径小于 5 cm 的灌木树种未测量)。

1.2 功能性状测定

(1) 气体交换能力的测定

在雨季天气晴朗时,利用 LI-6400 便携式光合仪(美国)于上午 9:00 – 11:30 和中午 13:00 – 15:00 两个时间段,在饱和光 1200 μmol · m⁻² · s⁻¹以及大气 CO₂浓度约 400 μmol/mol 条件下,剪取冠层带阳生成熟全展叶片的小枝,立即放入盛有水的桶中,每个树种选取 6 株,每株选择 4 ~ 6 个叶片,测定其净光合速率、气孔导度和蒸腾速率等指标。对于复叶树种,选择复叶中间的小叶进行测定,金凤花由于小叶过小,用末回复叶进行测定。

(2) 叶片正午水势

叶片水势(Ψ_L)采用压力室水势仪 SKPM 1400 (英国)测定。在中午 13:00 – 14:00 将叶片采下后,马上置于有湿纸巾的密封袋内,置于保温箱中,快速带回实验室后测定叶片水势。对于具有二回羽状复叶的植物金凤花,由于其小叶极小,因此采用末端复叶的水势代表其叶片水势,其余复叶树种的叶片水势均测定单个小叶。

表 1 本研究选取的 17 种植物材料
Table 1 Seventeen species selected in this study

种名 Species	胸径 DBH (cm)	高度 Height (m)
复叶树种(Compound-leaved species)		
顶果树 <i>Acrocarpus fraxinifolius</i> Wight ex Arn.	23.7 ± 2.3	12.4 ± 0.9
腊肠树 <i>Cassia fistula</i> L.	14.5 ± 0.9	6.9 ± 0.3
节果决明 <i>Cassia nodosa</i> Buch.-Ham. ex Roxb.	21.0 ± 1.1	7.9 ± 0.6
金凤花 <i>Caesalpinia pulcherrima</i> (L.) Sw.	灌木	1.9 ± 0.2
铁刀木 <i>Cassia siamea</i> Lam.	13.7 ± 0.8	7.7 ± 0.7
降香 <i>Dalbergia odorifera</i> T. Chen	24.9 ± 2.3	20.5 ± 1.1
吐鲁香膏树 <i>Myroxylon balsamum</i> L. Harms.	17.0 ± 1.2	15.1 ± 0.4
大穗崖豆 <i>Millettia macrostachya</i> Coll. et Hemsl.	21.3 ± 1.8	8.5 ± 0.4
紫檀 <i>Pterocarpus indicus</i> Willd.	17.9 ± 0.8	13.8 ± 0.5
长叶排钱树 <i>Phyllodium longipes</i> (Craib) Schindl.	灌木	3.6 ± 0.2
雨树 <i>Samanea saman</i> (Jacq.) Merr.	26.0 ± 3.5	9.5 ± 1.2
单叶树种(Simple-leaved species)		
白花羊蹄甲 <i>Bauhinia acuminata</i> L.	灌木	1.5 ± 0.1
鞍叶羊蹄甲 <i>Bauhinia brachycarpa</i> Wall.	灌木	3.4 ± 0.1
单蕊羊蹄甲 <i>Bauhinia monandra</i> Kurz	7.6 ± 0.6	4.1 ± 0.2
羊蹄甲 <i>Bauhinia purpurea</i> L.	13.1 ± 2.1	5.2 ± 0.7
黄花羊蹄甲 <i>Bauhinia tomentosa</i> L.	灌木	2.5 ± 0.2
洋紫荆 <i>Bauhinia variegata</i> L.	17.2 ± 1.8	6.2 ± 0.5

(3) 枝条和复叶叶轴正午水势

正午枝条水势(Ψ_s)使用枝叶平衡法测定。测定前一天的傍晚在原位套上密封袋并裹上铝箔纸,以防止其蒸腾。第二天中午(13:00–14:00),将叶片摘下,测量叶片水势。复叶叶轴正午水势(Ψ_r)的测定跟枝条的正午水势原理相同,将复叶的一个小叶套上密封袋并包裹铝箔纸。对于金凤花的叶轴正午水势,仍包裹其未回复叶来代替叶片。

(4) 叶片水力导度

中午水力导度(K_{leaf})参考原位蒸腾法进行测定。在中午13:00–14:00采样,用枝叶平衡法测定枝条木质部的水势(Ψ_s),用压力室法测定叶片水势(Ψ_L)。同时用LI-6400便携式光合测定仪测定叶片蒸腾速率(E)。 K_{leaf} 计算公式为: $K_{\text{leaf}} = E/\Delta\Psi = E/(\Psi_s - \Psi_L)$,其中, $\Delta\Psi$ 为枝条和叶片之间的水势差。

(5) 枝条相对含水量

在早晨6:00–7:00和中午13:00–14:00时,采集所测定的17个树种的枝条,直径约1 cm,长度约5 cm。将其放入含有湿纸巾的密封袋中,带回实验室后立即测定其鲜重(FW)。然后浸没在清水中24 h,擦干表面的水分,称量饱和鲜重(FW_s),最后将样本放在72℃的烘箱中烘干48 h,称量干重(DW)。相对含水量 $RWC =$

$(FW - DW) / (FW_s - DW) \times 100\%$ 。正午枝条相对含水量的降低百分比为早上和中午测定的差值(RWC_{CS})。

(6) 枝条边材密度

剪取长度约5 cm的小段进行边材密度的测定,通过排水法测定边材的体积,将测定完体积的边材小段放入烘箱中在72℃下烘48 h,取出后称量干重。边材密度为干重与体积的比值。

1.3 数据分析

复叶树种和单叶树种功能性状间的差异采用曼惠特尼U检验(Mann-Whitney U test)^[5]。采用皮尔森相关(Pearson's correlation)性分析功能性状间的相关关系,采用SMATR 2.0软件比较线性回归间斜率和截距的差异。使用软件Sigmaplot 12.5软件作图。

2 结果与分析

研究结果显示(表2),豆科单叶和复叶树种的最大气孔导度($P = 0.686$)与最大光合速率间差异均不显著($P = 0.96$),但复叶树种正午气孔导度与其最大气孔导度相比,降低了55.5%,显著高于单叶树种的34.1%($P = 0.05$),因而复叶树种的正午光合速率显著低于单叶树种。复叶树种叶片的正午水势(-1.87 MPa)与单叶树种相比(-2.05 MPa)

表2 11种复叶和6种单叶树种功能性状的差异

Table 2 Differences in stem and leaf eco-physiological traits between simple- and compound-leaved trees

性状 Trait	复叶树种 (CLT) Compound-leaved tree	单叶树种 (SLT) Simple-leaved tree	P
$MaxG_s$ ($\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	0.27 ± 0.02	0.27 ± 0.01	0.686
$MidG_s$ ($\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	0.12 ± 0.01	0.18 ± 0.02	0.068
PDG_s (%)	55.30 ± 3.42	34.10 ± 7.28	0.050
A_{max} ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	14.75 ± 0.98	15.06 ± 1.38	0.960
A_{mid} ($\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$)	6.18 ± 0.77	10.35 ± 0.80	0.007
Ψ_L (MPa)	-1.87 ± 0.13	-2.05 ± 0.11	0.191
Ψ_s (MPa)	-0.60 ± 0.09	-0.88 ± 0.06	0.018
Ψ_{s-L} (MPa)	1.27 ± 0.06	1.17 ± 0.06	0.615
Ψ_R (MPa)	0.91 ± 0.13	—	—
K_{leaf} ($\text{mmol} \cdot \text{s}^{-1} \cdot \text{m}^{-2} \cdot \text{MPa}^{-1}$)	4.50 ± 0.37	6.52 ± 0.35	0.009
RWC_{CS} (%)	5.18 ± 0.62	7.30 ± 1.30	0.094
WD (g/cm^3)	0.56 ± 0.04	0.58 ± 0.05	0.920

注: 数值为平均值 ± 标准误。Max G_s : 最大气孔导度; Mid G_s : 正午叶片气孔导度; PD G_s : 正午气孔导度下降百分比; A_{max} : 单位叶片面积的最大光合速率; A_{mid} : 单位叶片面积的正午光合速率; Ψ_L : 叶片正午水势; Ψ_s : 枝条正午水势; Ψ_{s-L} : 正午枝条叶片水势差; Ψ_R : 叶轴正午水势; K_{leaf} : 叶片水力导度; RWC_{CS} : 枝条相对含水量降低程度; WD: 边材密度。

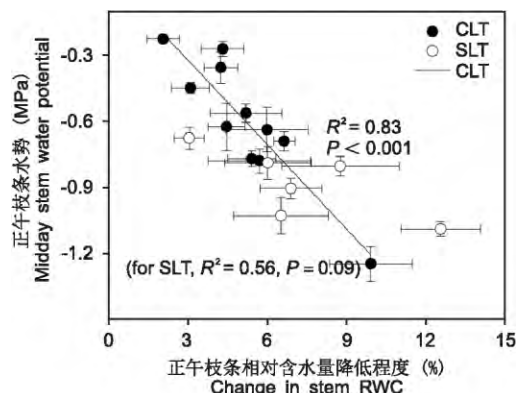
Notes: Values are means ± SE. Max G_s : maximum stomata conductance; Mid G_s : midday stomata conductance; PD G_s : percent decrease in G_s ; A_{max} : maximum leaf area-based photosynthesis rate; A_{mid} : midday leaf area-based photosynthesis rate; Ψ_L : midday leaf water potential; Ψ_s : midday stem water potential; Ψ_{s-L} : difference in midday stem and leaf water potential; Ψ_R : midday rachis water potential; K_{leaf} : leaf hydraulic conductance; RWC_{CS} : change in stem relative water content; WD: sapwood density.

没有显著差异; 复叶树种叶轴正午水势 (-0.91 MPa) 与单叶树种的枝条正午水势 (-0.88 MPa) 相近, 而复叶树种的枝条正午水势 (-0.60 MPa) 显著高于单叶树种。复叶和单叶树种的边材密度相近; 尽管单叶树种正午枝条相对含水量下降幅度更大, 但复叶和单叶树种枝条的正午相对含水量的降低程度间差异不显著。

本研究发现(图 1), 复叶树种的枝条正午水势与枝条正午相对含水量降低程度(与其凌晨相对含水量相比)间呈显著负相关($R^2 = 0.83$, $n = 11$, $P < 0.001$), 而单叶树种间则相关性不显著($R^2 = 0.56$, $n = 6$, $P = 0.09$)。此外, 复叶树种的正午枝条相对含水量降低程度与正午叶片水势($R^2 = 0.67$, $n = 11$, $P = 0.002$)和叶轴水势($R^2 = 0.76$, $n = 11$, $P < 0.001$)间也具有显著的负相关关系, 而单叶树种间同样相关性不显著($R^2 = 0.55$, $n = 6$, $P = 0.09$) (图 2: a, c)。复叶树种枝条正午水势与叶片正午水势($R^2 = 0.74$, $n = 11$, $P < 0.05$)以及复叶树种枝条正午水势和叶轴正午水势($R^2 = 0.87$, $n = 11$, $P < 0.001$)均呈显著正相关(图 2: b, d)。单叶树种的枝条和叶片正午

水势间同样呈显著正相关($R^2 = 0.82$, $n = 6$, $P = 0.002$), 并且其线性回归的截距显著高于复叶树种。

研究结果显示, 单叶和复叶树种的正午气孔导度与其叶片、枝条的正午水势之间均不存在相关性(图 3: a, b), 17 个树种 $\text{Mid } G_s$ 值总体上与 Ψ_L 、 Ψ_S 不存在相关性, 且 $\text{Mid } G_s$ 值与复叶树种的叶轴



CLT: 复叶树种; SLT: 单叶树种。下同。

CLT: Compound-leaved trees; SLT: Simple-leaved trees. Same below.

图 1 正午枝条水势与正午枝条相对含水量降低程度间的相关性
Fig. 1 Correlation between midday stem water potential and change in stem relative water content

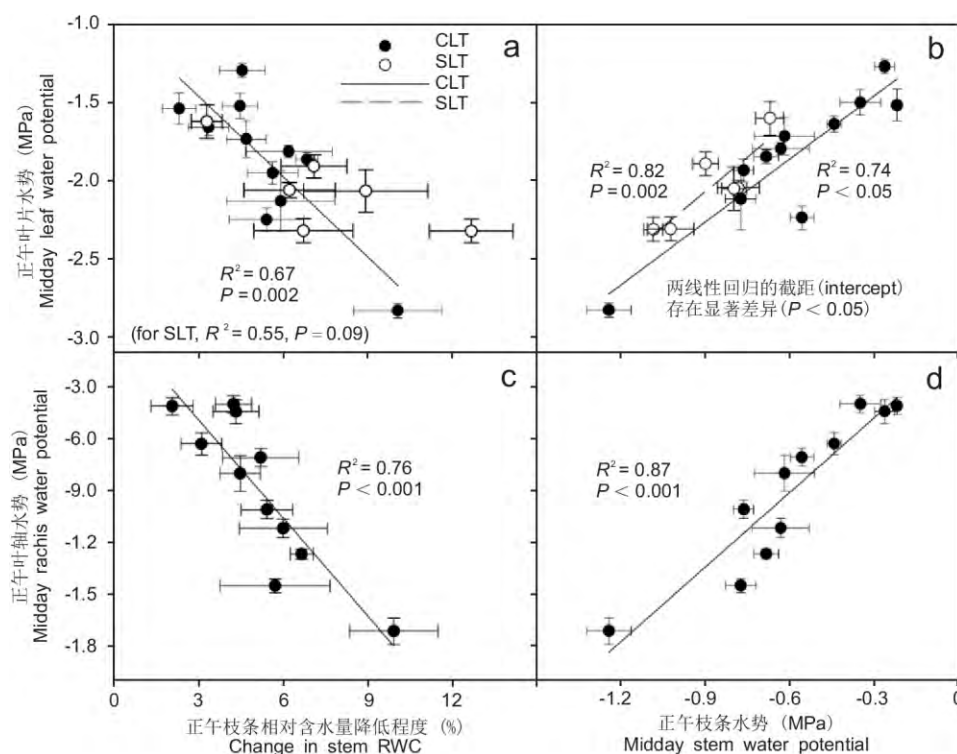


图 2 正午叶片和叶轴水势与正午枝条相对含水量降低程度(a, c)及其与正午枝条水势(b, d)间的相关性

Fig. 2 Midday leaf and rachis water potential in relation to change in stem relative water content (RWC, a, c) and midday stem water potential (b, d)

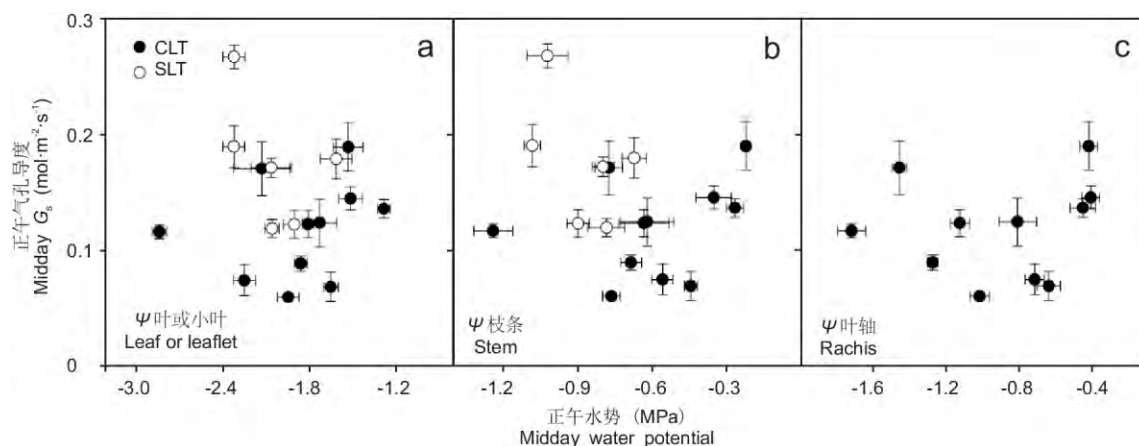


图3 叶片正午气孔导度与叶片正午水势(a)、枝条正午水势(b)和叶轴正午水势(c)之间的相关性
Fig. 3 Midday leaf stomatal conductance in relation to leaf midday water potential (a), stem midday water potential (b), and rachis midday water potential (c)

正午水势之间也不存在相关性(图3: c)。但是复叶树种的正午气孔导度与正午叶片水力导度(K_{leaf})之间为显著正相关(图4: a, $R^2 = 0.55$, $n = 11$, $P < 0.01$), 单叶树种间则相关性不显著(图4: a, $R^2 = 0.42$, $n = 6$, $P = 0.16$)。单叶树种或者复叶树种的 K_{leaf} 与叶片正午气孔导度的降低百分比(与其最大气孔导度相比)之间均不存在显著的负相关关系, 而17个树种作为一个整体时, 则呈现出显著的负相关(图4: b, $R^2 = 0.54$, $P < 0.001$)。同样, 单叶树种或者复叶树种的 K_{leaf} 与叶片正午光合速率间也不存在显著的正相关关系, 而作为一个整体时则显著正相关(图4: c, $R^2 = 0.39$, $P < 0.01$)。单叶树种的边材密度与叶片和枝条的正午水势均存在显著的负相关(图5: a, $R^2 = 0.76$, $n = 6$, $P < 0.05$; 图5: b, $R^2 = 0.78$, $n = 6$, $P < 0.05$), 复叶树种间则相关性不显著。树木高度与气孔导度、叶片、叶轴和枝条正午水势间均不存在相关性。

3 讨论

本研究发现, 复叶树种枝条正午相对含水量的降低程度(5.18%)小于单叶树种(7.3%), 尽管未达到显著水平, 但是复叶树种的正午枝条水势则显著高于单叶树种, 验证了本研究提出的科学假设(1)。而正午气孔导度与枝条、叶片和叶轴的正午水势之间均不存在相关关系, 与科学假设(2)不一致, 说明气孔调节参与保护枝条免受气穴化胁迫的方式在复叶树种中可能发生了改变。而正午气孔导

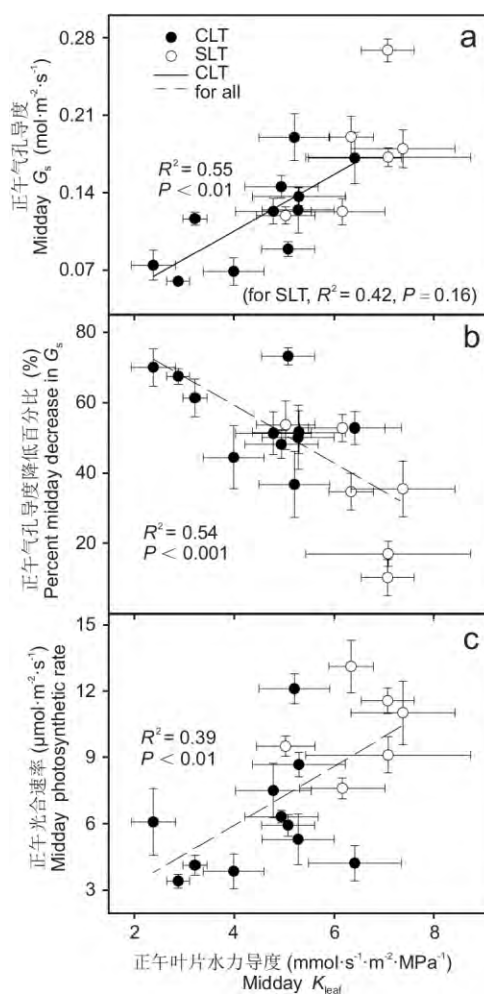


图4 正午叶片水力导度与正午气孔导度(a)、正午气孔导度降低百分比(b)和正午光合速率(c)之间的相关性
Fig. 4 Correlation between midday leaf hydraulic conductance and midday leaf stomatal conductance (a), percent midday decrease in stomata conductance (b), and midday photosynthetic rate (c)

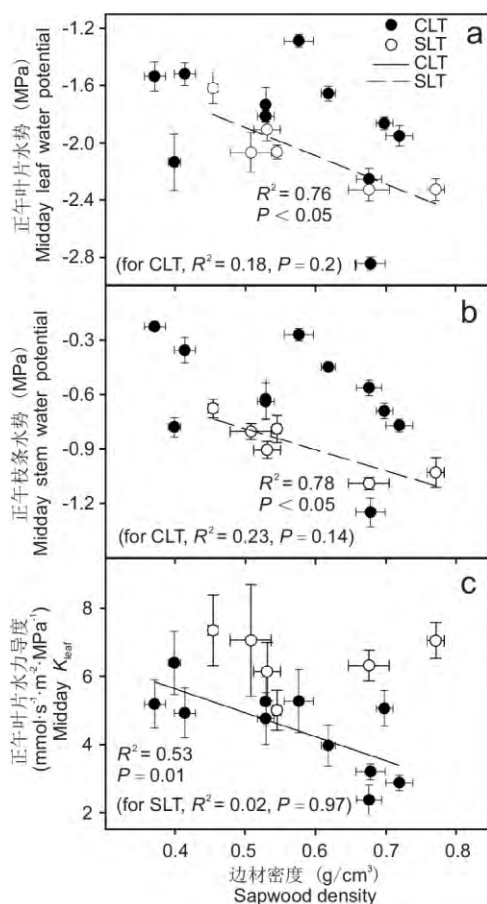


图 5 边材密度与叶片正午水势 (a)、枝条正午水势 (b) 和正午叶片水力导度 (c) 的相关性

Fig. 5 Relationship between sapwood density and midday leaf water potential (a), midday stem water potential (b), and midday leaf hydraulic conductance (c)

度与正午叶片水力导度间显著的正相关关系则提示了复叶树种中存在一种更直接的调控方式。

本研究中,复叶叶轴正午水势更接近于枝条的正午水势,尽管二者之间存在显著差异,但都显著高于叶片正午水势,这一结果与前人的研究结果一致^[15]。研究表明,叶轴水势可能是一个被气孔用来调控其在应对水分亏缺状态时闭合的生理参数,进而改变由蒸腾速率和植物水力学控制的叶片水分状态,这样可以阻止枝条木质部气穴化在水分缺乏状态下的进一步发展,表明叶轴在保护枝条导管免受气穴化胁迫中起到了“液压保险丝”的作用^[15,25,36]。复叶树种由于叶轴的存在,使得其枝条正午水势显著高于单叶树种,从而能够更好的降低其枝条木质部导管所受气穴化的威胁。从这一点来说,复叶不是简单的小叶的集合,即“复叶并非

一个大的单叶”^[37,38]。

本研究并未发现单叶或复叶树种的正午气孔导度与枝条的正午水势与之间存在相关性(图 3),这与 Zhang 等^[5]在亚热带山地林单叶树种中发现的正相关关系的研究结果不一致。原因可能与本实验在热带季雨林进行有一定关系,因为热带地区正午时温度更高,蒸腾压力可能会更大,使得枝条木质部所受到的气穴化威胁也较大,因此,本地区生长的树种可能会有不同的适应策略。Chen 等^[19]发现热带地区木质藤本和伴生树种的气孔导度与叶片或枝条的水势间均不存在线性相关。除了环境因素外,从叶型的角度来说,复叶树种的叶轴在保护枝条免受气穴化胁迫方面发挥了重要的作用^[15,25]。叶轴本身是可以舍弃的结构,必要时可以脱落,并不需要像枝条木质部一样需要特别的保护,所以对于复叶树种来说,可能是出于尽量把气穴化的风险往末端部位阻隔的缘故,从而阻断了正午气孔导度和枝条正午水势之间的关联。

复叶树种的枝条、叶轴和叶片的水分关系密切,本研究结果显示,正午水势两两之间均存在显著的正相关。并且叶片和叶轴正午水势与正午枝条相对含水量的降低程度呈负相关,反映出枝条储存水用于叶片日间蒸腾的枝叶水分协作状况。此外,单叶和复叶树种的边材密度和叶片与枝条的正午水势均呈现出负相关的趋势,单叶树种还达到了显著水平。密度较大的茎干储水能力较弱,但是耐气穴化的能力大大提高^[39]。这种水分运输通路上不同器官间直接的水分关联,可能有利于枝条的水分状况被叶片感知,进而影响气孔调节。

本研究发现,正午气孔导度在两类树种中均有不同程度的降低,但是单叶树种比复叶树种下降幅度要小。正午时,气孔导度与上午最佳状态相比,会有不同程度的降低,这在许多研究中都有报道^[5,40,41]。本研究所选的单叶树种都是多主脉的,较高的主脉密度在叶片水分供应方面存在巨大的优势^[42],在雨季水分充足的条件下,可以迅速补充蒸腾耗水,因此单叶树种的正午气孔导度相对于复叶树种降低幅度要小的多。正午气孔导度的下调,可以降低在高温高光照条件下的蒸腾速率,减少水分散失,降低枝条导管因供水压力过大而引起水柱断裂,进而发生栓塞的风险。研究表明,叶片水力导度的降低可以放大植物蒸腾失水和水势降

低的信号,进而可以加速气孔导度的下调甚至关闭气孔^[2]。本研究中,叶片的水力参数与气孔的状态具有更紧密的联系,如17个树种的叶片水力导度与正午气孔导度之间显著正相关,并且和正午气孔导度降低的百分比间显著负相关。这样叶片的水分状况可以更直接的影响气孔的开闭状态,从而更好的保护枝条免受气穴化胁迫。

综上所述,复叶树种与单叶树种在枝叶光合水分关系方面存在许多差异,例如,复叶树种具有较高的枝条正午水势,较小的正午枝条相对含水量降低程度,较大的正午气孔导度下降幅度,以及较低的正午光合速率。实验选取树种的正午叶片水力导度和气孔导度呈正相关,在缺水状态下,可以使气孔导度快速降低甚至关闭气孔,从而避免叶片水分的进一步丧失。边材密度与植物水分关系密切。上述研究结果为热带树木气体交换行为与水分的关系提供了新认识。

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