โครงการ
การเรียนการสอนเพื่อเสริมประสบการณ์

ชื่อโครงการ   การศึกษาความสัมพันธ์น้ำของต้นไม้ชนิดพันธุ์ *Tabebuia argentea* และต้นปาล์มชนิดพันธุ์ *Ptychosperma macarthurii* ในฤดูแล้งบนสวนลอยฟ้าเขตร้อน

Investigating water relations in a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species in the dry season at a tropical roof garden

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Investigating water relations in a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species in the dry season at a tropical roof garden

Ratchanon Ampornpitak

A Senior Project Submitted in Partial Fulfillment of the Requirements
for the Bachelor's Degree of Science Program in Environmental Science
Department of Environmental Science,Faculty of Science,
Chulalongkorn University
Academic Year 2020

SENIOR PROJECT

Project Title **Investigating water relations in a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species in the dry season at a tropical roof garden**

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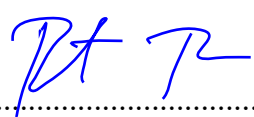
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บทคัดย่อ

ในปัจจุบันมีการขยายตัวเมืองอย่างต่อเนื่องในหลายพื้นที่ การขยายตัวของเมืองที่เพิ่มขึ้นส่วนใหญ่เกี่ยวข้องกับการสร้างอาคารคอนกรีตส่งผลทำให้มีพื้นที่สีเขียวในเมืองน้อยลง ดังนั้น จึงมีความพยายามที่จะสร้างพื้นที่สีเขียวในเมืองในพื้นที่ของอาคารต่าง ๆ เช่น สวนลอยฟ้า อย่างไรก็ตามการดูแลสวนลอยฟ้านั้น จะต้องคำนึงถึงการรดน้ำต้นไม้ โดยจะต้องพิจารณาถึงความสามารถในการรับน้ำหนักของอาคารด้วย ข้อจำกัดในการรดน้ำนี้ส่งผลให้ต้นไม้ที่ปลูกในสวนลอยฟ้าอาจจะถูกจำกัดปริมาณน้ำที่ใช้ในการเจริญเติบโต เพื่อปรับปรุงประสิทธิภาพในการให้น้ำของต้นไม้ในสวนบนลอยฟ้า โครงงานนี้จึงประเมินสถานะน้ำของต้นไม้ชนิดพันธุ์ *Tabebuia argentea* (Ta) และต้นปาล์มชนิดพันธุ์ *Ptychosperma macarthurii* (Pm) ที่เจริญเติบโตในพื้นที่สวนลอยฟ้าเดียวกัน โดยวัดศักย์ของน้ำในใบช่วงกลางวัน (Ψ_{MD}) และค่าการชักนำปากใบ (g_s) เพื่อศึกษารูปแบบการตอบสนองทางไฮดรอลิกของต้นไม้ชนิดพันธุ์ Ta และต้นปาล์มชนิดพันธุ์ Pm จากผลการศึกษาพบว่า g_s ของต้นไม้ชนิดพันธุ์ Ta มีค่าลดลงเมื่อ Ψ_{MD} สูงขึ้นโดยเฉพาะอย่างยิ่งภายใต้สภาวะดินที่ชื้น อาจจะเนื่องมากจากพฤติกรรมโดยธรรมชาติของต้น *Tabebuia* ที่ไม่ชอบความชื้นในดินสูง นอกจากนี้ น้ำในดินที่มากเกินไปจะไปจำกัดการดูดซึมน้ำของรากซึ่งส่งผลให้ Ψ_{MD} และ g_s ลดลง ในทางตรงกันข้ามต้นปาล์มชนิดพันธุ์ Pm ไม่มีการตอบสนองของ g_s ต่อ Ψ_{MD} จากผลการศึกษานี้แสดงให้เห็นว่าต้นไม้ชนิดพันธุ์ Ta ควรที่จะได้รับการรดน้ำอย่างเหมาะสมเนื่องจากการรดน้ำที่มากเกินไปอาจทำให้การบริการเชิงนิเวศของต้นไม้ชนิดพันธุ์ Ta แย่ลง อย่างไรก็ตามต้นปาล์มชนิดพันธุ์ Pm สามารถรักษาสถานะของน้ำและ g_s ได้โดยไม่คำนึงถึงการเปลี่ยนแปลงของความชื้นในดิน สำหรับการตอบสนองของต้นไม้ชนิดพันธุ์ Ta และต้นปาล์มชนิดพันธุ์ Pm ต่อความชื้นในอากาศ พบว่า g_s ในต้นไม้ชนิดพันธุ์ Ta มีความไวต่อการเปลี่ยนแปลงของความแตกต่างของไอน้ำระหว่างใบและอากาศ (LAVPD) มากกว่าต้นปาล์มชนิดพันธุ์ Pm ที่เติบโตภายในพื้นที่และสภาพแวดล้อมเดียวกัน ผลการศึกษานี้บ่งชี้ว่าต้นปาล์มชนิดพันธุ์ Pm มีความไวต่อการเปลี่ยนแปลงของสิ่งแวดล้อมน้อยกว่าต้นไม้ชนิดพันธุ์ Ta จากผลที่ได้จากโครงงานนี้ จึงแนะนำว่า การดูแลรักษาต้นไม้โดยการให้น้ำในปริมาณที่เหมาะสมอย่างจำเพาะกับชนิดพันธุ์ไม้ในเมืองเป็นกุญแจสำคัญในการเพิ่มผลประโยชน์ให้กับระบบนิเวศสีเขียวในเมืองและเพิ่มประสิทธิภาพของการใช้น้ำในเมือง สำหรับสวนลอยฟ้าแห่งนี้ผู้ดูแลสามารถประยุกต์ใช้ผลจากการศึกษานี้เพื่อปรับตารางการให้น้ำสำหรับต้นไม้ (*Tabebuia argentea*) และต้นปาล์ม (*Ptychosperma macarthurii*)

คำสำคัญ: พื้นที่สีเขียวในเขตเมือง, การจัดการน้ำ, ความสัมพันธ์น้ำ, สวนลอยฟ้า, *Tabebuia argentea*, *Ptychosperma macarthurii*

Project Title	**Investigating water relations in a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species in the dry season at a tropical roof garden**

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ABSTRACT

Ongoing urbanization are increasing in several urban area. The increased urbanization of towns mostly involves concrete buildings, resulting in less green space. Consequently, recent attempts to expand green areas in cities have invaded areas in buildings, such as a roof garden. However, when watering plants on a roof garden, one needs to consider the loading capacity of the roof. This may limit water supply to the plants. To improve the efficiency in irrigation of trees in a roof garden, we evaluated the water status of a tree (*Tabebuia argentea*, *Ta*) and a palm (*Ptychosperma macarthurii*, *Pm*) species, which are commonly grown in cities, growing in the same roof garden. Midday leaf water potential (Ψ_{MD}) and stomatal conductance (g_s) were measured to investigate the pattern of tree hydraulic responses of *Ta* and *Pm*. The result showed that, *Ta* had a significance response of g_s to Ψ_{MD}. Stomata in *Ta* decreased with increasing leaf water potential, especially under moist condition. This may be explained by the inherent behavior of *Tabebuia* trees which dislike high soil water. Excessive soil water restricts the root absorption of water leading to decreasing leaf water potential and stomatal conductance. In contrast, *Pm* had no response of g_s to Ψ_{MD}. This result implies that *Ta* should be appropriately watered because excessive watering could reduce ecosystem services by *Ta*. However, *Pm* can maintain plant water status and g_s regardless of changes in soil moisture. For the response of *Ta* and *Pm* to environmental conditions, g_s in *Ta* was more sensitive to change in leaf-to-air vapor pressure deficit (LAVPD) than *Pm* growing under the same site and environmental conditions. Based on these results, *Pm* is less sensitive to environmental changes than *Ta*. Hence, we suggest that *Ta* should not be irrigated to flood condition occurred while *Pm* may be watered less frequently to save water. This initial investigation implied that maintaining urban trees using appropriate irrigation that is specific to tree species is the key to maximize benefits from urban trees and optimize urban water use. For this particular roof garden, the result from this study can be applied to adjust irrigation schedule for the tree (*Tabebuia argentea*) and the palm (*Ptychosperma macarthurii*).

Keywords: urban greening, water management, water relation, roof garden, *Tabebuia argentea*, *Ptychosperma macarthuriis*

ACKNOWLEDGEMENTS

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CHAPTER 1
INTRODUCTION

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1.1 Introduction

Ongoing urbanization are increasing in several urban area causing increased temperature of town through the urban heat island effect (Oleson et al., 2011; Prudhomme et al., 2014). The increased urbanization of towns mostly involves concrete buildings, resulting in less green space. Consequently, recent attempts to expand green areas in cities have invaded areas in buildings, such as a roof garden. Besides adding more green space in compact urban areas (Rowe & Getter, 2006), roof gardens provide many environmental benefits, including conserving energy through improved building energy efficiency (Wong et al., 2003), enhancing urban biodiversity through provision of habitats for wildlife (Rowe & Getter, 2006) and mitigating the urban heat island effect (Mackey et al., 2012).

In cities, tree and palm species are usually planted in parks and gardens. Ecosystem services of tree and palm species, including carbon storage, habitat quality, shading effects and evaporative process, (Gillner et al., 2013; Pataki et al., 2011). However, the ecosystem services by tree and palm species can be impaired by low water supply (Bush et al., 2008), especially in urban environments where roadside and roof garden. In a limited green space, such as, in a roof garden, irrigation is controlled to reduce the chance of overloading the roof's structure (Johnston et al., 2004). Thus, plants in a roof garden potentially have low water availability and thus being exposed to water deficit, especially in the dry season with low precipitation, which is associated with high evaporation rates and low water retention capacities of soils. Such water-limiting conditions can induce hydraulic failure through the loss of hydraulic conductance, eventually leading to drought-induced mortality (Barigah et al., 2013). During drought period, many plant species shed leaves, reducing transpiration and photosynthesis, and adjust partitioning to roots and storage (McDowell et al., 2008a).

A previous study showed that the hydraulic efficiency of palms was higher than of that of trees in tropical species (Renninger et al., 2009) because palms, like monocots, have broader vessels than dicots (Olson et al., 2014). However, palms' strategy of having broader vessels could result in higher risk in embolism (Hacke et al., 2006). Urban trees mortality has been linked to drought by limit water supply to urban trees (Savi et al., 2015). But, understanding about tree hydraulic response of tree and palm species in urban area has been poorly investigated.

Therefore, it is critical to understand different tree hydraulic response of various plant species. The aims of this study are to (1) evaluate the water status of a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species, growing in the same roof garden, in the dry season; (2) compare a leaf morphological trait that is related to plant growth of both species. This study provided the understanding of tree and palm's hydraulics and response to environment, which is important in improving the sustainability of urban forests. Selected plant species planting of well adapted to urban environment ensures healthy plants providing ecosystem services for high quality of life in cites.

1.2 Objectives

1.2.1 To evaluate the water status of a tree (*Tabebuia argentea*) and a palm (*Ptychosperma macarthurii*) species, growing in the same roof garden, in the dry season.

1.2.2 To compare a leaf morphological trait that is related to plant growth of both species

CHAPTER 2
LITERATURE REVIEWS

2.1 Plant water relation

To regulate of water status and photosynthesis, plant must replace water lost through transpiration. As described by the cohesion tension theory, transpiration tension that pulls water from the soil through the plant to the crown (McDowell et al., 2008b). Nowadays, water potential is increasingly being used as a method to measure plant water status (Jones, 2019). Water potential is the main driving force to transport water from roots to the leaves. Water moves from higher potential to lower potential. Water potential is in decreasing order for the soil, roots, stem, leaves and atmosphere, respectively. In response to this decreasing order of water potential, water flows through the transpiration stream from roots to leaves and then subsequently lost to atmosphere via transpiration. Transpiration can occur at high rates and, therefore, water must effectively be replaced through root uptake and transported through vascular tissue (Parkash & Singh, 2020).

Most environmental stress factors have common effects on plants, including inhibition of growth, reduced photosynthesis, and accumulation of stress-related compounds. Often, environmental changing like drought occur as a result of dehydration caused by an imbalance between water uptake in the roots and water loss through leaf transpiration (Aroca, 2013). The first line of defense against plant dehydration is often stomatal closure, and since stomatal conductance and water transport are coupled, changes in one will affect the other, resulting in changes in overall photosynthetic processes (Zwieniecki & Secchi, 2015).

Plant's hydrodynamic response to the environments is to classify them into two categories based on the ability of the stomata to regulate the leaf water potential. Isohydric plants reduce stomatal conductance (g_s) rapidly as soil water potential decreases or as atmospheric conditions dry, thereby restricting excessive water loss and maintaining high plant water potential. In contrast, anisohydric species maintain open stomata and allow midday leaf water potential to decline with decreasing soil water potential to maintain CO_2 uptake (McDowell et al., 2008b).

Suresh & Mathur. (2009) reveled plant water status and drought tolerance in Oil Palm (*Elaeis guineensis Jacq.*). They found negative correlation between stomatal conductivity and leaf water potential measured at midday in adult palms during dry season and non-irrigation, which is unusual in cultivated plants and indicates a strong stomatal control of leaf water status. Young palms at 10 months after planting were unable to maintain a high leaf water status, possibly due to the absence of a voluminous stem and extensive root system, which the relative water content and leaf water potential at midday were lower than in those with a good water supply. An analysis of the leaf tissue water retention in adult trees has shown that these tissues possessed high apoplastic volume.

Renninger et al. (2013) measured cross-sectional areas, vessel diameters and frequencies of roots, stems and fronds as well as leaf areas of *I. deltoidea* saplings. This allowed for the calculation of theoretical specific conductivity, theoretical leaf-specific conductivity, and vessel diameter and vessel number ratios between distal and proximal locations in the palms. The result show that, *Iriartea deltoidea* palms have the largest, least frequent vessels, which that maximum number of vessels that fit into a given area compared with other major tree forms, and they invested the least space and carbon into water transport structures. Therefore, their results indicate that the palm *I. deltoidea* has a very efficient hydraulic system in terms of maintaining a large conducting capacity with a minimal vascular investment. This efficiency may allow palms to compete well with dicotyledonous trees in tropical and subtropical climates.

2.2 Stomatal conductance

Stoma is a key role in regulating the flow of water in the soil–plant–atmosphere continuum. Stomatal regulation help to maintain plant water status under varying soil moisture and atmospheric conditions. Gas exchange via stomata helps in CO_2 intake to use in photosynthesis and water loss through the stomata. Transpiration helps to regulate the leaf temperature and maintaining optimum leaf temperature is critical for various metabolic activities of the plant (Eaton & Belden, 1929). Gas exchange regulates the supply of carbon dioxide to parenchyma cells, which consequently affects the photosynthetic activity (Farooq et al., 2009).

Opening and closing of the stomata is controlled by guard cell. Guard cells adjust their turgor by influx and efflux of ions like K^+, H^+ and Cl^-. An increased in guard cell turgor result in stomata opened and loss water result in stomata closed. However, difference plants may differ ability to regulate stomata in response to their leaf water status. Some studies endorse that chemical signals are responsible for stomatal closure, while others support that the hydraulic signals are responsible. Abscisic acid (ABA) plays a key role in chemical signaling (Raghavendra et al., 2010). Under mild soil water deficit, ABA is synthesized in roots and transported to leaves resulting in ABA accumulation in leaves. On the contrary, some researchers report that stomatal adjustments occur in response to changing hydraulic parameters such as leaf water potential (Chen et al., 2019). Understanding about the mechanism of stomatal closing and opening has not been completely understood.

2.3 Leaf morphological trait

Specific leaf area (SLA) is the one-sided area of a fresh leaf, divided by its oven-dry mass. SLA is frequently used in growth analysis because it is often positively related to potential RGR across species. SLA tends to scale positively with mass-based light-saturated photosynthetic rate and with leaf nitrogen (N) concentration, and negatively with leaf longevity and C investment in quantitatively important secondary compounds such as tannins or lignin. In general, species in permanently or temporarily (e.g. deserts during the rainy season) resource-rich environments tend, on average, to have a higher SLA than do those in resource-poor environments, although there can also be considerable variation in SLA among co-occurring species (Cornelissen et al., 2003).

Wellstein et al. (2017) conducted a meta-analysis of experimental drought manipulation studies using rainout shelters in five sites of natural grassland ecosystems of Europe. The results show that, in the sub-Mediterranean systems, grasses significantly increased their SLA in the drought treatment. Lower SLA of fobs is most likely direct drought response given that competitive effect of grasses. Increasing SLA points towards a better growth performance of these grasses, which is most likely related to their strategy to allocate resources to belowground parts. This study points out that phenotypic adjustment is an important driver of short-term functional plant response to climatic extremes such as drought.

CHAPTER 3
MATERIALS AND METHODS

3.1 Study site and plant material

The study was performed in a roof garden on the 5th floor of Mahitaladhibesra building at Chulalongkorn University, Bangkok Thailand (13°44′02.9″N 100°31′54.1″E). According to statistic 30 years between 1981-2010 from Thai Meteorological Department, mean annual air temperature in Thailand was 28.6°C and mean annual rainfall was 1648 mm. In this study, we selected tree species (*Tabebuia argentea*) and palm species (*Ptychosperma macarthurii*), hereafter *Ta* and *Pm* respectively. Because its dominant tree and palm species in this garden (Tor-ngern et al., 2018). Three individuals from each species were selected for investigation. The study period was in the dry season, starting from January 12 to February 6, 2021.

3.2 Environmental measurements

Environmental condition that influences hydraulic of *Ta* and *Pm* species include atmospheric humidity, solar radiation and soil moisture. Atmospheric temperature (T,°C) and relative humidity (RH, %) and photosynthetically active radiation (PAR, $\mu mol\ m^{-2}s^{-1}$) were monitored concurrently by installing a temperature and relative humidity probe (HC2S3, Campbell Scientific, Logan UT, USA) and a quantum sensor (SQ-420, Apogee Instruments, Logan, UT, USA) respectively, on the 8th floor of the building above the canopy. Soil moisture at 5cm depth of each plot was measured using soil moisture sensors (CS616; Campbell Scientific, Logan, UT). The sensors were connected to a datalogger (CR1000; Campbell Scientific, Logan, UT) to provide power and record data every 30 minutes.

3.3 Stomatal conductance and leaf water potential measurements

Stomatal conductance (g_s), measured in mmol $m^{-2}\ s^{-1}$, is the measure of the rate of passage of carbon dioxide (CO_2) entering, or water vapor exiting through the stomata of a leaf. Three individuals of each species were selected to measure g_s and midday leaf water potential (Ψ_{MD}). Stomatal conductance and leaf-to-air vapor pressure deficit (LAVPD) was measured with a portable photosynthesis system (TARGAS^{-1}, PP Systems, Amesbury, MA, USA) between 10:00 and 14:00 h which measurement was taken under light saturation (PAR of 1,500 $\mu mol\ m^{-2}\ s^{-1}$); (C. Baligar, 2012). Midday leaf water potential was measured at midday (10:00-14:00 h) when high gas exchange rates occur, to estimate minimum leaf water potential which show plant water status, using a pressure chamber (PMS Instrument Company, Albany, OR, USA). Three fully expanded and sunlit leaves for each tree were measured g_s before leaf was collected to measure Ψ_{MD}. Stomatal conductance and Ψ_{MD} were measured during the study period for 10 days.

To measure Ψ_{MD}, cut each selected leaf from each tree with razor blade, and partly seal it in the pressure chamber, where most of the leaf is inside the chamber but the part of petiole is exposed to the outside of the chamber. And then, pressurized the chamber with N_2 until a drop of

water appear at the end of petiole. The amount of pressure that it takes to cause water to appear at the petiole which tells how much tension the leaf experiencing on its water. Because tension is measured, negative values are typically reported as leaf water potential (Ψ_{leaf}).

Stomatal conductance was measured and calculated from portable photosynthesis system which g_s was calculated from the following equation.

From Von Caemmerer & Farquhar, 1981, total leaf conductance to water vapor transfer is calculated as:

$$g_{total} = \frac{E \times (P - \frac{e_{leaf} - e_{out}}{2})}{(e_{leaf} - e_{out})} \tag{1}$$

Since $1/g_{total} = r_s + r_b$, stomatal resistance can be calculated as:

$$r_s (m^2 s\ mol^{-1}) = \left[\frac{(e_{leaf} - e_{out})}{E \times \left(P - \frac{e_{leaf} + e_{out}}{2}\right)} \right] - r_b \tag{2}$$

Stomatal conductance is the inverse of stomatal resistance:

$$g_s (mmol\ m^{-2}\ s^{-1}) = \frac{1}{r_s} \times 10^3\ (\frac{mmol}{mol}) \tag{3}$$

where:
e_{leaf} = Saturated water vapor pressure inside leaf at leaf temperature (mb)
e_{out} = Partial pressure of water vapor of stirred cuvette air (mb)
E = transpiration rate (mmol m^{-2} s^{-1})
r_b = Boundary layer resistance to water vapor (m^2 s mol^{-1})
P = Atmospheric pressure (mb)
r_s = Stomatal resistance to water vapor (m^2 s mol^{-1})
g_s = Stomatal conductance to water vapor (mmol m^{-2} s^{-1})

3.4 Specific leaf area

Specific leaf area (SLA) is the one-sided area of a fresh leaf divided by its oven-dry mass, expressed in m^2 kg^{-1}. For *Pm*, leaf was cut out some of leaf into smaller part and measure the cumulative area of all parts in the laboratory because *Pm* is large leaves than the window of the area meter. *Tabebuia argentea* leaves were collected whole twig sections with the leaves still attached and not removing the leaves until just before measurement. Put the samples in the plastic bag and store these in a cool box or fridge until further processing in the laboratory. Leaf areas were scanned using a scanner as a computer image and measured the area by using ImageJ 1.53a (Schneider, C. A.; Rasband, W. S. & Eliceiri, K. W. (2012)). After area measurement, placed each leaf sample in the oven at 80 °C for 48 h, then weighed the dry mass. Five fully expanded and

sunlit leaves for each tree were measured specific leaf area. Specific leaf area was calculated as follow:

$$SLA = \text{Leaf area } (m^2)/\text{Leaf dry weight (kg)} \qquad (4)$$

3.5 Statistical analysis

To evaluate the water status of a *Ta* and a *Pm* species growing in the same roof garden in the dry season, we analyzed the relationship between stomatal conductance and leaf water potential for each species using regression analysis and significance difference of g_s, Ψ_{MD} and LAVPD between the species and among measurement days using two-way ANOVA. Significance difference of soil moisture between *Ta* and *Pm* plots were analyzed using paired t-test. To compare a leaf morphological trait that is related to plant growth of both species, we analyzed significant difference of SLA for each species using independent t-test. Data were be analyzed with the Rstudio, version 1.3.1073 (The R Foundation for Statistical Computing, http://www. R-project.org).

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Environmental conditions and characteristic of studied tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*) species

Environmental conditions including air temperature (T), relative humidity (RH), and photosynthetically active radiation (PAR) obtained at the study site during the study period (12th January - 6th February 2021) are shown in Figure 1. The midday (10:00-14:00 h) means of air temperature and RH of the study site during the study period were 28.11 ± 2.67 (one standard deviation) °C and 47.41 ± 9.98 % respectively. And the average PAR of the study site during the study period was 1171.17 ± 221.56 µmol m^{-2} s^{-1}. The average soil moisture (SM) values in *Ta* and *Pm* plots were 0.35 ± 0.08 and 0.35 ± 0.08 m^3 m^{-3}, respectively (Table 4.1). To assess whether the *Ta* and *Pm* in this site experience drought, we compared the measured soil moisture values throughout the study period to the wilting point of 0.150 m^3 m^{-3} (Tor-ngern et al., 2018). The result showed that soil moisture in both plots were significantly higher than the wilting point ($p < 0.001$ for *Ta* plot and $p < 0.001$ for *Pm* plot, one-sample t-test). This confirms that both *Ta* and *Pm* received enough water and never experienced water limiting conditions. To assess whether the measured leaves of *Ta* and *Pt* in the site experience light saturation (e.g. sunlit condition), we compared the PAR values during measurement days to a PAR value above which photosynthetic rates saturate in the tropical trees. A previous study showed that the PAR value at which photosynthetic rate at the tropical forest in mid-canopy leaves reached saturation was approximately 800 µmol m^{-2} s^{-1} (Verryckt et al. 2020). The result showed that PAR values on the day of measurement were significantly higher than the PAR value for light-saturated photosynthesis ($P < 0.001$, one-sample t-test). Therefore, our measurements of sunlit leaves were confirmed.
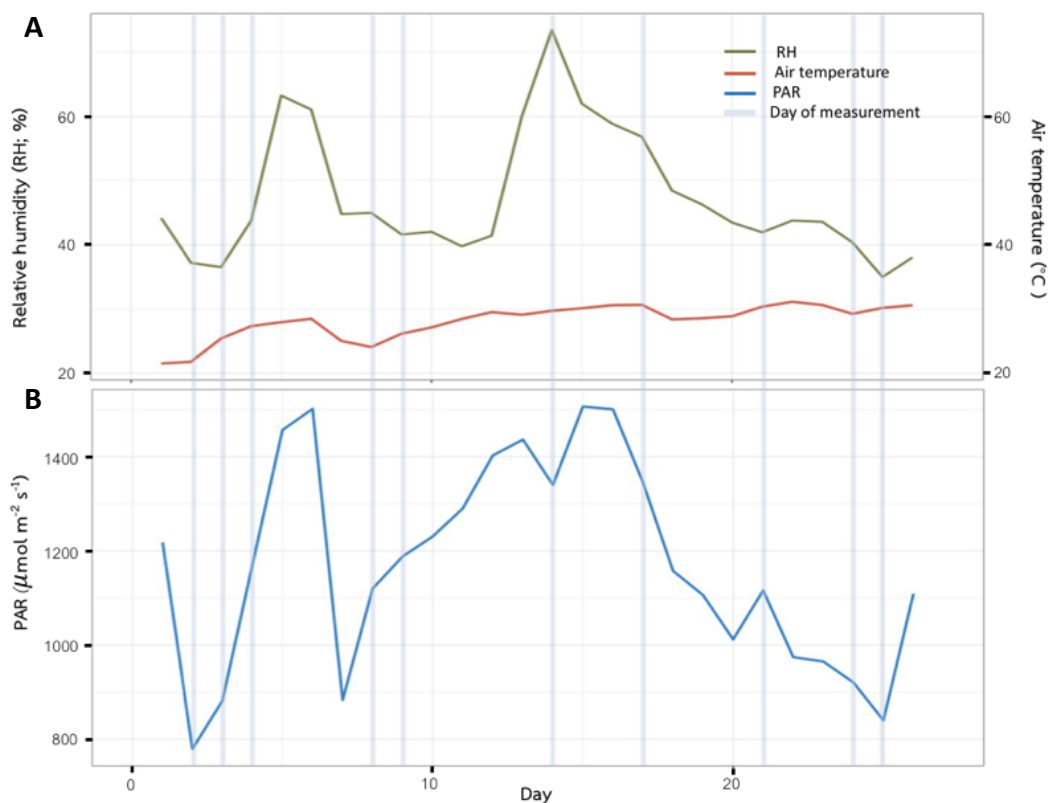
Figure 1 (A) Daily average of air temperature (T, °C), relative humidity (RH, %), and (B) photosynthetically active radiation (PAR, μmol m^{-2} s^{-1}) at the study site in midday (10:00-14:00 h) during the study period (12th January - 6th February 2021)

Table 4.1 summarize characteristic of the samples measured in this study and environmental conditions during the study period. The average diameters at breast height (DBH) of *Ta* and *Pm* were 17.67 ± 5.69 and 6.32 ± 0.18 cm, respectively. The coefficient of variation (CV) of DBH in *Ta* and *Pm* were 30.20 and 2.87 %, respectively. Mean stomatal conductance (g_s) of *Ta* and *Pm* were 96.46 ± 60.78 and 65.06 ± 25.59 mmol m^{-2} s^{-1}, respectively. Transpiration creates tension, leading to drives a continuous stream of water from the roots to the leaves (Qaderi et al., 2019). This process pulls water through the transpiration from the stomatal pore causing water moving from higher water potential to lower water potential and stomata are opened in response to difference between water vapor in leaf and the atmosphere (Pittermann, 2010). Plant water status had been determined by midday leaf water potential (Ψ_{MD}). Average Ψ_{MD} of *Ta* and *Pm* were -0.69 ± 0.46 and -1.33 ± 0.22 MPa, respectively. The Ψ_{MD} of *Pm* was significantly lower than that of *Ta*, which show in Figure 2A (p < 0.001). Palm is a monocot whose conduit diameter of xylem gets smaller and tapered with plant height (Kim et al., 2014) so that water transport through the soil-plant-atmosphere continuum is limited leading to the more negative Ψ_{MD} of palm. The more negative value of leaf water potential of a palm indicates a more dehydrated leaf (Parkash & Singh, 2020). Average LAVPD of *Ta* and *Pm* were 2.47 ± 0.52 and 2.34 ± 0.49 kPa, respectively. The g_s of *Ta* is significantly higher than *Pm* (p = 0.006), but the LAVPD of *Ta* and *Pm* were not significantly different (p = 0.277), which shown in Figure 2B and Figure 2C respectively. Soil moisture in *Ta* and *Pm* plots were not different (p = 0.104, paired-sample t-test), which shown in Figure 2D.

Table 4.1 Characteristics of trees (*Tabebuia argentea*) and palms (*Ptychosperma macarthurii*) were selected for measurement and all values of environmental conditions including air temperature (T, °C), relative humidity (RH, %), photosynthetically active radiation (PAR, μmol m^{-2} s^{-1}), and soil moisture are mean ± standard deviation (SD) at midday (10:00-14:00 h) during the study period. Measured values including leaf-to-air vapor pressure deficit (LAVPD, kPa), stomatal conductance (g_s, mmol m^{-2} s^{-1}), midday leaf water potential (Ψ_{MD}, MPa), DBH which represents stem diameter at breast height (i.e. 1.3 m from the ground), Leaf area (cm^2), Leaf dry matter (g), and specific leaf area (SLA, m^2/kg) are the mean ± standard deviation (SD) of 3 individuals of each species.

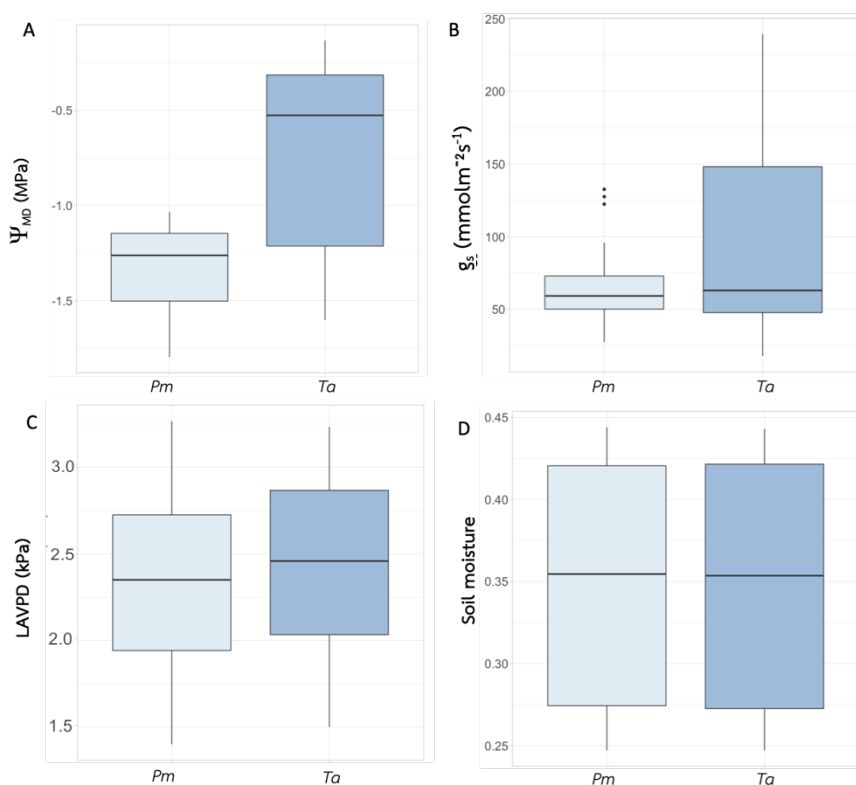| Species	T (°C)	RH (%)	PAR (μmol m^{-2} s^{-1})	Soil moisture (m^{3}m^{-3})	LA VPD (kPa)	g_s (mmol m^{-2}s^{-1})	Ψ_{MD} (MPa)	DBH (cm)	Leaf area (cm^2)	Leaf dry mass (g)	SLA (m^2/kg)
T.argentea	28.11 ± 2.67	47.41 ± 9.98	1171.17 ± 221.56	0.35 ± 0.08	2.47 ± 0.52	96.46 ± 60.78	-0.69 ± 0.46	17.67 ± 5.69	17.84 ± 8.60	0.26 ± 0.13	7.15 ± 1.18
P.macarthurii	28.11 ± 2.67	47.41 ± 9.98	1171.17 ± 221.56	0.35 ± 0.08	2.34 ± 0.49	65.06 ± 25.59	-1.33 ± 0.22	6.32 ± 0.18	122.93 ± 24.97	1.69 ± 0.35	7.23 ± 0.72

Figure 2 Box plots showing measured values of (A) midday leaf water potential (Ψ_{MD}) and (B) stomatal conductance (g_s) of *Pm* (light blue) and *Ta* (dark blue). Environmental factors including (C) leaf-to-air vapor pressure deficit (LAVPD) and (D) soil moisture measured in the *Pm* (light blue) and the *Ta* (dark blue) plots.

4.2 Relationship between stomatal conductance (g_s) and midday leaf water potential (Ψ_{MD}) of tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*) species

Responses of g_s to Ψ_{MD} in *Ta* and *Pm* did not show the same patterns (Figure 3). *Ptychosperma macarthurii* had no pattern of the response of g_s to Ψ_{MD}. Stomatal conductance and Ψ_{MD} had no significant relationship in *Pm* ($p = 0.5016$). Emilio et al. (2019) indicate that water storage in palm petioles could play an important role in while maintaining a high transpiration rate during drought. On the contrary, *Ta* had a pattern of the response of g_s to Ψ_{MD}, which is a linear function in a quadratic form. Stomatal conductance and Ψ_{MD} had significant relationship in *Ta* ($p < 0.0001$). Increased water potential causes high water content in guard cell lending to stomata opening (Buckley, 2019). But in *Pm*, it did not follow this pattern. Stomata in *Ta* had been closed when increasing leaf water potential, which corresponds to moist condition. This is because *Ta* is a species of *Tabebuia* native to South America (Kepler, 1990), which moderate dry conditions, so it may be sensitivity well water or flood. Additionally, based on our observation, the nearly flooded condition often occurred in this garden due to excessive watering in both plots. Saturated soil decreases the oxygen levels that are available for plant roots due to the low diffusion of O_2 in water. Furthermore, the poor O_2 of roots decreases the absorption of water by plants (Oliveira & Gualtieri, 2016). Oliveira & Gualtieri (2016) studied the effect of *Tabebuia aurea* to artificial flooding and found that flooded soil reduced photosynthesis and stomatal conductance in the *Tabebuia aurea*.
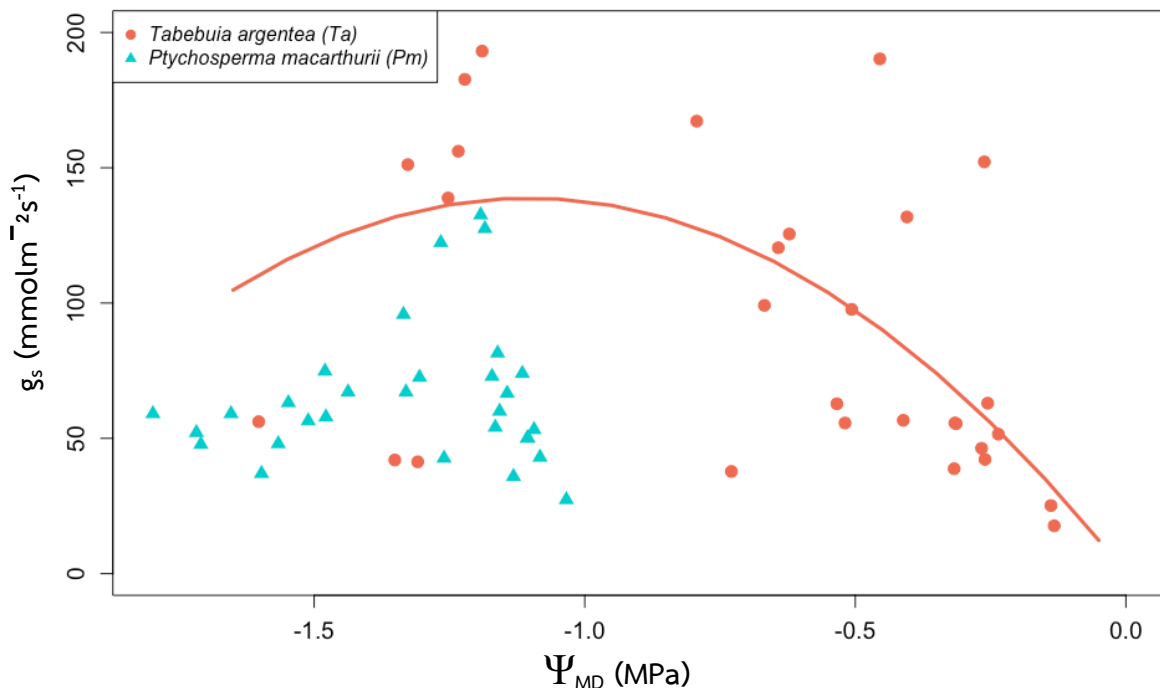

Figure 3 Relationship between stomatal conductance (g_s) and midday leaf water potential (Ψ_{MD}) of tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*). The Ψ_{MD} and g_s values reported for each species are the means of 3 individual *Ta* (circles) and *Pm* (triangles).

4.3 Relationship between midday leaf water potential (Ψ_{MD}) and environmental conditions of tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*) species

Environmental factors have a common effect on the plant such as an imbalance between water uptake in the roots and water loss through leaves via transpiration (Qaderi et al., 2019). The result in this study shows that the relationship between Ψ_{MD} and LAVPD of *Ta* and *Pm* had no pattern of response (Figure 4A). Midday leaf water potential and LAVPD of *Ta* and *Pm* had no significant relationship (p = 0.1398 for *Ta* and 0.2585 for *Pm*). The relationship between Ψ_{MD} and soil moisture of *Pm* had no pattern of response (p = 0.8215) but found significant pattern in *Ta* (p = 0.0015) which is in quadratic form (Figure 4B). Additionally, as stated before, this site had not experienced actual drought. Therefore, Ψ_{MD} of *Pm* did not respond to soil moisture. Increasing soil moisture cause higher water content in guard cell leading to higher leaf water potential in tree. Flood restricts the absorption of water of the root (Oliveira & Gualtieri, 2016) leading to decreasing leaf water potential and decreasing stomatal conductance which consistent with relationship between g_s and Ψ_{MD} of *Ta* (Figure 3).

Figure 4 (A) Relationship between midday leaf water potential (Ψ_{MD}) and leaf-to-air vapor pressure deficit (LAVPD) of *Ta* and *Pm*. (B) Relationship between midday leaf water potential (Ψ_{MD}) and soil moisture of *Ta* and *Pm* plots which report the means values at 10 days in the day of measurement. The Ψ_{MD} and LAVPD values reported for each species are the means of 3 individual *Ta* (circles) and *Pm* (triangles).

4.4 Relationship between stomatal conductance (g$_s$) and environmental conditions of tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*) species

Increasing LAVPD induced a decreased of g$_s$ in *Ta* and *Pm* (Figure 5A). Relationship between g$_s$ and LAVPD had significant relationship in *Ta* and *Pm* (p <0.0008 for *Ta* and p <0.0001 for *Pm*) which is nonlinear regression in exponential form. Stomatal regulation is directly responsible for controlling transpiration response to LAVPD so that when LAVPD is low and stomata are fully open (Grossiord et al., 2020). This response involves water status in cells within the leaf and guard cells. But in *Pm*, g$_s$ did not respond to leaf water potential because *Pm* maintain open stomata to maintain CO_2 uptake and allow photosynthesis despite the decreasing leaf water potential (Figure 3). According to Table 2, the sensitivity of g$_s$ to variations in LAVPD was higher in *Ta* than *Pm* so g$_s$ in *Ta* stronger response to LAVPD than *Pm*. In contrast, g$_s$ did not response to soil moisture in *Ta* and *Pm* (p=0.2833 for *Ta* and p=0.2278 for *Pm*, Figure 5B), potentially because this site had been regularly watered.
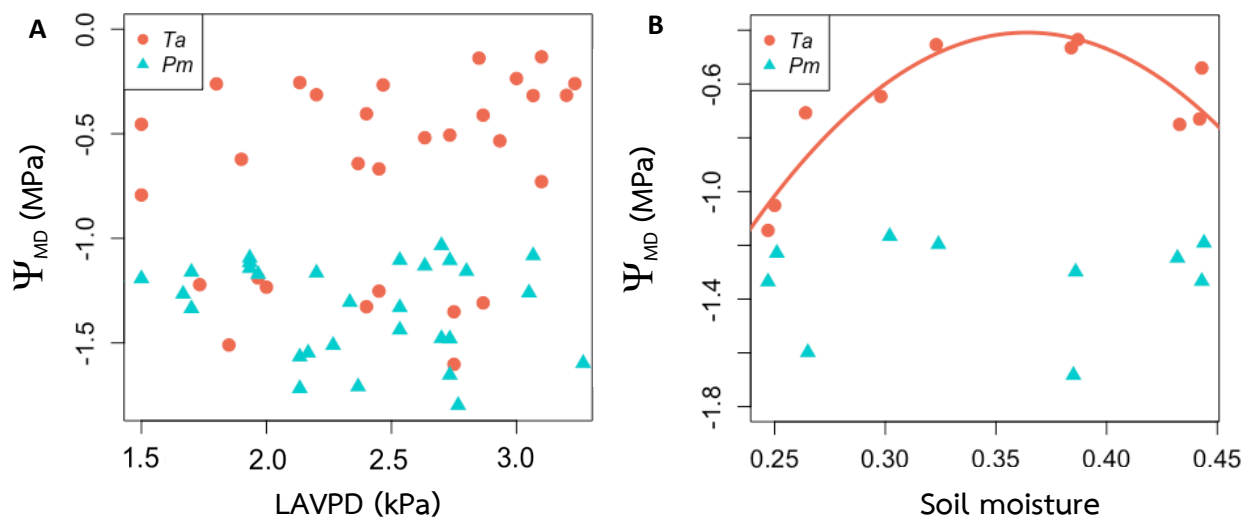

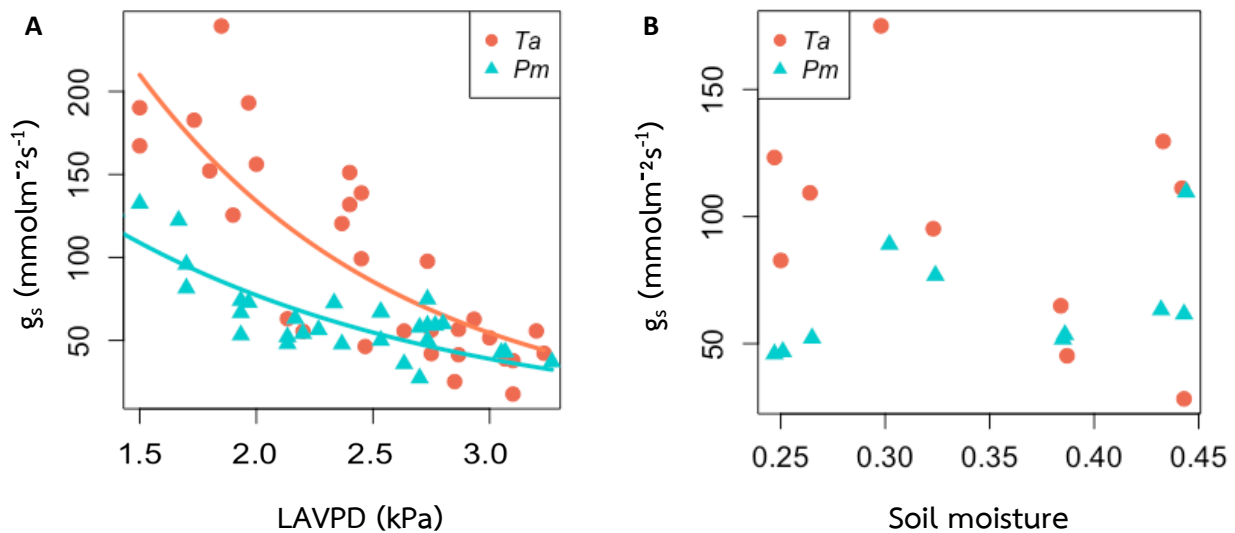**Figure 5** (A) Relationship between stomatal conductance (g$_s$) and leaf-to-air vapor pressure deficit (LAVPD) of *Ta* and *Pm*. (B) Relationship between stomatal conductance (g$_s$) and soil moisture of *Ta* and *Pm* plots which reported the means values at 10 days in the day of measurement. The g$_s$ and LAVPD values reported for each species are the means of 3 individual *Ta* (circles) and *Pm* (triangles).

Table 4.2 Summary of regression statistic. Regression analysis result for relationship between midday leaf water potential (Ψ_{MD}) and stomatal conductance (g_s), midday leaf water potential (Ψ_{MD}) and environmental conditions, stomatal conductance (g_s) and environmental conditions of *Ta* and *Pm* species for Figure 3, Figure 4 and Figure 5. r^2 and p-value are the coefficient of determination and p-value at significant level of 5% for the regression analyses.

Figure	Species	Variables	Relationship	r^2	p-value
Figure 3	*T. argentea*	g_s vs Ψ_{MD}	$y = -113.93x^2 - 251.51x$	0.8027	< 0.0001
	P. macarthurii	g_s vs Ψ_{MD}	n/a	n/a	0.5016
Figure 4A	*T. argentea*	Ψ_{MD} vs LAVPD	n/a	n/a	0.1398
	P. macarthurii	Ψ_{MD} vs LAVPD	n/a	n/a	0.2585
Figure 4B	*T. argentea*	Ψ_{MD} vs SM	$y = -46.720x^2 + 34.012x - 6.599$	0.8442	0.0015
	P. macarthurii	Ψ_{MD} vs SM	n/a	n/a	0.8215
Figure 5A	*T. argentea*	g_s vs LAVPD	$y = 809.7005e^{(-0.8996x)}$	0.6722	<0.0008*
	P. macarthurii	g_s vs LAVPD	$y = 304.8449e^{(-0.6866x)}$	0.6582	<0.0001*
Figure 5B	*T. argentea*	g_s vs SM	n/a	n/a	0.2833
	P. macarthurii	g_s vs SM	n/a	n/a	0.2278

* The p-value of coefficient for nonlinear regression

4.5 Comparison specific leaf area (SLA) of tree (*Tabebuia argentea*) and palm (*Ptychosperma macarthurii*) species

      Specific leaf area (SLA, leaf area per unit dry mass) are important traits in plant ecology because it is associated with plant growth and survival (Cornelissen et al., 2003). SLA is indicator traits of resource-use strategies, it is important to evaluate this trait for different plant species in various environments (Wilson et al., 1999). Mean SLA in *Ta* and *Pm* were 7.15 ± 1.18 and 7.23 ± 0.72 m^2 kg^{-1} respectively (Figure 6A). SLA in *Ta* and *Pm* were not different (p = 0.7102). So that, *Ta* and *Pm,* which growing in the same site, may be no different resource-use strategies. However, leaf area in *Pm* was higher than *Ta* (p < 0.001). Mean leaf area in *Pm* and *Ta* were 122.93 ± 24.97 and 17.84 ± 8.60 cm^2 respectively (Figure 6B). Average leaf dry mass in *Pm* and *Ta* were 1.69 ± 0.35 and 0.26 ± 0.13 g respectively (Figure 6C). Leaf area and leaf dry mass in *Pm* higher than tree (p < 0.001). Leaf water loss per unit leaf area is negatively correlated with leaf area (Wang et al., 2019). Higher leaf area trend to lower leaf water loss per unit leaf area.
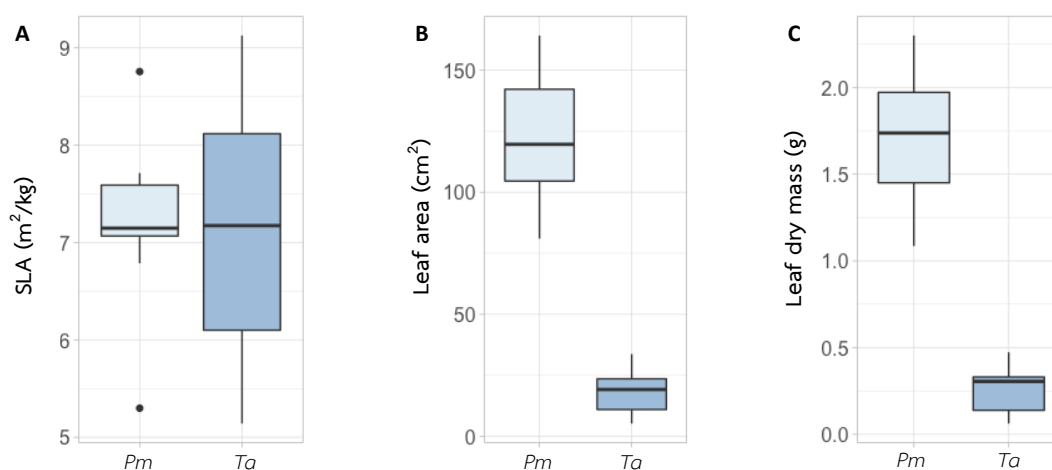

Figure 6 Box plots showing measured values of (A) Specific leaf are (SLA, m^2/kg) and (B) leaf area (cm^2) and (C) leaf dry mass (g) of *Pm* (light blue) and *Ta* (dark blue).

CHAPTER 5
RESEARCH CONCLUSIONS

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5.1 Conclusions

For improving the sustainability of urban forests and urban greening, selected plant species planting of well adapted to urban environment ensuring healthy plants providing ecosystem services is necessary for cities. Our results revealed that, response of tree hydraulic to environment and stomatal conductance (g_s) of a tree (*Tabebuia argentea*, *Ta*) and a palm (*Ptychosperma macarthurii*, *Pm*) species. Relationship between g_s and midday leaf water potential (Ψ_{MD}) in *Ta* had significant relationship but not found pattern in *Pm*. Stomata in *Ta* had been closed when increasing Ψ_{MD}. Moreover, relationship between Ψ_{MD} and soil moisture in *Ta* had significant relationship consistent with the relationship between g_s and Ψ_{MD}. Increasing soil moisture cause higher Ψ_{MD} in *Ta* leading to stomata closure because saturation soil restricts the absorption of water of the root. However, this pattern was not found in *Pm*. This pattern suggests that *Ta* should be appropriately watered. Excessive watered could reduce ecosystem services in *Ta*. Stomatal conductance and LAVPD had a pattern of response in *Ta* and *Pm*. Stomatal conductance in *Ta* is more sensitive to change in LAVPD than *Pm* growing under the same site and environmental conditions. Thus, based on this observation, *Pm* is less sensitive to environmental changing than *Ta*. *Ptychosperma macarthurii* can maintain plant water status and stomatal conductance regardless of soil moisture variation. Hence, we suggest that *Ta* should not be irrigated to flooded condition occurred while *Pm* may be watered less frequently to save water. This initial investigation implied that maintaining urban trees using appropriate irrigation that is specific to tree species is the key to maximize benefits from urban trees and optimize urban water use.

5.2 Recommendation

To confirm pattern of tree hydraulic response of *Tabebuia argentea* and *Ptychosperma macarthurii* to g_s and environment factor, future study involving an artificial drought may be performed.

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