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Article

Photosynthesis of Sago Palm (*Metroxylon sagu* Rottb.) Seedling at Different Air Temperatures

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Abstract: Photosynthetic activities of the sago palm (*Metroxylon sagu* Rottb.) were studied to find out its sensitivity to changes in ambient air temperature. The minimum ambient air temperature designed for the experiment was 25–29^{0}C, while the higher end was 29–33^{0}C. Several photosynthetic parameters were studied to support our analysis in sago photosynthetic activity, including diurnal leaf gas exchange, assimilation rate *vs*. CO_2 concentration, leaf greenness, leaf chlorophyll content, and photosynthetic rate *vs*. irradiance. We found that sago palm photosynthetic activity tends to be more sensitive to minimum than to maximum ambient air temperature. The plants exposed to higher air temperatures had dark green leaf color associated with higher rates of diurnal photosynthesis, chlorophyll content, and rubisco limited photosynthetic activity. They also exhibited higher trend in optimum irradiance absorption level. Consequently, maximum light energy dissipation occurred at higher temperatures.

Keywords: carbon response curve; light response curve; photosynthesis; pigment determination; sago palm

1. Introduction

Ambient air temperature generally has a significant impact the physiological performance of plants. Many studies reveal that inhibition of photosynthetic perfomance occurs at severely high (>35^{0}C) and low temperatures (<20^{0}C) [1]. However, in the tropical zone in which the sago palm typically grows, variation in air temperature within a year is less than in temperate zones, so this study focused on a moderate air temperature range from 25–33^{0}C to ascertain the sago palm's photosynthetic performance in the ambient air environment of its typical habitat.

The sago palm is a perennial monocot crop well known for its potential to accumulate high amounts of starch in its trunk. It can store approximately 300 kg (dry weight) of starch per tree [2]. The importance of sago palm as a staple food is well recognized in some areas of Southeast Asia and South Pacific. The carbohydrate contained in the trunk can be further processed into various basic raw materials for food, animal feed and industrial uses [3]. Coming from the arecaceae or palmae family, sago is able to grow in marginal terrain such as submerged and tidal areas where most agronomy crops cannot survive without drainage or soil improvement. As one of the most important crops for sustainable agriculture and for rural development in swampy areas of Indonesia, sago palm has become an important part of peatland restoration projects.

The optimum air temperature range for sago palm is very narrow, reported as from 25^{0}C to 29^{0}C [4]. Elsewhere it has been reported that the best growing conditions required a minimum of at least 26^{0}C [5]. The minimum temperature has been cited as an important factor limiting sago palm performance [6], which is likely due to the tendency of the photosynthesis enzyme Ribulose-1,5-bisposphate caboxylase/oxygenasi (Rubisco) to be very sensitive to air temperature. Minimum temperature reduces rubisco activity, which consequently reduces the utilization of RuBP by rubisco. Rubisco activase content is suppressed by up to 80% at 25^{0}C and below [7]. A study on hibiscus plants reported that the effective quantum yield of PSII (Φ_{PSII}) is suppressed below 10^{0}C [8].

Regarding maximum temperature, morphological observation of sago palm seedlings reported that at 35^{0}C leaves expanded but become less green [9]. Higher air temperature also plays an important role in sago seed germination. At 30^{0}C, seed germination was about 20% higher than at 25^{0}C [10]. In physiological studies, moderate heat stress affects light energy harvesting as more light is dissipated for non-photochemical quenching rather than photochemical quenching. Therefore, the CO_2 fixation process is depressed [11]. Another study confirmed that carboxylation efficiency decreased at 39^{0}C followed by a reduction in photosynthetic efficiency [12].

While it has been considered that variations of ambient air temperature in the sago palm habitat might affect its physiological performance, especially its photosynthetic activity, this has not been definitively proven. This

study aimed to provide useful data on sago palm physiology at different air temperatures beyond the little that has so far been published. Understanding the regulation of photosynthesis and chlorophyll fluorescence is very important as a tool in characterising plant reactions under abiotic stress, such as high and low temperature stress [13]. Thereby, the area for sago palm cultivation can be effectively selected to meet the need for appropriate air temperature, allowing optimum plant growth to be achieved and producing optimal yields.

Due to the abovementioned high degree of photosynthetic sensivity of the plant, especially at lower temperatures, it was hypothesised that even moderate changes in air temperature will inhibit the photosynthetic performance of sago palm.

2. Materials and methods

2.1. Plant material and culture conditions

The experiment was conducted in two phytotrons (glass house) with air temperatures ranging from 25–29^{0}C and 29–33^{0}C respectively at Nagoya University, Japan, from January to March 2017. These air temperatures were considered as the range of ambient temperature in sago palm habitats associated with tropical rainforest climate. Air relative humidity ranged from 30–50% and irradiance flux density from 600–800 µmol m^{-2} s^{-1}. Six one–year–old sago palm seedlings with six fully-developed leaves, grown individually in 1/10000a Wagner pots (diameter 115 mm and height 184 mm), were tested. The plant materials were obtained in seed form from Sentani District, Jayapura, Indonesia. Vermiculite was applied as the growing media for each plant. The nutrients were supplied through the application of Kimura B culture solution. The second youngest leaves were selected for all measurements. At the beginning, all plants were placed in the same phytotron with air temperature set at 25–29^{0}C. After that six plants were moved to a phytotron with air temperature at 29–33^{0}C. After one month of acclimation, measurement was conducted.

2.2. Diurnal leaf gas exchange

Diurnal leaf gas exchange was measured hourly from 7:00 AM to 05:00 PM. The diurnal leaf gas exchange measurement was end at 03:00 PM to the plants grown at 25-29^{o}C as the photosynthetic value was zero after 03:00 PM. The portable photosynthesis system, Li-6400XT (LiCor Inc., USA) with 6 cm^2 leaf chamber was utilized during the measurement. The CO_2 concentration was controlled at 400 µmol and photosynthetic photon flux density (PPFD) was set at 750 µmol m^{-2} s^{-1}. The CO_2 mixer was adjusted at 500 µmol and relative humidity in the leaf chamber was controlled at 40% in the phytotron. During measurement, leaf temperature was set at 25^{0}C. Net photosynthetic rate (P_N), stomatal conductance (g_s), transpiration rate (T_r), and intercellular CO_2 concentratio (C_i) parameters were obtained from this measurement.

2.3. Assimilation rate vs. CO_2 concentration (A/Ci curve)

A carbon response curve was constructed following the Farquhar photosynthesis model [14,15] to conceive the photosynthesis interference at different air temperatures. Changes in rates of assimilation in response to carbon dioxide variation was studied by setting several levels of CO_2 concentration with constant PPFD intensity set at 750 µmol. At the beginning, CO_2 concentration was set at 400 µmol and gradually reduced to the lowest concentration at 50 µmol. After reaching the lowest level, CO_2 concentration was gradually increased to a maximum level of 2000 µmol. Finally, CO_2 concentration was returned to 400 µmol with irradiance in the "off" mode. There were three replicates for each treatment.

The A/Ci curves data were obtained by A/Cc curve fitting utility version 1.1 developed by Sharkey [15]. The derived variables obtained from the fitting curve are maximum carboxilation capacity (V_{cmax}), and electron transport rate (J) [16]. The Rubisco limited photosynthesis (V_{cmax}) was calculated using the following equation:

$$A=V_{cmax}\left[\frac{C_c - \Gamma^*}{C_c + K_c(1+O/K_o)}\right] - R_D \quad [1]$$

V_{cmax} represents maximum Rubisco rate in CO_2 reduction, C_c is partial CO_2 pressure at rubisco, K_c is the Michaelis constant of Rubisco for CO_2, O is the partial pressure of O_2 at rubisco, K_o is the inhibition constant of Rubisco for O_2, Γ^* is the compensation point of photorespiration, and R_D is dark respiration in which CO_2 is released by the non-photorespiration process.

The following equation was used to calculate the RuBP limited photosynthesis:

$$A=J\,\frac{C_c - \Gamma^*}{4C_c + 8\Gamma^*} - R_d \quad [2]$$

J represents the RuBP limited photosynthesis for NADPH formation which is utilized in RuBP regeneration which takes four electrons per carboxylation and oxygenation [15].

2.4. Photosynthetic rate vs. Irradiance

A light response curve was constructed using a photosynthesis yield analyzer (MINI-PAM, Walz-Germany) after dark adaptation for 20 minutes. Nine irradiance levels were given from zero to 1300 µmol m^{-2} s^{-1} and each erradiance had an interval of 10 seconds to reach to steady state level. Three sago seedlings were choosen as replicates. Three leaflets from the second younger leaf of each plant were measured to obtained the mean value of each replicate.

The fluorescence data including quantum yield photosystem II (Φ_{PSII}), electron transport rate (ETR), non-photochemical quenching (NPQ), and coefficient of non-photochemical quenching (qN), were computed with WinControl software (Walz - Germany). The fraction of energy photo-chemically converted in photosystem II is represented by Φ_{PSII} which is calculated as:

$$\Phi_{PSII} = \frac{Fm' - F}{Fm'} = \frac{\Delta F}{F'} \quad [3]$$

Fm' is the maximum fluorescence yield in light adapted sample where all PSII is the open stage. F is yield fluorescence measured briefly before saturation pulse application, and ΔF is the increase of fluorescence induced by a saturation pulse [17]. The equation used to fit Φ_{PSII} is simple exponential decay function of the form $\Phi_{PSII} = e^{-x}$ after appropriate scalling,

$$\Phi_{PSII} = \Phi_{PSII\ max} \times e^{-k_y\ PPFD} \quad [4]$$

Φ_{PSII} is quantum yield, $\Phi_{PSII\ max}$ is maximum quantum yield at theoritical zero irradiance, k_y is a scaling constant, and PPFD is photon flux density (µmol (CO_2) m^{-2} s^{-1}).

Electron transport rate (ETR) is calculated by estimating gross photosynthesis using the following equation:

$$ETR = \Phi_{PSII} \times PPFD \times 0.5 \times 0.84 \quad [5)$$

Φ_{PSII} is the effective quantum yield, PPFD is the irradiance, allocation factor (0.5) is the partitioning energy between PS II and PS I, and 0.84 is the leaf absorbance factor (α_{leaf}) [18]. Following Ritchie and Bunthawin [19], ETR data was fit using non-linear least squares methods calculated as:

$$ETR = \frac{ETR_{max} \times PPFD}{PPFD_{opt}} \times e^{1-PPFD/PPFD_{opt}} \quad [6]$$

The excel routine for fitting Waiting-in-Line curves was utilized to fit the ETR *vs*. several levels of irradiance [20]. The excel routine was obtained personally from Ritchie. The non-photochemical quenching (NPQ) parameter corresponds to the loss of potential energy which is dissipated as heat also referred to as thermodynamic loss. NPQ is calculated as:

$$NPQ = \frac{Y(NPQ)}{Y(NO)} = \frac{Fm - Fm'}{F'} \quad [7]$$

qN is calculated as:

$$qN = \frac{F_m - Fm'}{F_m - F_0} \quad [8)$$

F is yield fluorescence measured briefly before saturation pulse application, F_m is the maximum fluorescense of dark adapted leaf, F_o is the minimum fluorescence, and F'_m is the maximum fluorescence measured at saturation pulse. The equation used to fit qN and NPQ vs. irradiance curves is simple exponential saturation functions:

$$qN = qN_{max}[1 - \exp(K_{qN} \times PPFD)] \quad [9]$$

while NPQ was calculated as:

$$NPQ = NPQ_{max} [1 - \exp(K_{NPQ} \times PPFD)] \quad [10]$$

PPFD is photon flux density, K_{qN} and K_{NPQ} are exponential constants, qN_{max} is the asymptotic maxima for qN, and NPQ_{max} is the asymptotic maxima for NPQ.

2.5. Chlorophyll content

A portable chlorophyll meter, SPAD-502Plus (Konica Minolta, Japan) was utilized to measure leaf greenness of the same leaves chosen for photosynthesis measurement. The same leaves were harvested for chlorophyll content analysis.

Chlorophyll determination was conducted following Arnon [21] and Lichtenthaler [22] after acetone 80% extraction using a spectrophotometry (UV-1800 Shimadzu). Chlorophyll and carotenoids concentrations were calculated in µg $gram^{-1}$ ground sample.

2.6. Statistical analysis

This experiment employed completely randomized design with two ranges of air temperature, 25–29^{0}C and 29–33^{0}C, with three replicates. The second upper- most leaf from each replicate was used for measurement. Each datum is presented as mean ± SE. Statistical differences were tested by student *t*-test.

3. Results

3.1. Diurnal leaf gas exchange

Data for sago palm data show considerable differences in net photosynthetic rate (P_N), stomatal conductance (g_s), and leaf transpiration rate (T_r) values between the two air temperature ranges (Fig. 1A). The open circles represent the P_N of sago palm seedlings growing at 25–29^{0}C room temperature while the closed circles represent the P_N of seedlings grown at 29–33^{0}C room temperature. In the first daily measurement at 7:00 h sago seedlings growing at the higher room temperature started with a higher P_N than the seedlings growing at lower temperature. The plants grown at 25–29^{0}C maintained the optimum P_N for a short period as the down-ward trend began around 12:00 h.

Stomatal conductance (g_s) and leaf transpiration rate (T_r) showed the same trend with P_N. At 25–29^{0}C, g_s showed a slight upward trend during the observation. Low stomatal aperture at 25–29^{0}C caused a reduction in T_r (Fig. 1*B*,*D*). At 29–33^{0}C, the higher P_N trend was followed by higher g_s and T_r. However, intercellular CO_2 concentration (C_i) at higher temperature showed a lower rate only in the first two hours of measurement (7:00 to 8:00 h) and the last two hours of measurement. They exhibited almost the same trend in C_i rate between 9:00 and 13:00 h (Figure 1*C*).

3.2. Photosynthetic activity and chlorophyll content

Photosynthetic activity and chlorophyll contetn of sago palm seedlings showed lower rates and concentrations respectively at 25–29^{0}C air temperature. The low P_N value was followed by lower values in biochemical limiting photosynthetic activities such as electron transport rate (J) and maximum carboxilation capacity (V_{cmax}). The other parameters to explained the low P_N at minimum air temperature was pigmentation. Chlorophyll content seems to be lower at minimum than at higher air temperatures tested. Although only Chl *b* showed significant difference in pigment content, all parameters were considerably higher in sago seedlings grown at 29–33^{0}C air temperature (Table 1).

Table 1. Photosynthetic parameters, and chlorophyll content of sago palm seedlings at different air temperatures. *: significant ($p \leq 0.05$), **: significant ($p \leq 0.01$), ns: not significant ($p > 0.05$) , respectively using Student *t*-test. Means ± SE, $n = 3$.

Parameters	25–29^{0}C	29–33^{0}C
P_N [µmol (CO_2) m^{-2} s^{-1}]	5.66 ± 0.91	8.62 ± 0.24*
J [µmol m^{-2} s^{-1})]	88.2 ± 10.98	114.1 ± 5.59ns
V_{cmax} [µmol m^{-2} s^{-1})]	40.1 ± 10.23	99.3 ± 10.86*
SPAD	46.2 ± 1.56	62.3 ± 1.91**
Chl *a* [µg g^{-1}]	838.1 ± 34.39	987.3 ± 99.04 ns
Chl *b* [µg g^{-1}]	258.5 ± 10.56	319.2 ± 11.45*
Chl *a*+*b* [µg g^{-1}]	1096.6 ± 35.9	1306.5 ± 102.8 ns
Carotenoid [µg g^{-1}]	223.7 ± 2.91	255.0 ± 2.91 ns

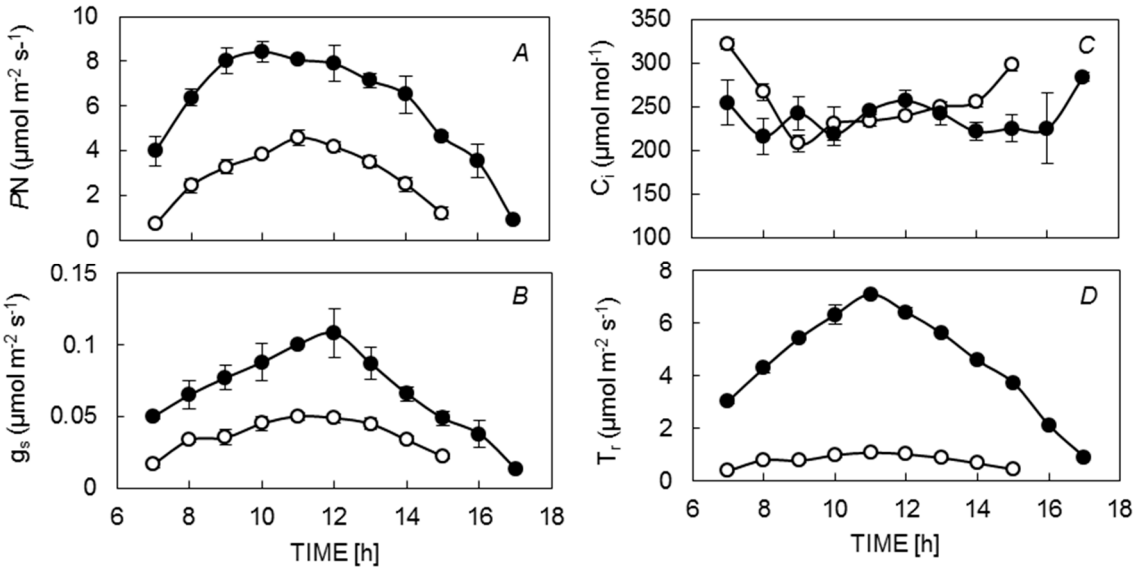

Figure 1. Diurnal change in [*A*] net photosynthetic rate (P_N), [*B*] stomatal conductance (g_s), [*C*] intercellular CO_2 concentration, [*D*] transpiration rate (T_r) of sago palm seedlings growing at different room temperatures. ○: 25–29^{0}C , ●: 29–33^{0}C. (Mean ± SE, n = 3).

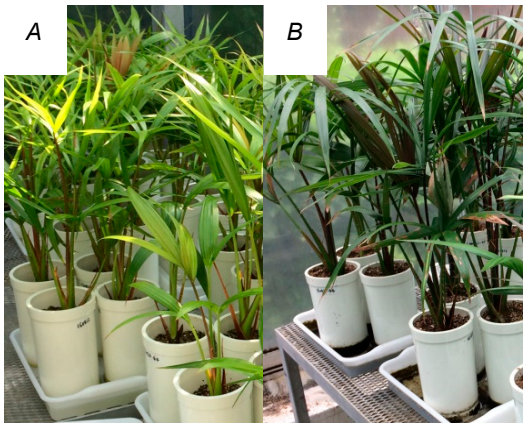

Figure 2. The leaf greenness of sago palm seedlings grown at 25–29^{0}C [*A*], and 29–33^{0}C [*B*] room temperature.

The leave color of sago palm grown at 29–33^{0}C was obviously darker than at the lower air temperature tested and was confirmed by significantly higher SPAD values. In addition, we noticed that most plants showed leaf emergence at the higher air temperature, although no measurement in leaf emergence rate undertaken.

3.3. Photosynthetic rate vs. Irradiances

Photosynthetic rate vs. Irradiances was measured and fit using non-linear least square fit. The graphics of quantum yield of PSII at both air temperatures were obtained (Fig. 3*A*). The curve of quantum yield of PSII (Φ_{PSII}) *vs*. irradiance at both air temperatures provided a maximum effective quantum yield ($\Phi_{PSII\ max}$) value at 25–29^{0}C and 29–33^{0}C. The Waiting-in-Line equation was used to fit ETR values (Fig. 3*B*) for both air temperature ranges tested. The variables obtained $PPFD_{opt}$, ETR_{max} and α_o are shown in Table 2. The fitted qN and NPQ data (Fig 3*C*,*D*) provide information about qN_{max} and NPQ_{max}. Most of variables in Table 2 are dominated by the sago seedlings growing at 29–33^{0}C air temperature. However, according to statistical analysis, there are no significant differences in maximum efficiency quantum yield ($\Phi_{PSII\ max}$), maximum electron transport rate (ETR_{max}), asymptotic photosynthetic efficiency (α_o), and maximum coefficient of non-photochemical quenching (qN_{max}) between the two air temperature ranges.

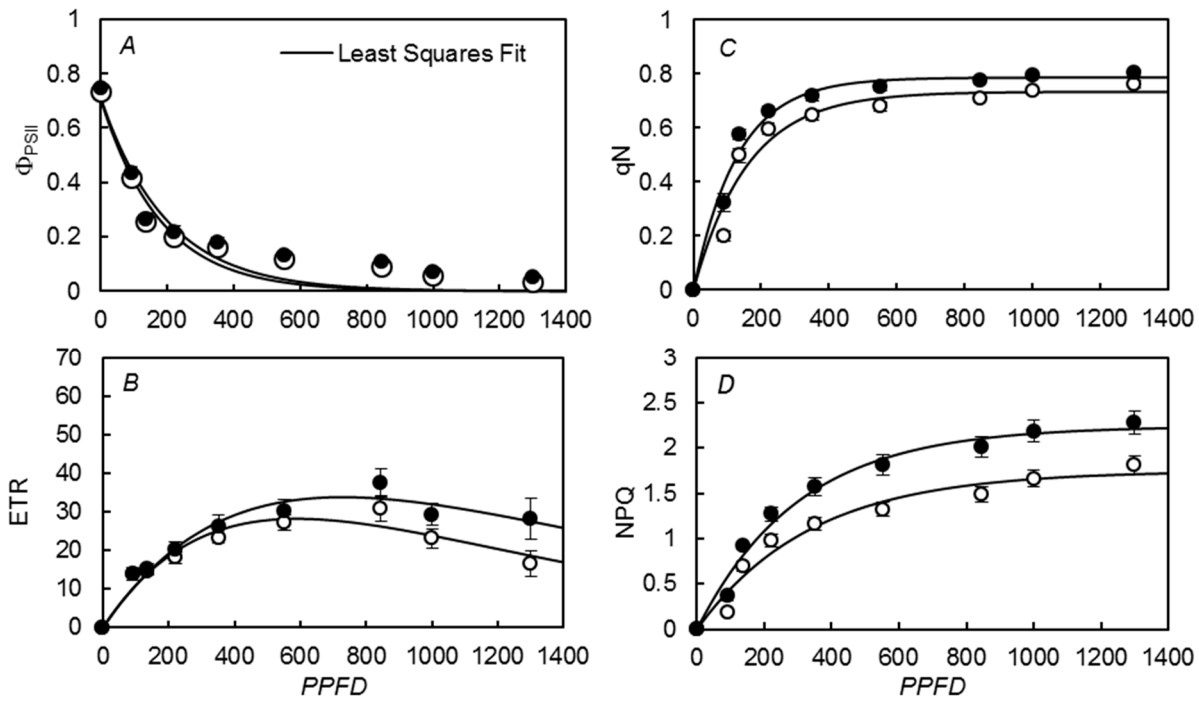

Figure 3. (**A**) Photosynthetic yield (Φ_{PSII}), (**B**) electron transport rate (ETR), (**C**) coeficient non-photochemical quenching (qN), and (**D**) non-photochemical quenching (NPQ) *vs*. irradiance of sago palm seedlings (estimated via non-linear least square fitting) at 25–29^{0}C (○) and 29–33^{0}C (●). Mean ± SE, n = 3, with 9 irradiance levels.

Table 2. Photosynthetic parameters (fitted by Waiting-in-Line equation) of sago palm seedling at 25–29^{0}C and 29–33^{0}C air temperatures (Means ± SE, n = *3* plants, 27 data points). *: significant ($p \leq 0.05$), ^{ns}: not significance ($P > 0.05$) as the results of Student t-test.

Parameters	**25–29^{0}C**	**29–33^{0}C**
Maximum yield ($\Phi_{PSII\ max}$)	0.70 ± 0.013	0.70 ± 0.025 ^{ns}
Optimum PPFD ($PPFD_{opt}$)	587.00 ± 29.81	725.59 ± 33.32 *
Maximum electron transport rate (ETR_{max})	28.28 ± 2.53	33.91 ± 3.76 ^{ns}
Asymptotic Photosynthetic efficiency (α_o)	0.13 ± 0.006	0.13 ± 0.009 ^{ns}
qN_{max}	0.73 ± 0.015	0.79 ± 0.014 ^{ns}
NPQmax	1.75 ± 0.08	2.25 ± 0.13 *

4. Discussion

At the beginning of measurement (7:00 h) sago palm seedlings revealed low photosynthetic rates in both treatments. This might be due to the light not reaching sufficient levels for optimum stomatal aperture as blue light induces the aperture of stomata [23]. Moreover, air temperature at that time has not reached the optimum level for higher rubisco activity. Consequently, with an increase in light intensity and air temperature from 8:00–11:00 h, P_N, g_s, and T_r trended upwards in both treatments. However, the plants showed midday depression as photosynthetic rate reduced from 12:00. This might be caused by stomatal and other non-stomatal limitations such as photoinhibition, photorespiration and reduction of rubisco activity under high temperature [24]. This is consistent with most field work cases, where it is difficult to obtain optimum P_N rate in sago palm when the measurement is conducted after 12:00 h. This information was confirmed by our findings from diurnal leaf gas exchange data. In addition, our data suggests that lower air temperature inhibited the seedlings' capacity to maintain a longer P_N rate. Higher temperatures (29–33^{0}C) appear to induce higher rubisco activity in sago palm seedlings than that achieved at lower temperatures (25-29^{0}C) (Table 1). Although producing the same diurnal leaf gas exchange trend across both air temperature ranges, the sago seedlings growing at 29–33^{0}C room temperature showed higher photosynthetic rate.

According to the data from figure 1*A*, a lower net photosynthetic rate at 25–29^{0}C was followed by lower stomatal conductance results in lower leaf transpiration rate. Low transpiration rate is considered to be one of the factors causing low P_N rate as CO_2 can only enter leaves through gas diffusion [23]. However, the intercellular CO_2 concentration (C_i) did not a show higher rate at 25–29^{0}C. C_i revealed almost the same trend in both air temperature ranges, except in the first two hours of measurement and the last two hours of measurement (Fig. 1*C*). When plants performed higher assimilation rates, intercellular CO_2 value should show a lower rate as the CO_2 is utilized during photosynthesis activity. Therefore, we assume that at 25–29^{0}C, the photosynthetic activity was not only limited by those components but also the other components such as rubisco activity, leaf chlorophyll content and the light harvesting system.

In the lower air temperature range (25–29^{0}C), the performances of rubisco activity (V_{cmax}) tend to be low. Low rubisco activity at 25^{0}C might be due to the reduction in RuBP regeneration [25,7]. RuBP regeneration might be affected by the lower RuBP consumption by rubisco. This could suggest that the activation state of rubisco could be different in plants grown at different air temperatures.

The higher performance in net photosynthetic rate of sago palm seedlings at higher temperatures tested also could not be separated from the support of higher photosynthetic apparatus formation, such as leaf chlorophyll. The higher temperatures induced higher formation of leaf pigments such as Chl *a*, Chl *b* and carotenoid. The sago seedlings grown at higher air temperatures produced leaves with a dark green color, while sago seedlings grown at lower air temperature produced light green leaves. An appropriate air temperature increases the capacity for thermotolerance which increases chlorophyll a:b ratio [26,27]. Air temperature also influences the formation of chlorophyll as temperature regulates the synthesis of chlorophyll precursor [28]. In our study, the phytotron at 29-33^{0}C provided an appropriate growth environment for sago palm seedlings. Those growing at 31^{0}C revealed higher uptake in macronutrients such as N, P, K, and Ca, which contribute to the maximum leaf area [9]. Therefore, it appears the higher uptake of nutrients induced the higher formation of leaf chlorophyll leading to greater capacity to harvest light energy. In addition, although no measurement in leaf emergence rate undertaken, we noticed that most plants showed leaf emergence at the higher air temperature, the same occurence had previously been found in the study of sago palm seedlings' response to various ranges of air temperature. It was found that at 35^{0}C leaf emergence rate increased although shoot elongation rate, leaf area and root growth rate decreased. However, at 23^{0}C leaf emergence rate decreased along with increased root growth rate [9].

In general, sago palm reach light saturation point from 600–750 µmol m^{-2} s^{-1} PPFD, although this point may vary depending on the leaf age and shaded conditions [29,6]. According to our finding, air temperature is also one of the factors affecting the light saturation point of sago palm seedlings, especially in the lower air temperature range tested. The optimum irradiances ($PPFD_{opt}$) of sago palm seedlings was rather low at 25–29^{0}C followed by early reduction in electron transport rate as photo inhibition might have occurred due to excess light energy. This can be seen from the down-ward trend which occurred when the light intensity increased above 600 µmol (Figure 3*B*). The sago palm seedlings grown at 29–33^{0}C maintained higher performance in light energy utilization for electron transport than those at 25–29^{0}C (Figure 2*B*). The increase in leaf temperature as long as it does not exceed the upper thermal limit, may enhances photon flux density which consequently affects the adjustment of thermotolerance in PSII and results in optimum photosynthetic rate [30,31,27]. In our study, sago palm photosynthetic optimum irradiance was higher when the plants were growing at the higher air temperature. The reduction in electron transport rate due to photo inhibition occured when PPFD increased above 800 µmol (Fig. 3*B*). However, the higher maximum electron transport rate showed not significant higher between the treatment.

Although the sago seedlings grown at higher temperature performed higher optimum irradiance, the utilization of light energy for photosynthetic activity tends to be less efficient. High dissipation of light energy in non-photochemical quenching (NPQ) at 29–33^{0}C also supports this analysis. The process is a plant mechanism to protect the photosynthetic apparatus from photo damage due to excess light energy [32]. Non-photochemical quenching dissipates the excess of light energy as heat.

5. Conclusion

According to the above findings, we conclude that sago palm photosynthetic performance is affected by changes in ambient air temperature especially at the minimum air temperature tested. This refers to the lower P_N performance at air temperatures ranging from 25–29^{0}C as compared to those at 29–33^{0}C. Low P_N was brought about by low values in other supporting variables such as stomatal conductance, leaf transpiration rate, maximum rubisco rate in CO_2 reduction, and optimum irradiance. A low level of formation of photosynthetic pigment also becomes a limiting factor in photosynthetic rate at the lower temperatures tested. Consequently, the harvesting and utilization of light energy for photosynthetic activities was affected. From this it could be concluded that the optimum air temperature would be associated with higher sago palm yield. Further investigation of photosynthetic response to different air temperatures using fully grown sago palms is needed to ascertain whether they show the same photosynthetic performance as in the seedling stage. If such study is able to confirm the broader representativeness of the present study, the findings might be used to make important decisions regarding the location of sago palm cultivation areas in the future for optimal production.

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