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Effect of High Temperature and Light Intensity on Physiology and Morphology in Young *Dipterocarpus alatus* Roxb. Leaf

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ABSTRACT

Heat and high light intensity affected physiology and morphology of young *Dipterocarpus alatus* Roxb. leaf studied. *D. alatus* is a native forest tree and being extended to cultivation in the field as an economic crop. Nowadays, climate change due to increasing in temperature and light intensity can affect growth, morphological and photosynthetic traits in *D. alatus*. This research aimed to study the effects of high temperature and strong light intensity on physiology and morphology of the young *D. alatus*. The experiment was decided in CRD with 5 replications. The two-year-old *D. alatus* was treated with combination stress between temperature (at 35°C or 41°C) and light intensity (at 700 or 1800 µmol $m^{-2}s^{-1}$) for 7 days. Plant morphology, gas exchange, PSII efficiency and photosynthetic pigment contents were measured. Strong light intensity (1800 µmol $m^{-2}s^{-1}$) affected plant morphology by leaf burning and heat injury. However, high temperature (41°C) combined with strong irradiation enlarged leaf injury and also increased percentage of heat injury (3.01±0.81%; T41L1800) compared to control (0.07±0.00%; T35L700). In contrast, it reduced percentages of leaf angle (-8.77±2.82%) and leaf area (-1.04±0.38%). In addition, the combination stress influenced reduction of net photosynthetic rate and contents of Chl *a*+*b* and Chl *a* but unaffected Chl *b* and *Car* contents. Therefore, combined stress affected young *D. alatus* by damaging

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photosynthetic pigments such as Chl *a* and injured leaf tissue. This resulted in reduction in both of photosynthetic mechanism and *D. alatus* leaf growth. Thus, young *D. alatus* leaf (two-year-old) was susceptible to heat combined with excessive light.

Keywords: Climate change, *Dipterocarpus species*, gas exchange, photosynthetic pigment

INTRODUCTION

Dipterocarpus alatus is a large tree species found in native tropical forest. Presently, heat and excessive light are harmful to global climate, thus there is an extension of *D. alatus* planting in the field as an economic crop for increasing green areas and income of farmers. In 2013, there were only a few forest areas in Thailand (approximately 31.58%) ("Forest area of Thailand", 2016). This causes global warming by increasing in temperature and strong irradiation. The prediction is global temperature in 2081 - 2100 rises up in the range 2.6 - 4.8°C (Intergovernmental Panel on Climate Change [IPCC], 2014). The global warming to 1.5°C increases the risk for long-term to change ecosystem, it can be explained by increases sea-level (IPCC, 2018). High temperature causes thylakoid membrane to lose its function and inner membrane of chloroplast is compromised causing decreases in chlorophyll content (Xu et al., 1995). At the temperature above 35°C, PSII efficiency was found decreased (Sanchez-Reinoso et al., 2014). When the plants are exposed to non-optimum temperature, the overall photosynthesis including PSII efficiency shows reduction. In addition, in tree, high temperature affects its growth and production by reducing photosynthesis. The photosynthetic response and tree recovery capacity under heat stress were investigated by gas exchange, chlorophyll fluorescence and electron transport. These measurements found that photosynthesis showed complete recovery after being treated with high temperature for less than 6 hr (Song et al., 2014). Vannajan (1997) reported that in *D. alatus* after being exposed to different temperature (18, 24, 30 and 36°C) and different Photosynthetic Photon Flux Density (PPFD) (0, 500, 1,000, 1,500 and 2,000 μmol $m^{-2}s^{-1}$) showed the values of net CO_2 gas exchange decreased with increasing in PPFD. In addition, transpiration rate increased but maximum net photosynthetic rate decreased at low temperature. Light intensity also affects plant growth and development and partitioning which are directly related to plant photosynthesis and metabolism. Plants exposed to strong light results in leaf burn and plant growth inhibition. *Dipterocarpus alatus* seedlings after being treated with light intensity at 10, 30, 50 and 100% showed that growth rate of their seedlings exposed to light intensity at 30 and 100% was similar. The optimum light intensity of *D. alatus* seedlings after transplanting was 50%. This resulted in higher survival and growth rate than other light intensities. In dry season, *D. alatus* seedlings exposed to 30% of light intensity showed higher in growth rate and strength of seedling than at 50 and 100 % (Bupabanpot et al., 1991). In addition, the high temperature and high

light intensity also influences to other plant species. Donsansuk et al. (2017) reported that in rice cv. PT60 after short-term heat exposure (40°C, 30 min) showed a decline in PSII efficiency and chlorophyll contents. Jagadish et al. (2007) found that in rice after exposure to high temperature above 33.7°C for less than 1 hr resulted in produced sterile seeds. Therefore, this research aimed to study the effect of high temperature and strong irradiation on photosynthetic performance, photosynthetic pigments and morphology of young *D. alatus* for basic knowledge.

MATERIALS AND METHODS

Plant Materials and Experimental Conditions

Two-year-old of *D. alatus* seedling was provided by Khon Kaen Plant Cultivation Center. *Dipterocarpus alatus* seedlings were transplanted in the pots (12 × 9 inch) containing mixed soil (loam : planting soil; 2 : 1) and planted in open air greenhouse at Agronomy field, Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand. The environmental conditions in greenhouse during April-December 2017 were shown as following: relative humidity = 88 - 96% and air temperature = 23.4 - 29.8°C. Then, these seedlings were treated with combination stress between temperature (at 35°C or 41°C) and light intensity (at 700 or 1800 µmol $m^{-2}s^{-1}$) in controlled temperature chamber (VRV. Corp., Ltd, Thailand).

Temperature and Light Intensity Treatment

After transplanting, healthy seedlings were selected for exposure with temperature combined with light intensity. All combination treatments were carried out in controlled temperature chamber (VRV. Corp., Ltd, Thailand), Plant Physiology Laboratory, Department of Agronomy, Faculty of Agriculture, Khon Kaen University, Thailand. The combined treatments of temperature and light intensity are shown in Tables 1 to 4.

Determination of Plant Growth and Morphology

Plant growth and morphology such as leaf number, plant height, leaf angle, leaf area and percentage of heat injury were investigated before (0 Day after treatment; DAT) and after (7 DAT) treated with combined conditions. Leaf number was counted in a whole plant. Plant height was measured from above soil ground to leaf tip of *D. alatus* seedlings. Leaf angle was manually measured in the 1^{st} – 6^{th} leaves from shoot tip by using protractor 180 degree (size = 4 inch). Six mature leaves were collected at 0 and 7 DAT for determining leaf area and percentage of heat injury. Both of their methods were investigated by taking a photo and analyzing them using Photoshop programmer (Adobe Photoshop CS6).

Table 1

The combined treatment of temperature and light intensity in controlled temperature chamber (VRV. Corp., Ltd, Thailand) (T35L700) was set up at 35°C during 12.00 p.m. - 3.00 p.m. and at 700 µmol $m^{-2}s^{-1}$ during 7.00 a.m. - 6.00 p.m., respectively and relative humidity was in the ranged between 50 – 80% during 12.00 a.m. – 12.00 p.m.

Diurnal time (hr)	Temperature (°C)	Relative humidity (%)	Light intensity* (µmol $m^{-2}s^{-1}$)
12.00 am - 3.00 a.m.	28	65	0
3.00 a.m. - 7.00 a.m.	25	80	0
7.00 a.m. - 9.00 a.m.	27	70	700
9.00 a.m. - 10.00 a.m.	30	60	700
10.00 a.m. - 12.00 p.m.	33	55	700
12.00 p.m. - 3.00 p.m.	35	50	700
3.00 p.m. - 5.00 p.m.	33	55	700
5.00 p.m. - 6.00 p.m.	32	56	700
6.00 p.m. - 9.00 p.m.	30	60	0
9.00 p.m. - 12.00 a.m.	28	65	0

Note. The temperature and relative humidity were derived from the statistic data of weather in Agronomy field, Faculty of Agriculture, Khon Kaen University, during March - May 2016 and 2017

*The distance of light intensity was 5 cm. far from the light source incident upper leaf

Table 2

The combined treatment of temperature and light intensity in controlled temperature chamber (VRV. Corp., Ltd, Thailand) (T35L1800) was set up at 35°C during 12.00 p.m. - 3.00 p.m. and at 1800 µmol $m^{-2}s^{-1}$ during 10.00 a.m. – 3.00 p.m., respectively and relative humidity was in the ranged between 50 – 80% during 12.00 a.m. – 12.00 p.m.

Diurnal time (hr)	Temperature (°C)	Relative humidity (%)	Light intensity* (µmol $m^{-2}s^{-1}$)
12.00 a.m. - 3.00 a.m.	28	65	0
3.00 a.m. -7 .00 a.m.	25	80	0
7.00 a.m. - 9.00 a.m.	27	70	700
9.00 a.m. - 10.00 a.m.	30	60	700
10.00 a.m. - 12.00 p.m.	33	55	1800
12.00 p.m. - 3.00 p.m.	35	50	1800
3.00 p.m. - 5.00 p.m.	33	55	700
5.00 p.m. - 6.00 p.m.	32	56	700
6.00 p.m. - 9.00 p.m.	30	60	0
9.00 p.m. - 12.00 a.m.	28	65	0

Note. The temperature and relative humidity were derived from the statistic data of weather in Agronomy field, Faculty of Agriculture, Khon Kaen University, during March - May 2016 and 2017

*The distance of light intensity was 5 cm. far from the light source incident upper leaf

Table 3
The combined treatment of temperature and light intensity in controlled temperature chamber (VRV. Corp., Ltd, Thailand) (T41L700) was set up at 41°C during 12.00 p.m. - 3.00 p.m. and at 700 µmol $m^{-2}s^{-1}$ during 7.00 a.m. – 6.00 p.m., respectively and relative humidity was in the ranged between 40 – 80% during 12.00 a.m. – 12.00 p.m.

Diurnal time (hr)	Temperature (°C)	Relative humidity (%)	Light intensity* (µmol $m^{-2}s^{-1}$)
12.00 a.m. - 3.00 a.m.	28	65	0
3.00 a.m. - 7.00 a.m.	25	80	0
7.00 a.m. - 9.00 a.m.	30	65	700
9.00 a.m. - 10.00 a.m.	35	56	700
10.00 a.m. - 12.00 p.m.	38	45	700
12.00 p.m. - 3.00 p.m.	41	40	700
3.00 p.m. - 5.00 p.m.	38	45	700
5.00 p.m. - 6.00 p.m.	35	50	700
6.00 p.m. - 9.00 p.m.	32	55	0
9.00 p.m. - 12.00 a.m.	28	65	0

Note. The temperature and relative humidity were derived from the statistic data of weather in Agronomy field, Faculty of Agriculture, Khon Kaen University, during March - May 2016 and 2017
*The distance of light intensity was 5 cm. far from the light source incident upper leaf

Table 4
The combined treatment of temperature and light intensity in controlled temperature chamber (VRV. Corp., Ltd, Thailand) (T41L1800) was set up at 41°C during 12.00 p.m. - 3.00 p.m. and at 1800 µmol $m^{-2}s^{-1}$ during 10.00 a.m. – 3.00 p.m., respectively and relative humidity was in the ranged between 40 – 80% during 12.00 a.m. – 12.00 p.m.

Diurnal time (hr)	Temperature (°C)	Relative humidity (%)	Light intensity* (µmol $m^{-2}s^{-1}$)
12.00 a.m. - 3.00 a.m.	28	65	0
3.00 a.m. - 7.00 a.m.	25	80	0
7.00 a.m. - 9.00 a.m.	30	65	700
9.00 a.m. - 10.00 a.m.	35	56	700
10.00 a.m. - 12.00 p.m.	38	45	1,800
12.00 p.m. - 3.00 p.m.	41	40	1,800
3.00 p.m. - 5.00 p.m.	38	45	700
5.00 p.m. - 6.00 p.m.	35	50	700
6.00 p.m. - 9.00 p.m.	32	55	0
9.00 p.m. - 12.00 a.m.	28	65	0

Note. The temperature and relative humidity were derived from the statistic data of weather in Agronomy field, Faculty of Agriculture, Khon Kaen University, during March - May 2016 and 2017
*The distance of light intensity was 5 cm. far from the light source incident upper leaf

Determination of Leaf Gas Exchange and PSII Efficiency

After *D. alatus* seedlings treated with combined conditions for 7 days, these seedlings were determined with leaf gas exchange and PSII efficiency. Parameters of leaf gas exchange (net photosynthetic rate; *A*, stomatal conductance; g_s, transpiration rate; *E*, intercellular CO_2 concentration; C_i and vapor pressure deficit; *Vpd*) in *D. alatus* seedlings were measured by using Licor–6400XT Portable Photosynthesis System (LICOR Inc., Lincoln, Nebraska, USA). All leaf gas exchange parameters were investigated in young fully expanded leaf at a middle part of leaf. The conditions of leaf gas exchange measurement were set up as following: leaf temperature at 30°C, relative humidity at 70%, ambient atmospheric CO_2 concentration at 400 ppm and light intensity at 700 µmol $m^{-2}s^{-1}$. For investigation of A/C_i curve was set up CO_2 concentrations as 0, 50, 100, 200, 400, 500, 800 and 1,000 ppm under light intensity at 700 µmol $m^{-2}s^{-1}$.

Parameters of PSII efficiency measurement (minimal fluorescence in light adapted state; F_o', maximal fluorescence in light adapted state; F_m', Steady state fluorescence; F_s, effective quantum yield of PSII efficiency; $\Delta F/F_m'$, variable to maximum quantum yield of PSII; F_v'/F_m' and electron transport rate; ETR) were carried out by using Licor–6400XT. PSII efficiency parameters were calculated according to Schreiber (2004). Portable Photosynthesis System (LICOR Inc., Lincoln, Nebraska, USA). All their measurements were investigated concomitant with the same leaf gas exchange measurement.

Determination of Photosynthetic Pigment Contents

Photosynthetic pigment contents (total chlorophyll; Chl *a*+*b*, chlorophyll a; Chl *a*, chlorophyll b; Chl *b* and carotenoid; *Car*) were determined according to Arnon (1949). Leaf samples (0.1 g) were cut into small pieces and put in a glass test tube and soaked in 10 ml of 80% acetone for 72 hr in darkness. The solution was filtered with Whatman filter paper No.1 and then total extraction volume (V) was recorded. The absorbance was measured at OD440, OD645 and OD663 by using a UV-Vis spectrophotometer (Model i3, Jinan Hanon Instruments co., Ltd, China) and using 80% acetone as a blank. All photosynthetic pigment parameters were calculated using the equations below as described by Arnon (1949) and were expressed in mg/g fresh weight (mg/gFW). The carotenoid (*Car*) content was calculated using the following Bajracharya (1999):

$$\text{Chl } a+b = [20.2(OD645) + 8.02(OD663)] \times V/(1000 \times W)$$

$$\text{Chl } a = [12.7(OD663) - 2.69(OD645)] \times V/(1000 \times W)$$

$$\text{Chl } b = [22.9(OD645) - 4.68(OD663)] \times V/(1000 \times W)$$

$$Car = (4.69 \times OD440) - [0.268(20.2 \times OD645) + (8.02 \times OD663)] \times V/(1000 \times W)$$

Statistical Data Analysis

The experiment was designed in completely randomized design (CRD) with 5 replications. The significant difference data between different treatments were analyzed by one way analysis of variance (ANOVA) and Duncan's new multiple range test (DMRT) at $p \leq 0.05$ by using SPSS Window version 16.0.

RESULTS AND DISCUSSIONS

Effect of High Temperature Stress and Light Stress on Morphology of Young *Dipterocarpus alatus*

The effect of temperature and light intensity on morphology of young *D. alatus* treated with temperature at 35 or 41°C and light intensity at 700 or 1800 µmol $m^{-2}s^{-1}$ was shown in Figure 1 and Table 5. Leaf characteristic of young *D. alatus* after treatment with temperature and light intensity resulted in mild heat injury indicated by a small burn and necrosis at leaf tip in T35L1800 and severe heat injury indicated by a large burn and necrosis at middle and base of leaf in T41L1800 (Figure 1). However, in both of T35L700 and T41L700 leaf morphology was unaffected after treatment under these conditions. Therefore, these results suggested that high light intensity (1800 µmol $m^{-2}s^{-1}$) induced leaf injury indicated by burning and necrosis lesions. The combination stress between high temperature (41°C) and high light intensity (1800 µmol $m^{-2}s^{-1}$) induced enlarged leaf injury compared to temperature at 35°C and high light intensity at 1800 µmol $m^{-2}s^{-1}$. The number of leaves and height showed no significant difference in all treatments. However, leaf numbers and height were decreased with increasing temperature and light intensity as shown in Table 5. The highest leaf numbers and height were found in treatment T35L700 approximately 5.96±1.19 leaves and 2.21±1.35 cm, respectively. Light intensity is an important requirement factor for plant growth and development. In addition, different plant species require

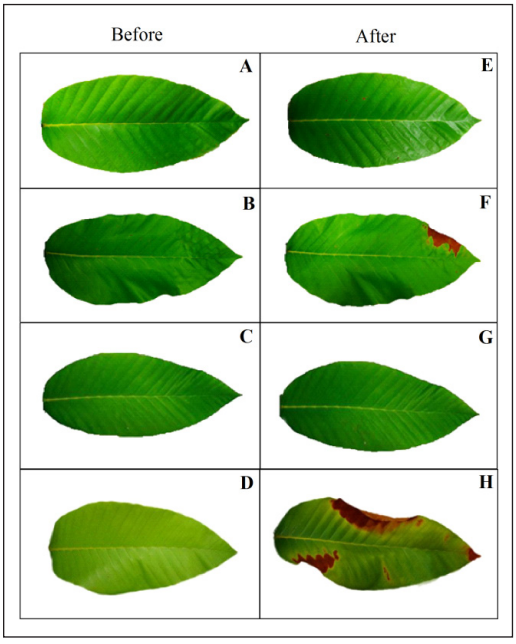

Figure 1. Dipterocarpus alatus leaves showed heat injury symptoms after treatment with different temperatures and different light intensity. A-D showed *D. alantus* leaf before being treated with combined stress and E-H showed *D. alantus* leaf after treated with combined stress at 7 days. A and E indicated *D. alantus* leaf treated with temperature at 35°C and light intensity at 700 µmol $m^{-2}s^{-1}$. B and F indicated *D. alantus* leaf treated with temperature at 35°C and light intensity at 1800 µmol $m^{-2}s^{-1}$. C and G indicated *D. alantus* leaf treated with temperature at 41°C and light intensity at 700 µmol $m^{-2}s^{-1}$. D and H indicated *D. alantus* leaf treated with temperature at 41°C and light intensity at 1800 µmol $m^{-2}s^{-1}$

Table 5
Reduction percentage of number of leaves, height, leaf angle, leaf area and % heat injury after treated with combined stress. The values were means ± SE; n = 3 - 4

Treatment			% Reduction				
Treatment	Temperature (°C)	Light intensity (µmol $m^{-2}s^{-1}$)	Number of leaves	Height (cm)	Leaf area (cm^2)	Leaf angle	% Heat injury
T35L700	35	700	+5.96±1.19	+2.21±1.35	+1.33±0.07^a	+3.83±0.49^a	+0.07±0.00^a
T35L1800	35	1800	+4.44±4.44	+1.44±0.53	-0.84±0.34^b	+1.21±1. 59^a	+0.46±0.18^a
T41L700	41	700	+2.22±2.22	+0.62±0.36	+0.78±0.35^a	+1.43±0.79^a	+0.21±0.04^a
T41L1800	41	1800	+1.08±1.08	+0.80±0.40	-1.04±0.38^b	-8.77±2.82^b	+3.01±0.81^b
	Mean		3.43	1.27	0.06	-0.57	0.94
	F-test		ns	ns	**	**	**

Note. ns indicated no significance and the different small letters in the same column indicated significant difference between treatments by Duncan multiple range test (DMRT) at $p \leq 0.05$

various light intensity because light intensity can directly affect physiological and morphological plant adaptation (Böhnke & Bruelheide, 2013). Percentages of reduction in leaf area, leaf angle and heat injury were found significantly different in all treatments. The values of leaf area and leaf angle were decreased with increasing in temperature and light intensity (at 41°C and 1800 µmol $m^{-2}s^{-1}$; T41L1800) which were found approximately -8.77±2.82% and -1.04±0.38%, respectively. However, percentage of heat injury was found increased with increasing in temperature and light intensity (Table 5). The highest percentage of heat injury was found at the highest temperature at 41°C and the highest light intensity at 1800 µmol $m^{-2}s^{-1}$ (Table 5). This suggested that high temperature and high light intensity degraded and damaged chlorophyll molecules resulted in cell damage. These caused leaf necrosis symptoms that we called heat injury as shown in Figure 1H.

Effect of High Temperature Stress and Light Stress on Gas Exchange of Young *Dipterocarpus alatus*

The performance of photosynthesis in gas exchange of young *D. alatus* is shown in Figure 2. Net photosynthetic rate (*A*) in young *D. alatus* leaf treated with temperature at 35°C and light intensity at 1800 µmol $m^{-2}s^{-1}$ (T35L1800) and temperature at 41°C and light intensity at 1800 µmol $m^{-2}s^{-1}$(T41L1800) exhibited significantly lower than those treated with temperature at 35°C and light intensity at 700 µmol $m^{-2}s^{-1}$ (T35L700) and temperature at 41°C and light intensity at 700 µmol $m^{-2}s^{-1}$ (T41L700), respectively (Figure 2A). The lowest value of *A* was found in T41L1800 (approximately 3.99±0.62 µmol CO_2 $m^{-2}s^{-1}$). This suggested that strong irradiation was more influenced in *A* than high temperature. This result is according to some studies showing strong irradiation reduced gas exchange parameters. Ping et al. (2015) reported that apple leaf (*Malus domestica*

Borkh.) exhibited a marked decline in net photosynthetic rate (*A*) and Rubisco activity under strong irradiation at 100%. However, this study showed that the combination stress between high temperature and strong irradiation stimulated a marked decrease in *A* indicated by the lowest value of *A* in T41L1800. For stomatal conductance value (g_s), the combination stress between high temperature at 41°C and strong irradiation at 1800 µmol $m^{-2}s^{-1}$ (T41L1800) induced a significant decrease in g_s (0.04±0.01 mol H_2O $m^{-2}s^{-1}$) compared to other treatment such as T35L1800 (0.10±0.02 mol H_2O $m^{-2}s^{-1}$) and T41L700 (0.10±0.01 mol H_2O $m^{-2}s^{-1}$) (Figure 2B). This result suggested that strong combination stress between high temperature and strong irradiation influenced stomata closure in young *D. alatus*. Other parameters such as transpiration rate (*E*), intercellular CO_2 concentration (C_i) and vapor pressure deficit (*Vpd*) found no significant difference between treatments as shown in Figures 2C, 2D and 2E, respectively. For trend of

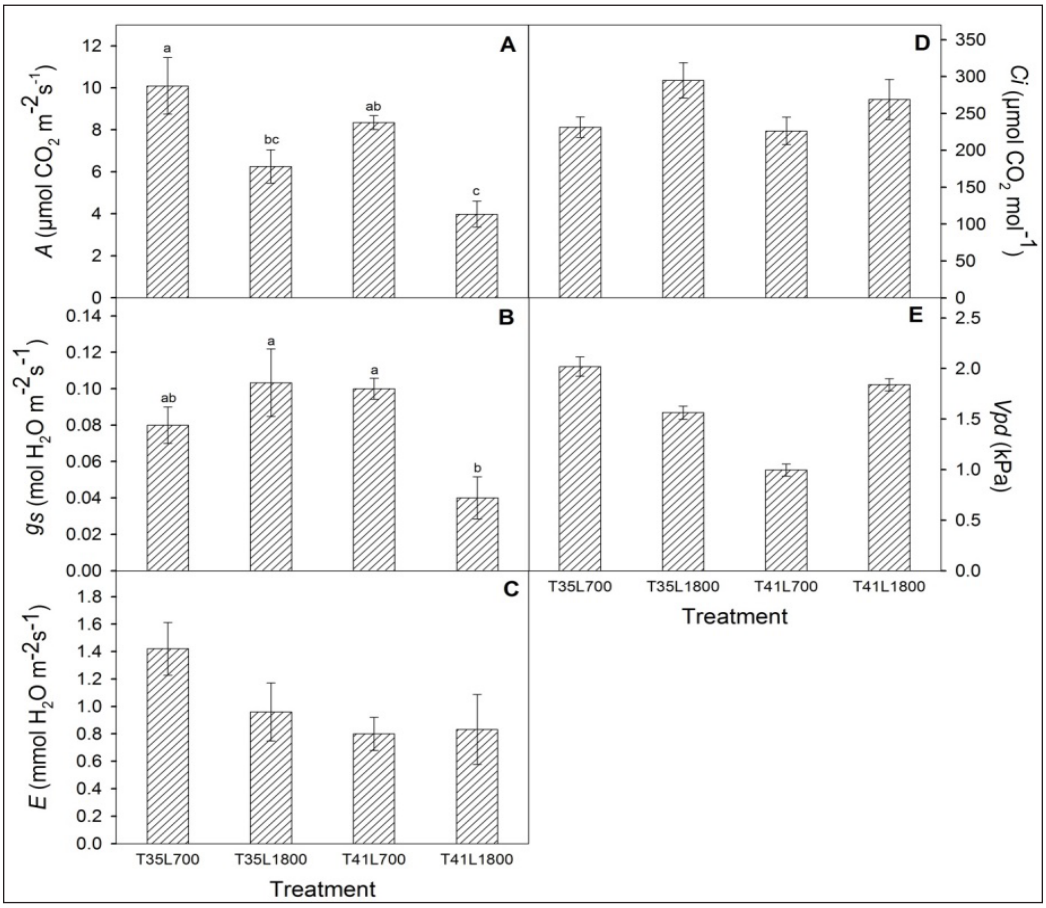

Figure 2. Effect of temperature (35°C; T35 or 41°C; T41) and irradiation (700 µmol $m^{-2}s^{-1}$; L700 or 1800 µmol $m^{-2}s^{-1}$; L1800) on net photosynthetic rate; *A* (A), stomatal conductance; g_s (B), transpiration rate; *E* (C), intercellular CO_2 concentration; C_i (D) and vapor pressure deficit; *Vpd* (E) in young *Dipterocarpus alatus* leaf after 7 days. The values were mean ± SE; n = 3 - 4

E value showed decreased with increased in temperature and irradiation (Figure 2C). The intercellular CO_2 concentration was higher in strong irradiation combined with normal- and high temperature (Figure 2D). For *Vpd* values exhibited fluctuations in between treatments (Figure 2E). This suggested that *Vpd* values depended on air humidity during measurement not influenced from temperature and irradiation treatment. From photosynthetic results, we indicated that high temperature and strong irradiation affected markedly lower rate of photosynthesis and transpiration in young *D. alatus* by stomatal closure, even though there was a high intercellular CO_2 concentration.

Effect of High Temperature Stress and Light Stress on PSII Efficiency of Young *Dipterocarpus alatus*

Photosynthetic efficiency of PSII parameters in young *D. alatus* is shown in Figure 3. The trend of effective quantum yield of PSII efficiency, $\Delta F/F_m'$ and variable to maximum quantum yield of PSII, F_v'/F_m'

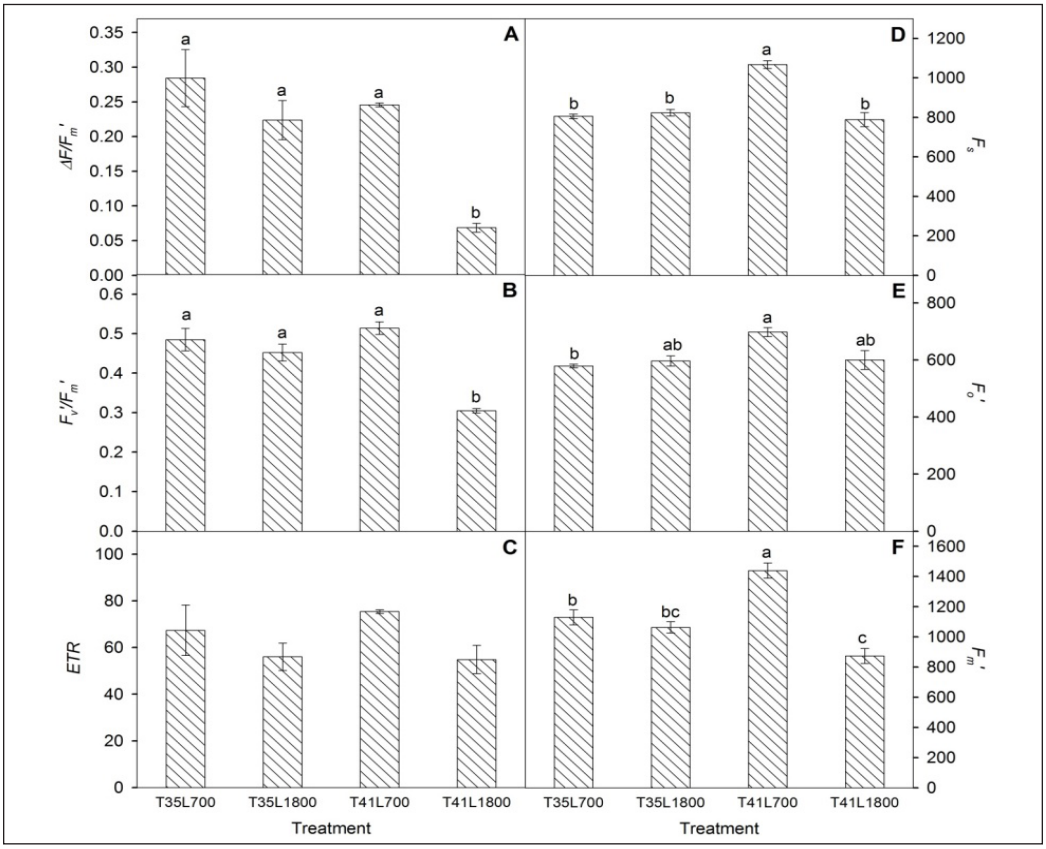

Figure 3. Effect of temperature (35°C; T35 or 41°C; T41) and irradiation (700 µmol $m^{-2}s^{-1}$; L700 or 1800 µmol $m^{-2}s^{-1}$; L1800) on effective quantum yield of PSII efficiency; $\Delta F/F_m'$ (A), effective maximum quantum yield of PSII; F_v'/F_m' (B), electron transport rate; *ETR* (C), steady state fluorescence; F_s (D), minimal fluorescence in light adapted state; F_o' (E) and maximal fluorescence in light adapted state; F_m' (F), in young *Dipterocarpus alatus* leaf. The values were mean ± SE; n = 3 - 4

was significantly declined with increased temperature at 41°C and strong irradiation at 1800 µmol $m^{-2}s^{-1}$ (T41L1800) as shown in Figures 3A and B. The slightly reduction of electron transport rate value was found in young *D. alatus* treated with strong irradiation at 1800 µmol $m^{-2}s^{-1}$ combined with temperature at 35 or 41°C (Figure 3C). In addition, the lowest of maximal fluorescence in light adapted state, F_m' was found in young *D. alatus* treated with high temperature at 41°C and strong irradiation at 1800 µmol $m^{-2}s^{-1}$ (T41L1800) as shown in Figure 3F. The higher of all PSII efficiency parameters ($\Delta F/F_m'$, F_v'/F_m', ETR, F_s, F_o' and F_m') was found in T41L700 compared to other treatments. These results suggested that high temperature combined with strong irradiation affected photosynthetic light reaction by reduced mechanism of PSII efficiency and electron transport. However, high temperature combined with normal irradiation did not affect photosynthetic efficiency of PSII. As a result, combined stress between high temperature and strong irradiation influenced reduced photosynthetic mechanism at PSII more than individual stress.

Effect of High Temperature Stress and Light Stress on Photosynthetic Pigment of Young *Dipterocarpus alatus*

The effect of temperature and light intensity on photosynthetic pigment contents in young *D. alatus* is shown in Table 6. Photosynthetic pigment contents were investigated in terms of total chlorophyll (Chl *a*+*b*), chlorophyll a (Chl *a*), chlorophyll b (Chl *b*) and carotenoid (*Car*) after 7 days treated with temperature at 35 or 41°C and irradiation at 700 or 1800 µmol $m^{-2}s^{-1}$. The contents of Chl *a*+*b* and Chl *a* were found markedly reduced with increased temperature combined with strong irradiation (T41L1800) compared to other treatments (Table 6). For Chl *b* and *Car* treated with high temperature and strong irradiation (T41L1800) exhibited no significant difference compared to other treatments by slightly reduction. These results suggested that the combination stress between high temperature and strong irradiation affected photosynthetic pigments by reducing total chlorophyll and Chl *a* contents in contrast to Chl *b* and *Car* contents which were unaffected from combination stress. Because *Car* worked as an antioxidant for plant protecting it from environmental stress especially high sunlight. Group of *Car* protected plants from high sunlight such as zeaxanthin (Dongsansuk et al., 2013). High temperature affects chloroplast function and decrease in chlorophyll contents (Paethaisong et al., 2019; Pansarakham et al., 2018; Purnama et al., 2018; Xu et al., 1995). These resulted in changing in physiological process (Björkman et al., 1980; Paethaisong et al., 2019) and reduction in plant photosynthetic rate (Berry & Raison, 1981; Dongsansuk et al., 2017) while our results showed combination stress affected photosynthetic function such as photosynthetic rate and PSII efficiency. Phonguodume et al. (2012) showed 5 tropical trees such as *Anisoptera costata*, *Afzelia xylocarpa*, *Dipterocarpus alatus*, *Dalbergia Cochinchinensis* and

Table 6
Effect of high temperature and strong irradiation on photosynthetic pigment changing in young Dipterocarpus alatus *leaves. The values were mean ± SE, n = 3 – 4*

Treatment		Photosynthetic pigment contents (mg/g FW)			
Temperature (ºC)	Light intensity (µmol $m^{-2}s^{-1}$)	Chl *a*+*b*	Chl *a*	Chl *b*	*Car*
35	700	0.921±0.05	0.632±0.04	0.248±0.01	0.259±0.01
35	1800	0.798±0.12	0.573±0.09	0.212±0.03	0.224±0.00
41	700	0.709±0.06	0.499±0.05	0.199±0.01	0.229±0.01
41	1800	0.602±0.08	0.390±0.07	0.201±0.02	0.250±0.02
Mean		0.757	0.524	0.215	0.240
F-test		ns	ns	ns	ns

Note. ns indicated no significant difference at $p \leq 0.05$ and the different small letters in the same column indicated significant difference between treatments by Duncan multiple range test (DMRT) at $p \leq 0.05$

Hopea odorata when exposed to 30-50%, 50-70% and 100% of light intensity had their total chlorophyll contents changed significantly in different species.

CONCLUSION

The results concluded that morphology and physiology in young *Dipterocarpus alatus* leaf showed severe injury under high temperature at 41°C and strong light intensity at 1800 µmol $m^{-2}s^{-1}$. These were indicated by leaf burned and injured and also reduced significantly different physiological processes such as reduction in photosynthetic rate and photosynthetic pigment contents. Therefore, young *D. alatus* leaf (2-year-old) was sensitive to the combination stress between heat and excessive light.

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