

## 夜间低温对生长在两种光强下两个芒果品种的气体交换和叶绿素荧光的影响\*

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**摘要:** 研究了夜间低温对两个芒果 (*Mangifera indica*) 品种翡翠芒 (Khieo Sawoei) 和四季芒 (Choke Anand) 光合生理的影响。两个芒果品种的幼苗盆栽于全光和 50% 相对光强下一年。在第二年的冬季, 连续 7 天晚上将芒果幼苗移到 4 °C 的冷库中, 白天保持原条件。于低温处理前、处理期间和结束低温处理后 10 天中测定芒果幼苗的光合生理特征。结果表明, 夜间低温导致两个芒果品种的净光合速率、气孔导度和光系统 II 的最大光化学效率 ( $F_v/F_m$ ) 降低、非光化学猝灭 (NPQ) 上升。夜间低温对生长在全光下的芒果幼苗光合作用的抑制比 50% 光下的更重。翡翠芒的  $F_v/F_m$  比四季芒下降的更多, 但后者的 NPQ 上升更多。夜间低温还导致两种光下芒果幼苗叶片的叶绿素含量下降, 类胡萝卜素/叶绿素比值、丙二醛含量、膜的透性和可溶性化合物 (可溶性总糖和脯氨酸) 上升。解除低温胁迫后, 四季芒  $F_v/F_m$  的恢复比翡翠芒的快。解除低温胁迫 7 天后二者的  $F_v/F_m$  能完全恢复。上述结果表明, 翡翠芒对低温更敏感, 遮荫可以明显缓解两个芒果品种低温引起的光抑制。

**关键词:** 叶绿素荧光; 气体交换; 芒果; 膜脂过氧化; 夜间低温; 渗透调节

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## The Effect of Night Chilling on Gas Exchange and Chlorophyll Fluorescence of Two Mango Cultivars Growing under Two Irradiances

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**Abstract:** We investigated the effect of night chilling on the photosynthetic physiology of two cultivars of mango (*Mangifera indica*) 'Choke Anand' and 'Khieo Sawoei'. The potted mango seedlings of both cultivars were grown under the full light and 50% daylight for one year. In the following winter season (February 2006), the seedlings were moved to a cold storage room maintaining 4 °C for seven consecutive nights and returned to their original places during the rest of the day. Photosynthetic physiology was measured before, during the treatment, and during 10 days after the treatment. Chill-night treatment resulted in strong suppression in net photosynthesis ( $P_n$ ), stomatal conductance ( $g_s$ ), and maximum photochemical efficiency of PSII ( $F_v/F_m$ ), and increased non-photochemical quenching (NPQ) for both cultivars. Overall, the chilling-induced photosynthetic suppression was stronger in seedlings grown in full sunlight than in 50% daylight. The decrease in  $F_v/F_m$  was stronger in 'Khieo Sawoei' than in 'Choke Anand' cultivar, and the increase of NPQ was relatively higher in 'Choke Anand' compared to 'Khieo Sawoei' cultivar. Night chilling resulted in a decrease in chlorophyll content and in-

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crease in the carotenoid: chlorophyll ratios, the malondialdehyde (MDA) contents, membrane leakage, as well as compatible solutes (total soluble sugar and proline) under both irradiances. After termination of the chilling treatment, the recovery of  $F_v/F_m$  was relatively quicker in 'Choke Anand' than in 'Khieo Sawoei' cultivar. Both cultivars showed a complete recovery after seven days of termination of the chilling treatment. These results showed that 'Khieo Sawoei' was more sensitive to chilling than 'Choke Anand', and shading significantly alleviated the chilling-induced photoinhibition.

**Key words:** Chlorophyll fluorescence; Gas exchange; Mango; Membrane lipid peroxidation; Night chilling; Osmotic adjustment

Low temperature is a major factor limiting the productivity and geographical distribution of many plant species. Chilling, non-freezing, temperatures can cause injury for many tropical and subtropical plants, including important fruit trees such as mango (Graham and Patterson, 1982). Mango occupies third place in total World production of major tropical fruit crops after citrus, and banana (Alonso and Blaikie, 2003). China is the second-largest producer of mango in the World (FAO, 2002). One of the major areas of growing tropical crops including mango is the southern Yunnan Province, which is located at the northern border of the tropics. In the wet tropics, plants including mango grow all year round, when introduced to the marginal areas they are vulnerable to chilling temperatures (Greer, 1990; Ortiz-Lopez *et al.*, 1990; Cao *et al.*, 2006).

Strong cold winds coming from northern China occasionally hit the southern Yunnan, with the extreme temperature down to 2 °C in the lowland and along with the clear-sky condition. Even in a normal winter, the temperature in the lowland can go down to about 6 °C. In the study area Xishuangbanna, extreme chilling temperatures can cause severe injury and even death of tropical crops such as mango, coffee, and rubber tree (Hong and Li, 2001). Exposure to chilling temperatures results in suppression in the activities of photosynthetic enzymes, increase in stomatal limitation, and therefore reduction in photosynthesis of tropical plants (Nir *et al.*, 1997; Flexas *et al.*, 1999; Allen *et al.*, 2000; Guo and Cao, 2004). Further effects of chilling temperatures include a decrease of root functioning and water transport of xylem because of low soil temperatures, which in turn induce further reduction in stomatal conductance and thus leaf transpiration (Hallgren and Oquist, 1990).

Under the clear-sky conditions, suppression of

photosynthesis leads to excess light energy in the chloroplasts and consequently photoinhibition and photooxidation (Demmig-Adams and Adams, 1992; Chow, 1994). Chronic photoinhibition in mango as indicated by sustained reduction of maximum quantum efficiency of PSII photochemistry ( $F_v/F_m$ ) was reported during the Israeli winter, which was correlated with the previous minimum night air temperature (Nir *et al.*, 1997; Allen *et al.*, 2000). Under this photoinhibitory conditions, protective thermal dissipation occurs, mainly by the formation of a trans-thylakoid of pH gradient (Krause and Behrend, 1986) and through the xanthophyll cycle (Demmig-Adams, 1990). These processes enable the plants to balance the light energy received by the photosynthetic reaction centers (Chow, 1994). However, under these conditions plants also produce reactive oxygen species, which cause enhancement of the peroxidation of membrane lipids and even destruction of the photosynthetic apparatus (Parkin *et al.*, 1989; Foyer *et al.*, 1994).

The accumulation of osmolyte compounds (e.g., total soluble sugar and proline) in the cells is likely a response to water deficit induced by chilling stress (Gzik, 1996; Bajji *et al.*, 2001). Osmotic adjustment causes decrease in osmotic potential of the plant tissue hence allows the leaves to withstand a low water potential without loss of turgor (Holbrook and Putz, 1996). The combined effects of low temperature and high irradiance are more harmful than the individual effect of each stress on the plant (Long *et al.*, 1994).

The main objective of this study was to compare the effect of chilling night temperature on the photosynthesis of the most two common mango cultivars in the study region, i.e., 'Choke Anand' and 'Khieo Sawoei', and to identify which cultivar is more tolerant to the potential extreme chilling temperature of the region.

In addition, the present study tested whether partial shading could alleviate the adverse effect of chill-night on photosynthesis in mango seedlings.

## Materials and Methods

### Study site and treatments

This study was conducted at the Xishuangbanna Tropical Botanical Garden (21°56' N, 101°15' E; 600 m altitude), situated in the southern part of Yunnan Province, southwestern China, the northern border of the tropics. Here the mean annual temperature is 21.7 °C; the mean monthly temperature is 25.3 °C in the hottest month (July) and 15.6 °C in the coolest month (January; Liu and Li, 1996). The mean annual precipitation is about 1560 mm, 80% of which falls from May to October.

In November 2004, about one meter high of seedlings (two years old) of two cultivars of mango (*Mangifera indica* L.) 'Choke Anand' and 'Khieo Sawoei' were obtained from a local commercial nursery. The seedlings were transplanted into 15 L pots, one seedling per pot. They were grown under two irradiance levels: the full light and 50% daylight that were obtained by using black neutral density shade nets suspended above the plant. They were regularly pruned to maintain about 1 m tall plants with single apical shoot, and were irrigated and fertilized according to standard commercial practices. The mean daily maximum, minimum, and average temperatures during the three weeks prior the measurements were 27.2 °C, 13.5 °C, and 17.13 °C. The air temperatures (maximum, average, and minimum) during the experiment were recorded by a weather station that was situated 30 m away from the experimental plot, while photosynthetically active radiation (PAR) on leaves was measured with the thermocouple attached to the leaf clip during the chlorophyll fluorescence measurement (Fig. 1).

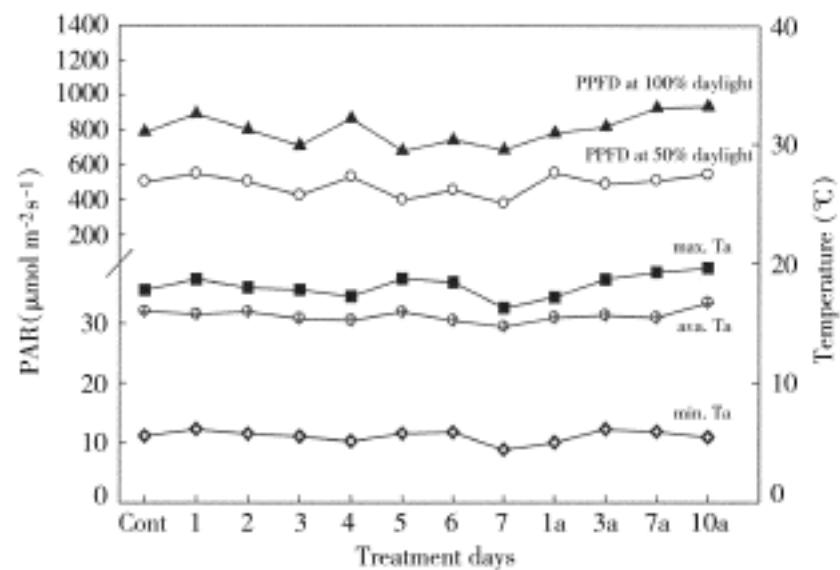


Fig. 1 Maximum (max. Ta), minimum (min. Ta) and average air temperatures (ava. Ta) and photosynthetically active radiation (PAR) at plant leaf level in both light levels (50% and 100% sunlight) during the experiment period

In the beginning of February 2006, four to five potted seedlings of each irradiance regime per cultivar were moved into a dark cold storage room at 4 °C from 17.30 h to 05.30 h (solar time) next morning for 7 constitutive nights. They were returned to the original site for the rest of the day.

### Gas exchange and chlorophyll fluorescence measurements

Using a photosynthetic system (LI 6400 LI-COR, Inc., Lincoln, NE, USA), gas exchange of these chilling-treated seedlings were measured from their recent mature leaves of 4-5 replicate plants during the period from 09.00 h to 12.00 h in the morning, under photosynthetic flux density (PPFD) of 1000  $\mu\text{mol m}^{-2} \text{s}^{-1}$  that was provided by an integrated LED light source (LI-6400; -02B LI-COR, Inc., Lincoln, NE, USA). The air humidity in the leaf chamber was about 60%, with  $\text{CO}_2$  concentration of 350-360  $\mu\text{mol mol}^{-1}$ , with ambient air temperature of 21-24 °C, and flow rate of the air was 500  $\mu\text{mol s}^{-1}$ . The measurements were done on the day before chilling, on each of 7 d during the chill-night treatment, and subsequent four days (1, 3, 7, and 10 day) after termination of the chilling treatment.

At predawn and midday of these days, chlorophyll fluorescence was measured to quantify chilling injury to photosystem II (PSII), using a fluorometer (FMS2; Hansatech, Norfolk, UK). Initial ( $F_0$ ) and maximal fluorescence ( $F_m$ ) were measured in the leaves that have been dark-adapted for at least 20 min.  $F_m$  was estimated by illuminating the dark-adapted leaves with a pulse of PPFD 5000  $\text{mol m}^{-2} \text{s}^{-1}$  for 0.7 s. The maximum quantum yield of PSII was estimated by the ratio  $F_v/F_m = (F_m - F_0) / F_m$  according to Genty *et al.* (1989). Steady-state chlorophyll fluorescence ( $F_s$ ) and maximal fluorescence in the light-adapted state ( $F_m'$ ) were determined at incident sunlight, which was measured with a quantum sensor attached to the leaf clip. Actual PSII quantum yield was calculated (Genty *et al.*, 1989) as  $\text{PSII} = (F_m' - F_s) / F_m'$ .

Non-photochemical quenching, representing the absorbed light energy dissipated as heat was calculated as (Bilger and Björkman, 1990):  $\text{NPQ} = (F_m^o - F_m) / F_m$ . Predawn maximal fluorescence ( $F_m^o$ ) was used to calculate NPQ. On the day before, the seventh day with and the seventh day after the chill-night treatment, the midday allocations of photons absorbed by PSII reaction centers to photosynthetic electron transport and to thermal dissipation were assessed according to Hendrickson *et al.* (2004). The fraction of photons allocated to PSII photochemistry ( $\text{PSII}$ ) was the same as  $\text{PSII}$  indicated above. The sum of the fractions of the light that was lost by either constitutive thermal dissipation ( $\text{D}$ ) or via fluorescence ( $\text{F}$ ) was derived as  $\text{f}_{\text{D,F}} = F_s/F_m$ , and the fraction of light that was dissipated via pH and

xanthophyll-regulated process was  $NPQ = F_s/F_m - F_s/F_m$ .

#### Determination of chlorophyll, MDA content and membrane leakage

On the day before, the seventh day of night chilling and the seventh day after chilling-treatment, leaves similar to those used for physiological measurements were sampled to determine their chlorophyll and carotenoid contents following Lichtenthaler and Wellbum (1983), and malondialdehyde (MDA) content according to Hodges *et al.* (1999), using a spectrophotometer (UV-B2501; Shimadzu; Kyoto, Japan). MDA is a product of peroxidation of membrane lipids.

Some leaves were used to measure membrane leakage. Leaf discs were rinsed three times in ion-free water, dried on degreased-gauze, and ten discs were transferred into each test tube. Ion-free water (20 ml) was added into each of the test tubes and the test tubes were vacuum-infiltrated and shaken for 1 h in a shaker (WD. 940.5B. Beijing 61, Beijing, China) at the room temperature. The conductance (R1) of the liquid in each test tube was measured with an electrode conductivity meter (DOS-307, Leici, Shanghai, China). Afterwards, the tubes were capped, boiled for 30 min, and then cooled to room temperature and shaken for 1 h at the room temperature. The conductance (R2) of the liquid in each test tube was measured once again. The ratio of the two readings (R1/R2) was used as a measure of the relative injury.

#### Determination of contents of proline and total soluble sugars

Using the leaf samples collected on the three days indicated above, extraction and estimation of free proline were conducted according to the procedures described by Bates *et al.* (1973). The dry leaf sample of 500 mg for each cultivar was homogenized in 10 cm<sup>3</sup> of 3% (m/v) aqueous sulphosalicylic acid and the homogenate was filtered through Whatman No. 2 filter paper. In a test tube, 2 cm<sup>3</sup> of the filtrate was mixed with 2 cm<sup>3</sup> acid ninhydrin and 2 cm<sup>3</sup> glacial acetic acid and incubated in 100 °C water bath for 1 h. The reaction was terminated by placing the tube in ice bath and then extracted with 4 cm<sup>3</sup> toluene. The chromophore phase was aspirated from the aqueous phase. The absorbance was read at 520 nm using the same spectrophotometer. According to Dubois *et al.* (1956), the content of total soluble sugar was estimated using the phenol sulphuric acid.

#### Statistical analysis

The difference in the means of chlorophyll and MDA content, membrane leakage, and contents of proline and total soluble sugars among different days for the same cultivar under the same irradiance were analyzed with one-way ANOVA. Differences were considered significant at a probability level of  $P < 0.05$ . Two-way ANOVA was used to evaluate effects of cultivar, irradiance and their interaction on the physiological traits.

## Results

### Gas exchange and chlorophyll fluorescence

The exposure to 4 °C for seven consecutive chilling nights led to a progressive decline in net photosynthesis ( $P_n$ ) and stomatal conductance ( $g_s$ ) in both mango cultivars (Fig. 2) under both irradiances, with the sharp decreases following the first chilling night. These decreases were more pronounced in the seedlings under full light than those under 50% sunlight. In both cultivars,  $P_n$  increased linearly from the first day to the seventh day after the chilling treatment, with almost complete recovery on the seventh day.

Maximum photochemical efficiency ( $F_v/F_m$ ) at predawn and midday, and actual photochemical efficiency of PSII ( $\Psi_{II}$ ) followed the similar changing trend of  $P_n$  in both mango cultivars (Fig. 3). During the chill-night treatment, both predawn and midday value of  $F_v/F_m$  and  $\Psi_{II}$  kept declining with increasing in the number of chilling nights but this decline was stronger and attained lower value for 'Khieo Sawoei' cultivar than 'Choke Anand' cultivar under the same irradiances (Fig. 3). The recovery of  $F_v/F_m$  values at predawn and midday in both cultivars were almost completed after seven days since termination of the chilling treatment.

NPQ rates increased with the number of chilling nights for both cultivars but this increase was stronger and attained greater value for 'Choke Anand' compared to 'Khieo Sawoei' cultivar for both irradiances. The NPQ rates decreased following the termination of the chilling treatment (Fig. 3).

On the day before treatment, after 7 day of chilling treatment and after 7 day of recovery, the fate of absorbed light energy in the leaves of both mango cultivars was evaluated (Fig. 4). The results showed that  $NPQ$  was significantly higher while  $\Psi_{II}$  was significantly lower after 7 nights of chilling treatment under both light regimes. Meanwhile the decrease of  $f_{i,D}$  was not pronounced under both light regimes. After 7 nights of chilling treatment, about 75% and 55% of the absorbed light were dissipated thermally for the seedlings under full light and 50% daylight, respectively (Fig. 4).

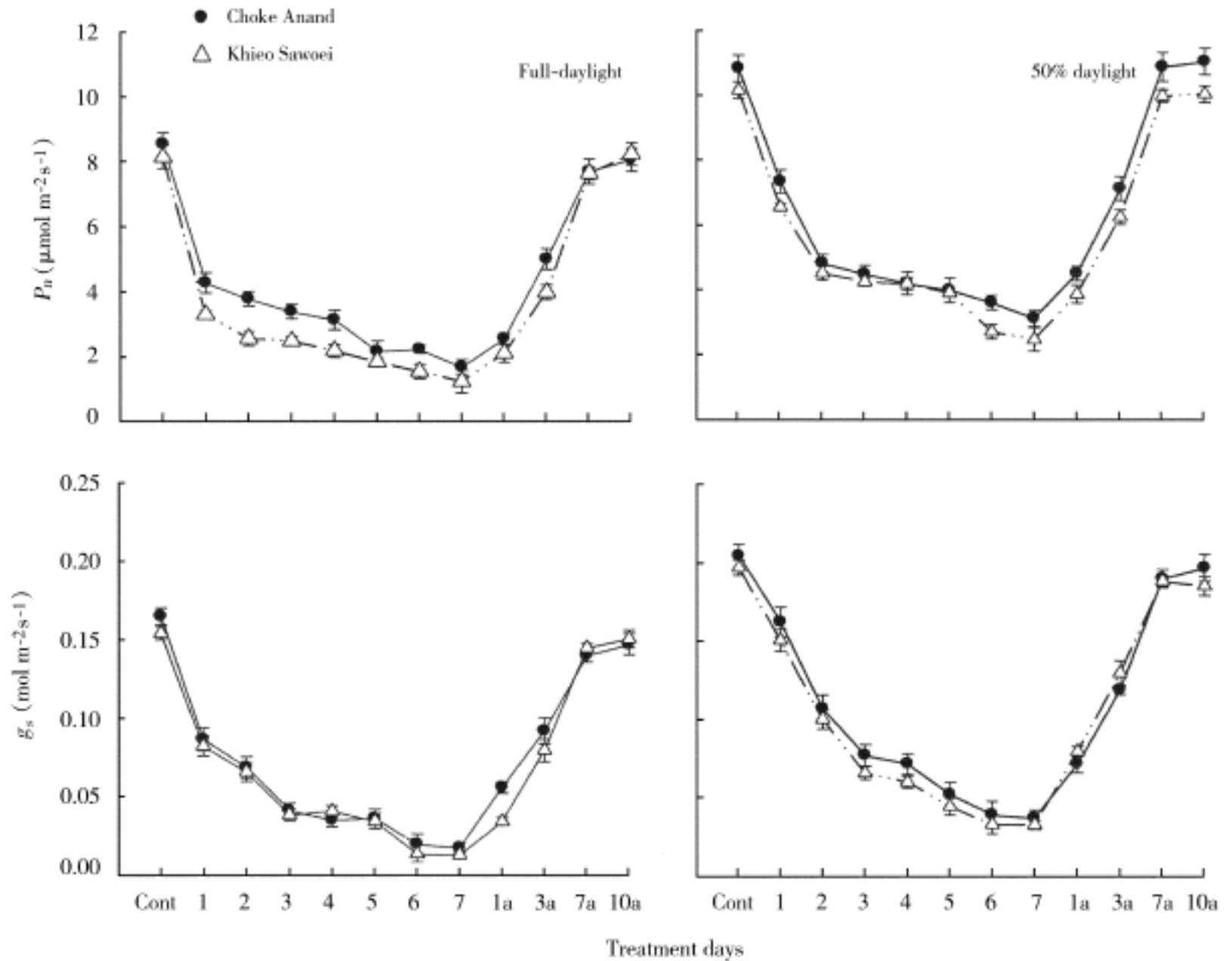


Fig. 2 Net photosynthetic rates ( $P_n$ ) and stomatal conductance ( $g_s$ ) in two mango cultivars grown under two irradiances, measured in the morning on the day before treatment (cont), seven days with the chill-night treatment (1-7), and 10 days after termination the treatment (1a-10a). Symbols and bars denote means  $\pm$  SE ( $n = 5$ )

### Contents of photosynthetic pigments and MDA

The chlorophyll (Chl) content was lower, while carotenoid/chlorophyll ratio (Car/Chl) tended to be higher with increase in the growth irradiance in both cultivars after the chill-night treatment. The 'Choke Anand' cultivar had higher Chl contents and lower MDA contents and membrane leakage (EC%) values than 'Khieo Sawoei' cultivar after the chill-night treatment. The decrease in Chl content and increase in Car/Chl, EC% and MDA were greater in seedlings under the full irradiance than 50% daylight for both cultivars. During the chilling treatment, some chlorosis of leaf blades was observed in sun-exposed seedlings in both cultivars, while no chlorosis found on the leaves of the seedlings under 50% daylight.

### Contents of proline and total soluble sugars

The chilling treatment resulted in an increase in

the contents of proline and total soluble sugars under both irradiance regimes (Table 1), with greater increase for seedlings in full irradiance than in 50% daylight. The 'Choke Anand' cultivar had higher contents of soluble sugar and proline compared to 'Khieo Sawoei' cultivar after the chilling treatment.

The two-way ANOVA results reveal significant differences between the two cultivars in PSII, dawn  $F_v/F_m$ , NPQ, and contents of MDA, Proline and TSS but no significant difference between cultivars in  $P_n$ ,  $g_s$ , midday  $F_v/F_m$ , Chl a + b, Car/Chl and EC% (Table 2). Moreover, all the physiological parameters were significant different between the light levels. The effects of light level on physiological parameters were more pronounced than the cultivar. The effect of interaction between light and cultivar was only significant on  $P_n$  and  $g_s$ .

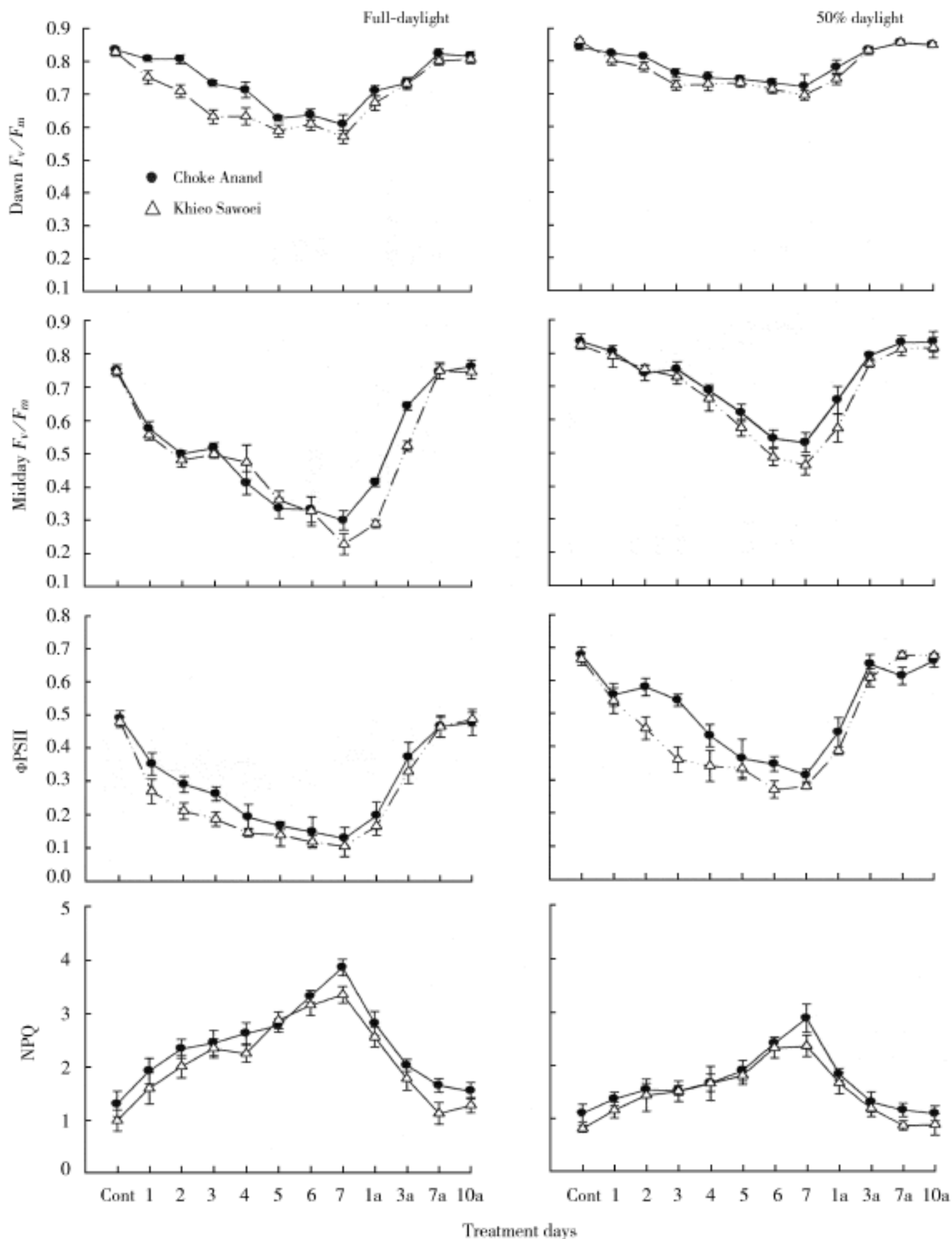


Fig. 3 Maximum photochemical efficiency ( $F_v/F_m$ ) of photosystem II at predawn and midday, and midday actual quantum yield of photosystem II (PSII) and non-photochemical quenching (NPQ) in two mango cultivars grown under two irradiances, on the day before treatment (cont), seventh days with (1-7), and 10 days after termination the chilling treatment (1a-10a). Symbols and bars denote means  $\pm$  SE ( $n = 5$ )

## Discussion

The present study showed that the chill-night treatment induced strong depression of  $P_n$  during the subsequent days for both studied cultivars (Fig. 2). This is consistent with the previous studies on the tropi-

cal plants (Nir *et al.*, 1997; Allen *et al.*, 2000; Guo and Cao, 2004; Feng and Cao, 2005). However, the effects of chilling treatment on the present mango seedlings were less pronounced compared to the coffee species (Guo and Cao, 2004) and the tropical trees *Calophyllum*

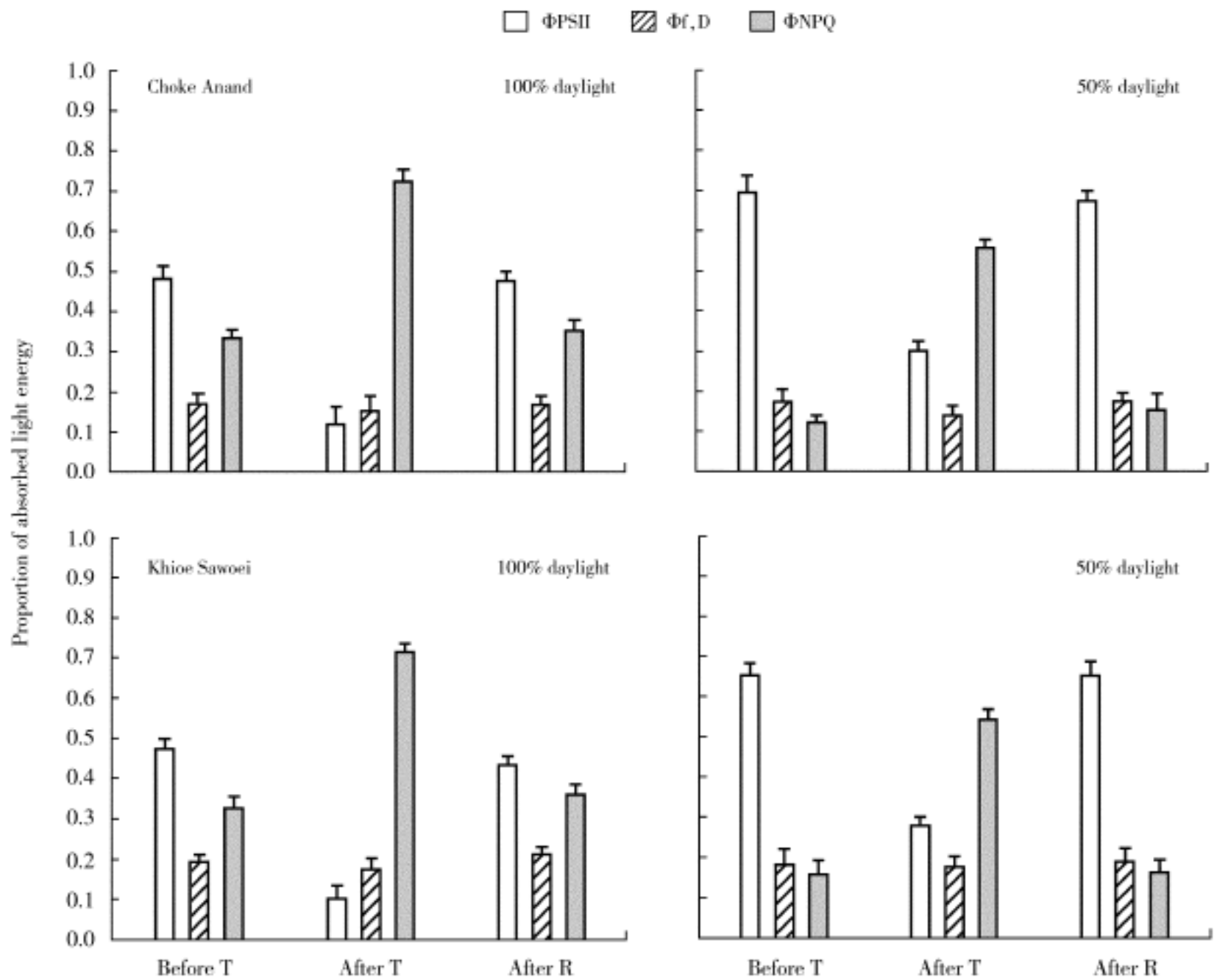


Fig . 4 The partitioning of absorbed light energy on midday in two mango cultivars grown under two irradiances, on the day before treatment (Before T), the seventh day with (After T) and the seventh day after the chilling treatment (After R) . Symbols and bars denote means  $\pm$  SE (n = 5)

Table 1 Chlorophyll (Chl a + b) content, carotenoid: chlorophyll ratios (Car/Chl), membrane leakage (EC%), malondialdehyde (MDA) content, proline content and total soluble sugar content (TSS) in two mango cultivars ( ' Choke Anand ' and ' Khieo Sawoei ' ) on the day before treatment (A), the seventh day (B) since chill-night treatment and the seventh day since the termination of the chilling treatment (C) . Both cultivars were grown under 100% and 50% sunlight . Different letters within the same parameters under the same irradiances indicate significant differences in the means of the same cultivars (  $P < 0.05$  ) .

Light intensity		Chl a + b (mg g <sup>-1</sup> FW)	Car/Chl	EC %	MDA (nmols g <sup>-1</sup> FW)	Proline ( $\mu$ mol g <sup>-1</sup> DW)	TSS (mg g <sup>-1</sup> DW)
' Choke Anand '							
100%	A	2.32 $\pm$ 0.11a	0.252 $\pm$ 0.016a	9.3 $\pm$ 1.3a	14.1 $\pm$ 1.1a	2.6 $\pm$ 0.3a	46.4 $\pm$ 4.1a
	B	1.57 $\pm$ 0.13b	0.373 $\pm$ 0.013b	28.9 $\pm$ 1.1b	51.3 $\pm$ 1.7b	5.8 $\pm$ 0.2b	85.7 $\pm$ 3.6b
	C	2.21 $\pm$ 0.08a	0.262 $\pm$ 0.018a	11.6 $\pm$ 1.7a	17.2 $\pm$ 1.0a	3.2 $\pm$ 0.2a	53.3 $\pm$ 4.8a
50%	A	2.97 $\pm$ 0.11a	0.221 $\pm$ 0.022a	7.1 $\pm$ 1.4a	9.1 $\pm$ 0.9a	2.0 $\pm$ 0.1a	39.3 $\pm$ 2.7a
	B	2.33 $\pm$ 0.17b	0.272 $\pm$ 0.017b	21.3 $\pm$ 1.1b	35.7 $\pm$ 1.7b	3.9 $\pm$ 0.3b	68.2 $\pm$ 3.8b
	C	2.82 $\pm$ 0.074a	0.231 $\pm$ 0.016ab	8.9 $\pm$ 1.3a	11.7 $\pm$ 0.9a	2.1 $\pm$ 0.1a	43.7 $\pm$ 4.0a
' Khieo Sawoei '							
100%	A	2.24 $\pm$ 0.15a	0.231 $\pm$ 0.018a	10.1 $\pm$ 1.3a	15.7 $\pm$ 1.5a	2.3 $\pm$ 0.2a	43.2 $\pm$ 4.7a
	B	1.51 $\pm$ 0.08b	0.347 $\pm$ 0.016b	32.9 $\pm$ 1.0b	64.3 $\pm$ 1.8b	5.5 $\pm$ 0.1b	82.2 $\pm$ 3.1b
	C	2.05 $\pm$ 0.10a	0.257 $\pm$ 0.014a	10.8 $\pm$ 1.1a	19.5 $\pm$ 2.3c	2.9 $\pm$ 0.1a	46.7 $\pm$ 2.4a
50%	A	2.77 $\pm$ 0.11a	0.208 $\pm$ 0.017a	8.0 $\pm$ 1.8a	10.6 $\pm$ 0.8a	1.6 $\pm$ 0.2a	37.3 $\pm$ 3.9a
	B	2.19 $\pm$ 0.08b	0.261 $\pm$ 0.014b	23.6 $\pm$ 1.6b	43.2 $\pm$ 1.5b	3.2 $\pm$ 0.1b	50.9 $\pm$ 3.0b
	C	2.72 $\pm$ 0.17a	0.211 $\pm$ 0.013ab	9.3 $\pm$ 1.4a	12.9 $\pm$ 1.0c	1.9 $\pm$ 0.1a	39.1 $\pm$ 2.8a

Table 2 The two-way ANOVA result on the effect of cultivar and irradiance on various physiological parameters

Parameter	Cultivar		Light intensity		Interaction	
	F	P	F	P	F	P
$P_n$	0.090766	ns	48.781	*	19.46616	*
$g_s$	0.041426	ns	24.62407	*	13.89751	*
Dawn $F_v/F_m$	5.021605	*	24.10188	*	0.210357	ns
Midday $F_v/F_m$	2.595906	ns	66.23515	*	1.654176	ns
PSII	10.12924	*	440.5738	*	1.070911	ns
NPQ	4.937512	*	17.99851	*	0.001571	ns
Chl a + b	1.06994	ns	53.17999	*	0.135114	ns
Car/Chl	1.583122	ns	37.97655	*	0.167574	ns
EC %	4.322181	ns	29.55097	*	0.299146	ns
MDA	66.22471	*	218.1706	*	3.841054	ns
Proline	10.7084	*	174.9523	*	1.181721	ns
TSS	8.777987	*	107.416	*	1.312286	ns

ns, insignificant difference at  $P > 0.05$ ; \* significant difference at  $P < 0.05$ .

*polyanthum* and *Linociera insignis* (Feng and Cao, 2005) in the same study area with the same night-temperature treatment reported in previous studies.

The parallel reduction in both  $g_s$  and  $P_n$  during the chilling treatment suggests the involvement of stomatal limitation to photosynthesis, as found as a positive response to chilling in numerous species, including mango (Nir *et al.*, 1997; Allen *et al.*, 2000), olive (Bongi and Long, 1987), grapevine (Flexas *et al.*, 1999) and coffee species (Guo and Cao, 2004). Chill nights can cause increase in resistance to water absorption from the soil and decrease in hydraulic conductivity of xylem (McWilliam *et al.*, 1982; Pavel and Ferees, 1998). Consequently, the plants may suffer from some degree of water deficit, resulting in the reduction of stomatal conductance. A decrease of stomatal conductance under these conditions is helpful for the plants to prevent excessive water loss.

Decreases in  $F_v/F_m$  and PSII, along with increase in NPQ or  $NPQ_{NPQ}$ , were similar in both mango cultivars following the chilling treatment (Fig. 3 and 4). Overall, the results indicated that the chill-night treatment induced suppression in the photosynthesis of the mango leaves up to chronic photoinhibition in case in the seedlings under full light, as also reported by previous studies on mango after chill night (Nir *et al.*, 1997; Allen *et al.*, 2000). This is also in agreement with other studies on other tropical plants in the same study area (Guo and Cao, 2004; Feng and Cao, 2005). High fraction of absorbed energy dissipated as

heat under low temperature as indicated by increasing  $NPQ_{NPQ}$  is helpful to minimize the damaging potential of excess energy especially in fully open site (Sveshnikov *et al.*, 2006; Hendrickson *et al.*, 2004). The greater NPQ in 'Choke Anand' (Fig. 3) explain a higher light energy dissipation, which must result in a less excessive energy load on the photosynthetic apparatus than in 'Khieo Sawoei'. Our previous study (Elsheery *et al.*, 2007) has also shown that 'Choke Anand' cultivar is chilling-tolerant compared to other cultivars grown in a common garden in the same site as the present study. The fast recovery of chlorophyll fluorescence parameters in both mango cultivars suggests that the decline in PSII efficiency was reversible, serving as a photoprotective role against chilling stress under both irradiances. Moreover, every day during the winter season in Xishuangbanna, there is heavy fog cover from midnight until noontime of the following day (Liu and Li, 1996). The fog blocks direct sun, thereby reducing the adverse effects of chilly night temperatures on tropical plants.

Chilly night temperatures resulted in a decrease of chlorophyll content, while increasing of Car/Chl ratio in both mango cultivars and two irradiances. The excessive light energy can cause the oxidation of chlorophyll. Carotenoids acts as photoprotective pigments by avoiding the generation of singlet oxygen by quenching the triplet-state chlorophyll molecules and by scavenging any singlet oxygen produced thus avoiding chlorophyll photooxidation (Young, 1991). Xanthophyll is the



main carotenoid component that is involved in light energy dissipation (Demmig-Adams and Adams, 1992). Thus, the large increase in NPQ, and the ratio of total carotenoids to Chl a + b, in both mango cultivars after chilling nights (Fig. 3, Table 1), can be considered as positive response to dissipate the excessive light energy in mango cultivars.

Excess light energy can also enhance production of free oxygen radicals, which lead to peroxidation of fatty acids in cell membranes (Parkin *et al.*, 1989; Foyer *et al.*, 1994). In the present study, higher concentration of MDA, which is the product of lipid peroxidation, in the leaves of the mango cultivars after chilling treatment (Table 1), indicated an increased oxidative stress in these leaves.

The accumulation of osmolyte compounds in the cells is likely a response to water deficit induced by chilling stress, which seems to act as a survival mechanism for the plant under stress (Gzik, 1996; Bajji *et al.*, 2001). Osmotic adjustment causes decrease in the osmotic potential of the plant tissue hence allow the leaves to withstand a lower water potential without loss of turgor (Holbrook and Putz, 1996). Accumulation of compatible solutes is cryptoprotective mechanism in some plants (Alberdi and Corcuera, 1991). Proline accumulates in many plants species under stress conditions to protect folded protein structure against denaturation, stabilizes cell membrane by increasing interacting with phospholipids, functions as hydroxyl radical scavenger, or serves as an energy and nitrogen source (Aspinall and Paleg, 1981; Samaras *et al.*, 1995).

In conclusion, the night chilling resulted in a severe reduction of gas exchange rates and photochemical efficiency in both mango cultivars. The reduction in these parameters was stronger in the mango seedlings grown under full light than in those under 50% daylight. Chill-night treatment induced photoinhibition in seedlings in full light, which was recovered after a week after the chilling treatment. The quick recovery in gas exchange parameters and chlorophyll fluorescence indicate that both mango cultivars are actually quite chilling tolerant but the 'Choke Anand' cultivar showed higher resistance to chilling than 'Khieo Sa-

woei' cultivar as indicated by the slower recovery of the latter. Shading significantly mitigated adverse effect of chilling nights.

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