# Chapter 4

## Effects of Night Break Treatment on Photosynthesis and Growth of *Curcuma alismatifolia* Gagnep.

### 4.1 Introduction

The main environmental factors responsible for floral induction are photoperiod and temperature. Photoperiod (i.e. the duration, rather than the quantity, of light in the daily cycle) regulated flowering by exposure to long days (LDs) or short days (SDs) depending on the plant species. (Corbesier and Coupland 2005; Bernier *et al.,* 1998; Thomas and Vince-Prue, 1997). Hagiladi *et al.* (1997) and Ruamrungsri *et al.* (2007) have reported that *C. alismatifolia* is a facultative long day (LD) plant, of which it will eventually flower under unfavorable photoperiods and thus it cannot be said to have a critical day length (CDL). It has been suggested that, for such plant, the CDL might be considered as that photoperiod above which the time to flower is minimal (Thomas and Vince-Prue, 1997). Ruamrungsri *et al.* (2007) reported that the night break treatment by supplemental lighting from 08.00 - 10.00 pm was required to promote growth and flower quality when this plant was grown in moderate temperature during November to January in Thailand. Other reports revealed that supplemental lighting increased photosynthetic rate and maintained a higher degree of photosynthetic rates during the day than the control plant in tomato, lettuce and garland chrysanthemum (Erhioui, *et al.,* 2002; Fukuda, *et al.,* 2000).

Similar to the report from Langton *et al*. (2003) which indicated that LD treatments increased chlorophyll content in *Petunia*, *Impatiens*, geranium and pansy. The night break affected the increase of photosynthate translocation to sinks which was ensured by high production and high reserves of carbohydrates under short day (SD) within light at night times (Gosselin *et al*., 1996). This might be due to a direct effect of LD lighting on photosynthesis (Adams *et al.,* 2008). It increased dry weight of impatiens and tomato which related to the increase of growth. Plant under supplemental illumination had increased photosynthesis and starch content in leaf (Gosselin *et al.,*1996) and the increase of leaf area and dry weight as the results from the increase of photosynthetic area (Cockshull, 1966). On the other hand, photosynthesis could be limited by carbohydrate accumulation in the leaves which it was stimulated by the initiation of tubers (Vivienne, 1997).

However, there were no data concerning photosynthesis under supplemental lighting in *Curcuma* plant. Thus, this experiment aimed to study the photosynthetic rate and chlorophyll fluorescence of *C. alismatifolia* as affected by supplemental lighting or night break compared with control. Therefore, to clarify the understanding on the effect of supplemental lighting on the photosynthetic rate it should be related to the increase of plant growth and inflorescence quality.



## 4.2 Materials and methods

### 4.2.1 Plant materials

Rhizomes of *C. alismatifolia* Gagnep. of approximately 1.5-2.0 cm in diameter, each comprised of 4 storage roots, were soaked in water for 3 days to stimulate sprouting. The sprouted rhizomes were grown in 6 x 4 inch black plastic bag in June 8,

2007, with average temperatures 33/28 $^{o}$C (day/night), relative humidity (RH) 61 % and 13 hours of day length (Appendix 14), using media containing a mixture of sand: rice husk: rice hull: soil with the ratio of 1:1:1:1 (by volume). After shoot sprouted to about 1 inch, the plants were transferred into two different treatments i.e., 1) plant grown under natural light (average of 12 hours) and 2) plant grown under natural light plus supplemental lighting (SL) at 08.00 - 10.00 pm by a 100 watts incandescent lamp in greenhouse. Plants were supplied with chemical fertilizers after sprouting using the 15:15:15 ($N:P_2O_5:K_2O$) at 7 g plant$^{-1}$ for every 15 days until flowering, after that it was applied with 13: 13: 21 ($N:P_2O_5:K_2O$) at 7 g plant$^{-1}$ for every 15 days until senescence. The experiments were conducted at Lampang Agricultural Research and Training Center, Rajamangala University of technology Lanna, Thailand.

**4.2.2 Data collection**

**4.2.2.1 Plant growth parameters**

Plant growth parameters, i.e. plant height, number of leaves per plant, number of shoots per clump and leaves area were measured. Leaf color was recorded using chlorophyll meter (Spad-502; Minolta CO., LTD). Flower quality attributes were determined at flowering stage (13 weeks after planting; WAP). Dry weight of plant was measured at 7 growth stages, i.e. 1) the 1$^{st}$ fully expanded leaf (L1: 6 WAP), 2) the 2$^{nd}$ fully expanded leaf (L2: 7 WAP), 3) the 3$^{rd}$ fully expanded leaf (L3: 8 WAP), 4) the 4$^{th}$ fully expanded leaf (L4: 9 WAP), 5) flowering (F: 13 WAP), 6) flower senescence (Fs: 18 WAP), and 7) harvest (H: 21 WAP) (Fig. 4.1).

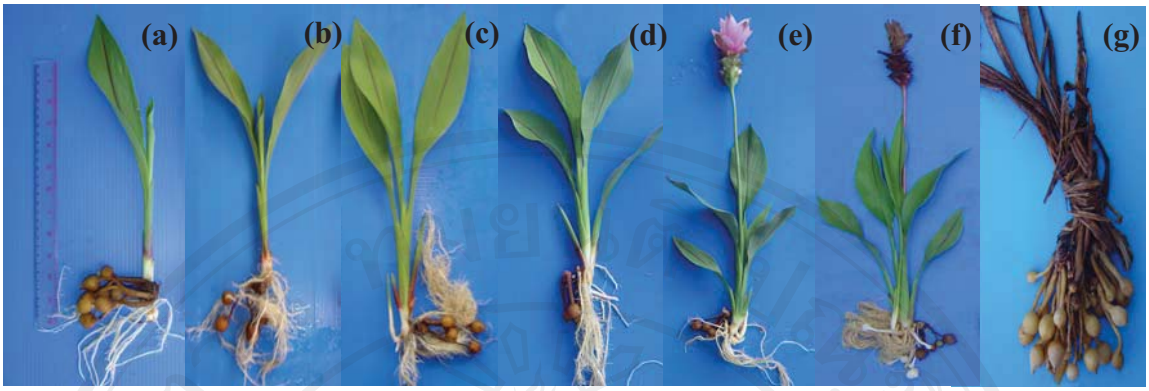


**Figure 4.1** Plants measurement at seven different growth stages; (a) the 1st fully expanded leaf, (b) the 2nd fully expanded leaf, (c) the 3 rd fully expanded leaf, (d) the 4th fully expanded leaf, (e) flowering, (f) flower senescence and (g) harvest.

**4.2.2.2 Photosynthesis parameters**

4.2.2.2.1 Measurement of photosynthetic efficiency

Diurnal photosynthetic rate (*Pn*) was measured at the 1st - 4th fully expanded leaf (stages L1-L4) using leaf chamber analyzer (Model LCA4, ADC, Hoddessdon, Herts, England) at 2 hours interval, during 06.00 am to 09.00 pm. The collected data were expressed in terms of the photosynthetic rate (*Pn*; $\mu molCO_2m^{-2}s^{-1}$), stomata resistance (*Rs*; $molm^{-2}s^{-1}$) and photosynthetically active radiation (*PAR*; $\mu molm^{-2}s^{-1}$).

4.2.2.2.2 Measurement of chlorophyll fluorescence

Chlorophyll fluorescence deliberated the maximum phototchemical yield of PSII and it was measured by the portable saturation pulse modulation chlorophyll fluorescence (Model Plant efficiency analyzer; PEA, Hansatech Instruments, UK.). Upon the application of a saturating flash, fluorescence (*F*) raised from the ground state value (*Fo*) to its maximum value (*Fm*). In this condition, the first electron

acceptor of PSII, was fully reduced. This allowed the determination of the maximum quantum efficiency of photosystem II (PSII) primary photochemistry, given by *Fv/Fm* = (*Fm-Fo*)/*Fm* (Baker *et al.,* 2007; Fracheboud, 2002). Measurements were made at the growth stage of L1-L4 during 03.00 am to 09.00 pm. Fluorescence measurements were carried out on the middle leaf surface, using a 15 minutes dark-adaptation period prior to the measurement.

## 4.3 Results

### 4.3.1 Plant growth

The results showed that the height of *C. alimatifolia* plant grown under night break treatment was similar to that of under the control treatment during 6-12 weeks after planting (WAP) (Fig. 4.2 a) and after that the height of night break treated plant was significantly taller than that of control at 13 WAP, i.e. at the flowering stage with the respective plant height of 43.12 and 43.96 cm. (Table 4.1). However, the number of leaves per plant, number of shoots per clump and total leaves area of *C. alimatifolia* were not different comparable between treatments in all stages of plant growth (Table 4.1 and Fig. 4.2).

Total leaves area and leaf color (SPAD unit) of plants under the night break treatments were also not different from those under the control treatment (Table 4.2 and Table 4.3), except at L2 (Table 4.2). Therefore, night break treatment did not affect on most growth parameters of *C. alismatifolia*, except the plant height at flowering stage (F) and total leaves area at L2 growth stage.

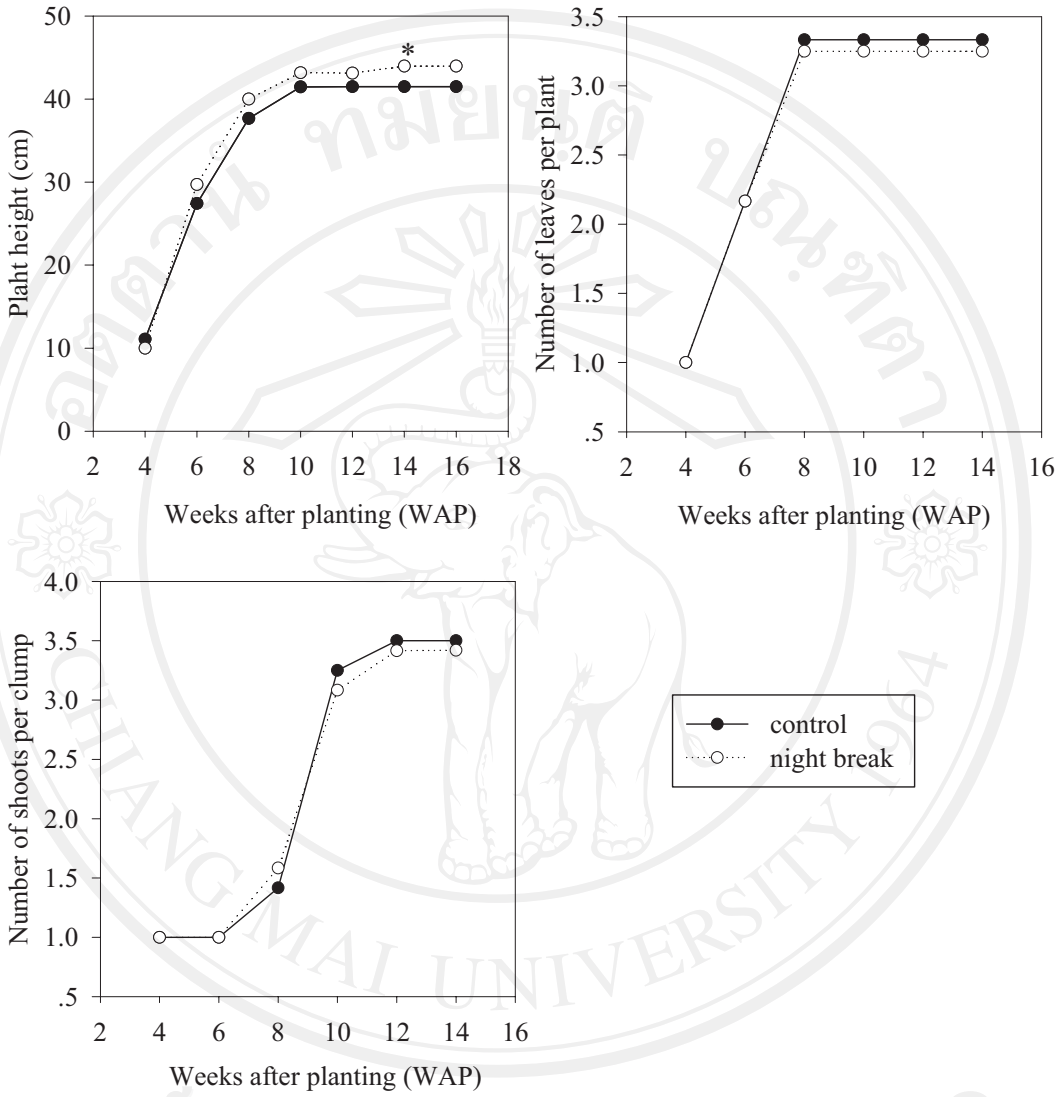


**Figure 4.2** Plant height (a), number of leaves per plant (b), and number of shoots per clump (c) of *C. alismatifolia* Gagnep. as affected by different night break treatments.

(*: significantly different between treatments)

**Table 4.1** Growth of *C. alismatifolia* Gagnep. as affected by night break treatments at flowering stage (13 weeks after planting).

| Treatment | Plants height (cm)* | Number of leaves per plant$^{ns}$ | Number of shoots per clump$^{ns}$ | Number of days to the first floret opening (days)$^{ns}$ | Total leaf area ($cm^2$)$^{ns}$ |
|---|---|---|---|---|---|
| Control | 41.50b | 3.33 | 3.50 | 83.67 | 425.21 |
| Night break | 43.96a | 3.25 | 3.42 | 81.25 | 420.18 |
| LSD $_{0.05}$ | 2.34 | - | - | - | - |

*Values within columns followed by different letters are significantly different at <0.05.
ns : not significantly different.

**Table 4.2** Total leaves area of *C. alismatifolia* Gagnep. as affected by night break treatments at different growth stages.

| Treatment | Growth stages | | | | |
|---|---|---|---|---|---|
| | L1$^{ns}$ | L2$^{*}$ | L3$^{ns}$ | L4$^{ns}$ | F$^{ns}$ |
| Control | 84.89 | 103.31b | 108.16 | 105.88 | 108.86 |
| Night break | 88.70 | 121.96a | 116.57 | 101.61 | 107.50 |
| LSD $_{0.05}$ | - | 12.88 | - | - | - |

*Values within columns followed by different letters are significantly different at <0.05.
ns : not significantly different.

**Table 4.3** Leaf color (SPAD unit) of *C. alismatifolia* Gagnep. as affected by night break treatments at different growth stages.

| Treatment | Growth stages | | | | |
|---|---|---|---|---|---|
| | L1$^{ns}$ | L2$^{ns}$ | L3$^{ns}$ | L4$^{ns}$ | F$^{ns}$ |
| Control | 44.22 | 53.35 | 50.07 | 53.61 | 55.28 |
| Night break | 46.56 | 54.20 | 51.58 | 50.74 | 52.04 |
| LSD $_{0.05}$ | - | - | - | - | - |

ns : not significantly different.



**4.3.2 Inflorescence quality**

Inflorescence quality, in terms of the length of flower stalk, length of spike, the number of coma bracts, the number of green bracts, the number of days to the first floret opening and the number of flowers per clump, was not statistically different between treatments (Table 4.4).

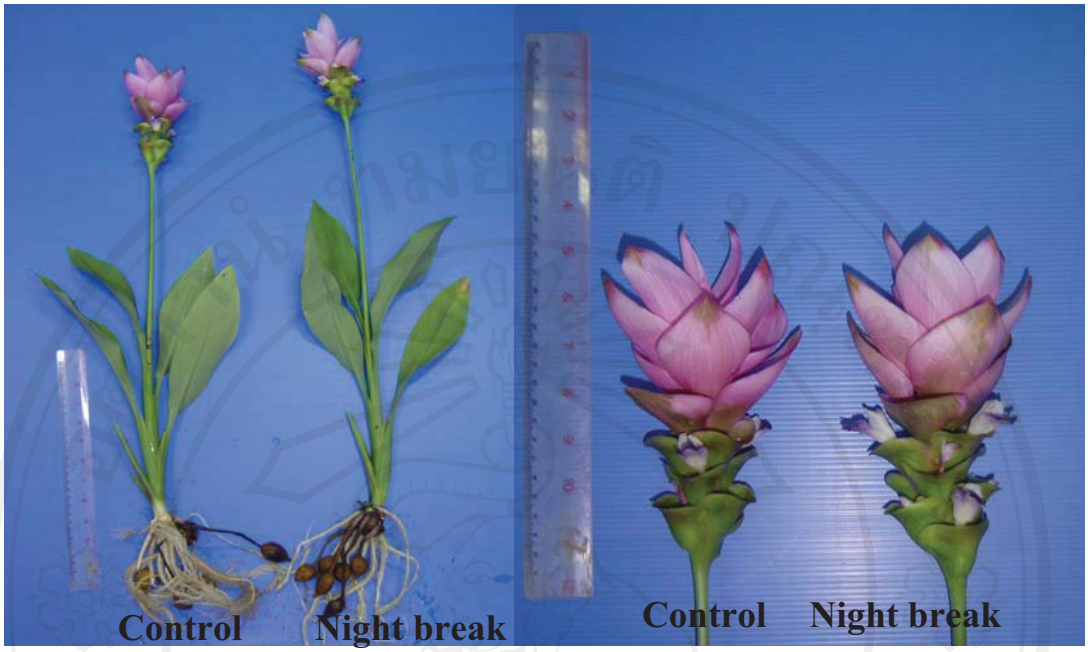


**Figure 4.3** Inflorescence quality of *C. alismatifolia* Gagnep. as affected by night break treatments.

**Table 4.4** Inflorescence quality attributes of *C. alismatiflia* Gagnep. as affected by night break treatments at flowering stage.

| Treatment | Length of flower stalk (cm)$^{ns}$ | Length of spike (cm)$^{ns}$ | Number of flowers per clump$^{ns}$ | Number of coma bracts$^{ns}$ | Number of green bracts$^{ns}$ |
|---|---|---|---|---|---|
| Control | 44.92 | 16.54 | 1.33 | 10.00 | 8.58 |
| Night break | 45.67 | 16.46 | 1.50 | 9.92 | 8.50 |
| $LSD_{0.05}$ | - | - | - | - | - |

ns : not significantly different.



### 4.3.3 Dry weight accumulation

The results showed that dry weight of major organs were not affected by night break treatment, except that of fibrous roots at L2 stage and leaves blade at L2, L3

stages of plant growth (Table 4.5). After harvest, dry weight of new storage roots and the total dry matter of plant grown under night break were lower than that in control treatment, but the dry weight of new rhizome was not statistically different (Table 4.6). In present experiment, dry matter of storage roots under night break was significantly lower than that in control and the terminal of contractile roots did not swell normally (Fig.4.4 b).

**Table 4.5** Dry weight (g) of old storage roots, old rhizome, fibrous roots, leaves, sheath leaves and new rhizome as affected by night break treatments at different growth stages of *C. alismatifolia* Gagnep.

| Treatment | Growth stages | | | | | |
|---|---|---|---|---|---|---|
| | L1 | L2 | L3 | L4 | F | Fs |
| | | | Old storage roots $^{ns}$ | | | |
| Control | 4.06 | 2.77 | 2.53 | 1.84 | 1.57 | 1.50 |
| Night break | 3.87 | 2.65 | 2.49 | 1.65 | 1.54 | 1.43 |
| LSD $_{0.05}$ | - | - | - | - | - | - |
| | | | Old rhizome $^{ns}$ | | | |
| Control | 2.15 | 1.79 | 1.72 | 1.41 | 1.17 | 1.21 |
| Night break | 1.85 | 1.64 | 1.53 | 1.19 | 1.17 | 1.16 |
| LSD $_{0.05}$ | - | - | - | - | - | - |
| | | | Fibrous roots $^{*}$ | | | |
| Control | 0.20 | 0.64a | 0.81 | 0.96 | 1.25 | 1.27 |
| Night break | 0.19 | 0.51b | 0.77 | 0.86 | 1.15 | 1.18 |
| LSD $_{0.05}$ | - | 0.06 | - | - | - | - |
| | | | Leaves $^{*}$ | | | |
| Control | 0.51 | 1.75a | 2.58a | 2.97 | 3.17 | 2.92 |
| Night break | 0.48 | 1.38b | 2.23b | 2.89 | 3.16 | 2.90 |
| LSD $_{0.05}$ | - | 0.15 | 0.29 | - | - | - |
| | | | Sheath leaves $^{ns}$ | | | |
| Control | 0.44 | 0.90 | 1.50 | 1.59 | 1.55 | 1.53 |
| Night break | 0.40 | 0.88 | 1.49 | 1.56 | 1.45 | 1.26 |
| LSD $_{0.05}$ | - | - | - | - | - | - |
| | | | New rhizome $^{ns}$ | | | |
| Control | 0.19 | 0.43 | 0.60 | 0.62 | 0.67 | 2.68 |
| Night break | 0.17 | 0.41 | 0.59 | 0.61 | 0.54 | 2.35 |
| LSD $_{0.05}$ | - | - | - | - | - | - |

$^{*}$Values within columns followed by different letters are significantly different at <0.05.
ns : not significantly different.

**Table 4.6** Dry weight of new storage roots and whole plant of *C. alismatifolia* Gagnep. as affected by night break treatment at harvest (21 weeks after planting).

| Treatment | Dry weight | | |
|---|---|---|---|
| | new rhizome (g)$^{ns}$ | new storage roots (g)$^{*}$ | whole plant (g)$^{*}$ |
| Control | 3.84 | 4.25a | 9.13a |
| Night break | 3.00 | 1.23b | 5.00b |
| LSD $_{0.05}$ | - | 1.51 | 3.28 |

$^{*}$Values within columns followed by different letters are significantly different at <0.05.
ns : not significantly different.

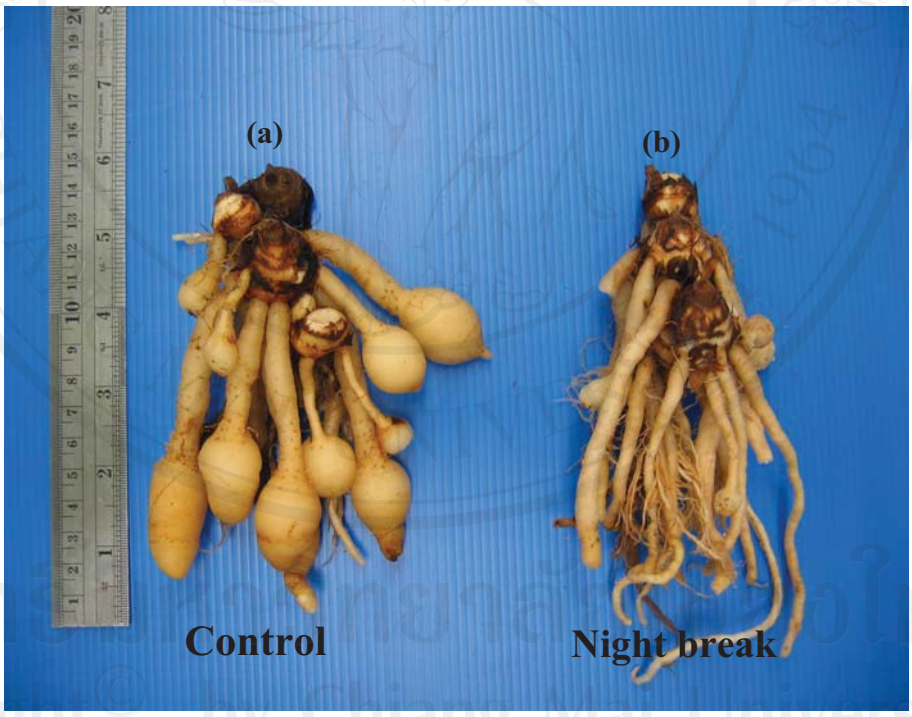


**Figure 4.4** New storage roots of *C. alismatifolia* Gagnep. under control treatment (a) and as effected by night break (b) condition at harvest.

The dry weight accumulation of most major organs of *C. alismatifolia* was linearly related to the variable growing period (Fig. 4.5). Dry weight of old rhizome and old storage roots were negatively correlated with growing period (Fig. 4.5 a,b), which meant that the dry matter of these organs gradually decreased a long with the growing period. However, there were no statistical differences between control and night break treatment (Table 4.5). Conversely, dry weight of leaves, sheath leaves, new rhizome, fibrous roots and total dry weight were positively linear related to the variable of growing period (Fig. 4.5 c-g). The responses of new rhizome dry weight under control condition through growing periods were stronger than that under night break treatment (slope ≈ 0.038).

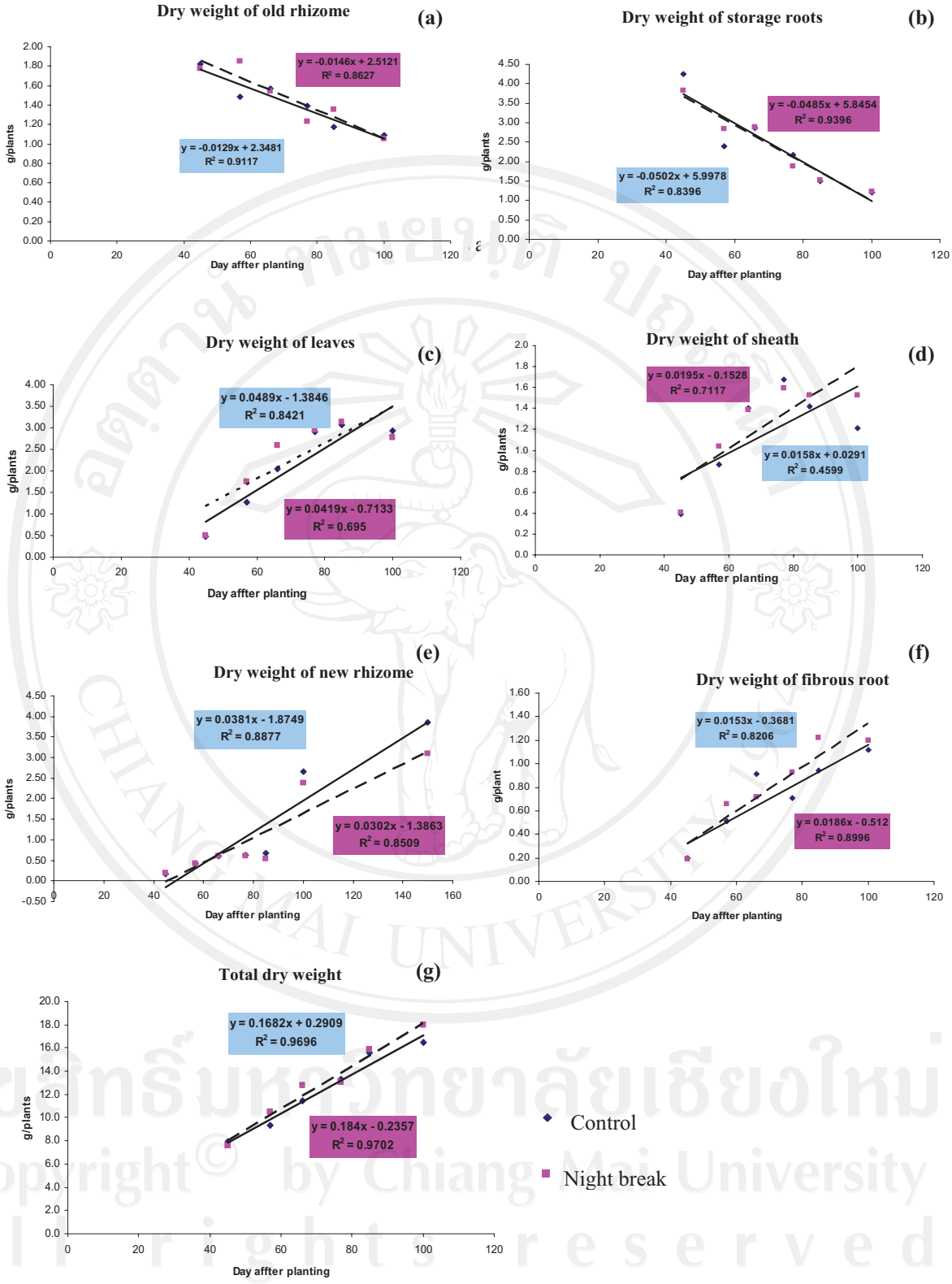


**Figure 4.5** Linear regression of dry weight (g plants$^{-1}$) of (a) old rhizome, (b) old storage roots, (c) leaves, (d) sheath leaves, (e) new rhizome, (f) fibrous roots and (g) total dry weight of *C. alismatifolia* as affected by night break treatment against plant growth stages.

**4.3.4 Photosynthetic rate (*Pn*) and chlorophyll fluorescence of *Curcuma alismatifolia* Gagnep.**

Photosynthesis began with the absorption of light energy and using it resulting in a charge to the reaction contents, which lead to the reduction of $CO_2$ to carbohydrates. The photosynthetic rates (*Pn*) were calculated when carbon dioxide concentration in detective chamber decreased due to it used as a photosynthetic substrate. The diurnal photosynthetic rates of *C. alismatifolia* were measured every two hours from 6.00 am to 09.00 pm. It was found that photosynthetic rate reached its maximum at 10.00 am then decreased until 06.00 pm, except at L1 growth stage (Fig. 4.6).

The *Pn* at L1 of night break treatment plant tended to be greater than that in the control at 6.00, 8.00 and 12.00 pm. The maximum *Pn* occurred at 10.00 am with value 6.99 $\mu molCO_2m^{-2}s^{-1}$ and decreased slightly at 12.00 pm (6.71 $\mu molCO_2m^{-2}s^{-1}$) (Fig. 4.6 a). However, photosynthetic rate was not statistically different between treatments.

At L2 growth stage the peak of *Pn* of the night break treated plant was at 10.00 am the same as that of control plant and gradually decreased until at 06.00 pm, then changed to increase moderately at 09.00 pm during the night break treatment (Fig. 4.6 b). The result of *Pn* at L3 growth stage was similar to that at L2 stage of plant growth. They were not statistically different in the plant *Pn* between night break and control treatment during 8.00 am -12.00 pm (2.27-7.54 $\mu molCO_2m^{-2}s^{-1}$). At night time, the *Pn* of control was about 0.81 $\mu molCO_2m^{-2}s^{-1}$and it was significantly lower than that of night break treatment with 1.59 $\mu molCO_2m^{-2}s^{-1}$ (Fig.4.7 c). At L4 stage, the *Pn* of control plant reached a maximum at 12.00 pm with 6.31 $\mu molCO_2m^{-2}s^{-1}$ and then decreased continuously until 06.00 pm. The *Pn* rate of control leaf reached a minimum of -1.21

$\mu molCO_2m^{-2}s^{-1}$ at 09.00 pm. In contrast, it was 0.76 $\mu molCO_2m^{-2}s^{-1}$ under night break condition at respective period (Fig.4.6 d).

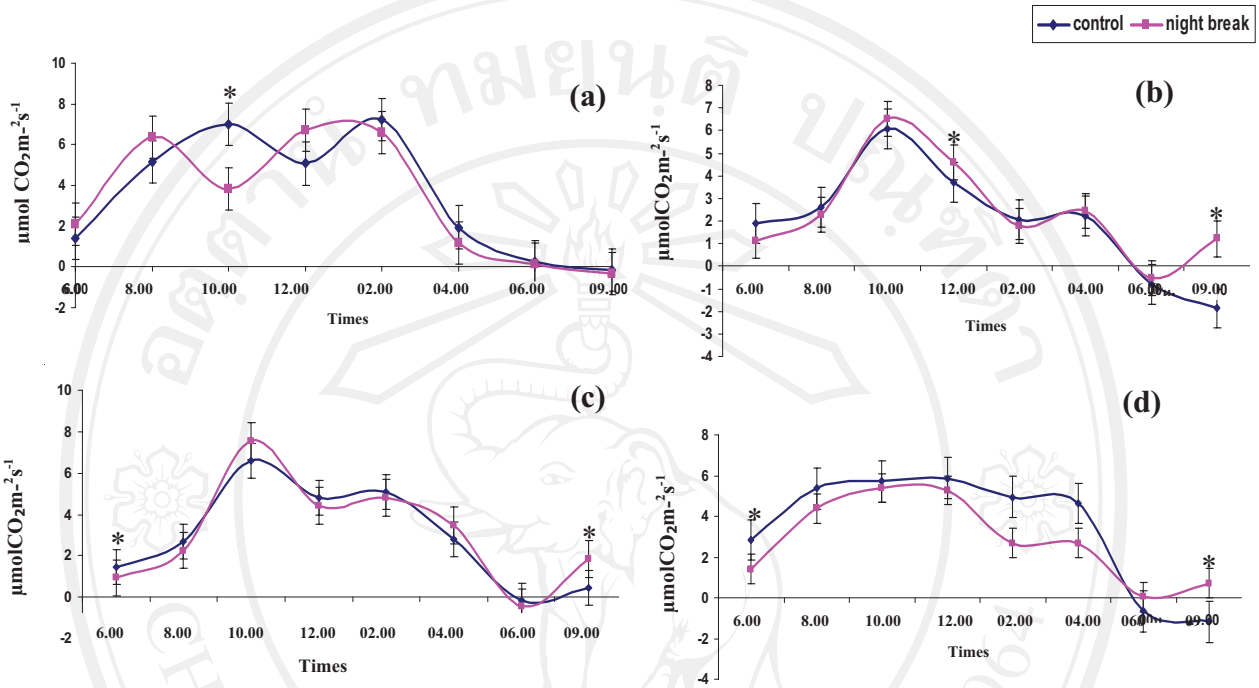


**Figure 4.6** Photosynthetic rates of *C. alismatifolia* Gagnep. at L1 (a), L2 (b), L3 (c) and L4 (d) as affected by night break treatment compared with control. (*: significantly different between treatments)

The diurnal of the photosynthetically active radiation (*PAR*) at L1 growth stage was the highest at 10.00 am with 1148.3 and 1435.2 $\mu molm^{-2}s^{-1}$ in control and night break plants, respectively, and it was not different between treatments. It continuously decreased until 06.00 pm, then *PAR* slightly increased at 09.00 pm under night break to the maximum value of 20.75 $\mu molm^{-2}s^{-1}$ and it was significantly higher than that in the control where its' minimum value was 0 $\mu molm^{-2}s^{-1}$ (Fig. 4.7 a). At L2 stage, the highest *PAR* was measured at 10.00 am and 12.00 pm with 1037 and 1470.9 $\mu mol.m^{-2}.s^{-1}$ of control and night break,

respectively, it was significantly different between treatments, and subsequently decreased until at 06.00 pm. The *PAR* values at 09.00 pm were 0 and 13.00 $\mu molm^{-2}s^{-1}$ for the control and night break, respectively (Fig. 4.7 b). At L3 stage, *PAR* was greatest at 02.00 pm and it was significantly different between control and night break conditions. After that, they were continuously declined until 06.00 pm, then raised at 09.00 pm. The *PAR* of the night break plant was at the highest of 12.25 $\mu molm^{-2}s^{-1}$ at 09.00 pm and was significantly different between treatments (Fig.4.7 c). At L4 growth stage the highest *PAR* was found at 12.00 pm with the values of 1642.2 and 690.92 $\mu molm^{-2}s^{-1}$ in control and night break, respectively, then decreased until 06.00 pm. At night time, the *PAR* in the night break treated plant increased again at 09.00 pm with 72.75 $\mu mol.m^{-2}.s^{-1}$ and it was significantly higher than that in control treatment (0 $\mu molm^{-2}s^{-1}$) (Fig.4.7 d). In this experiment, the changes of *PAR* at the different leaf growth stage were at the highest during 12.00 - 02.00 pm in a day time and then decreased gradually until 06.00 pm. The increase of *PAR* was found again at 09.00 pm under night break treatment.

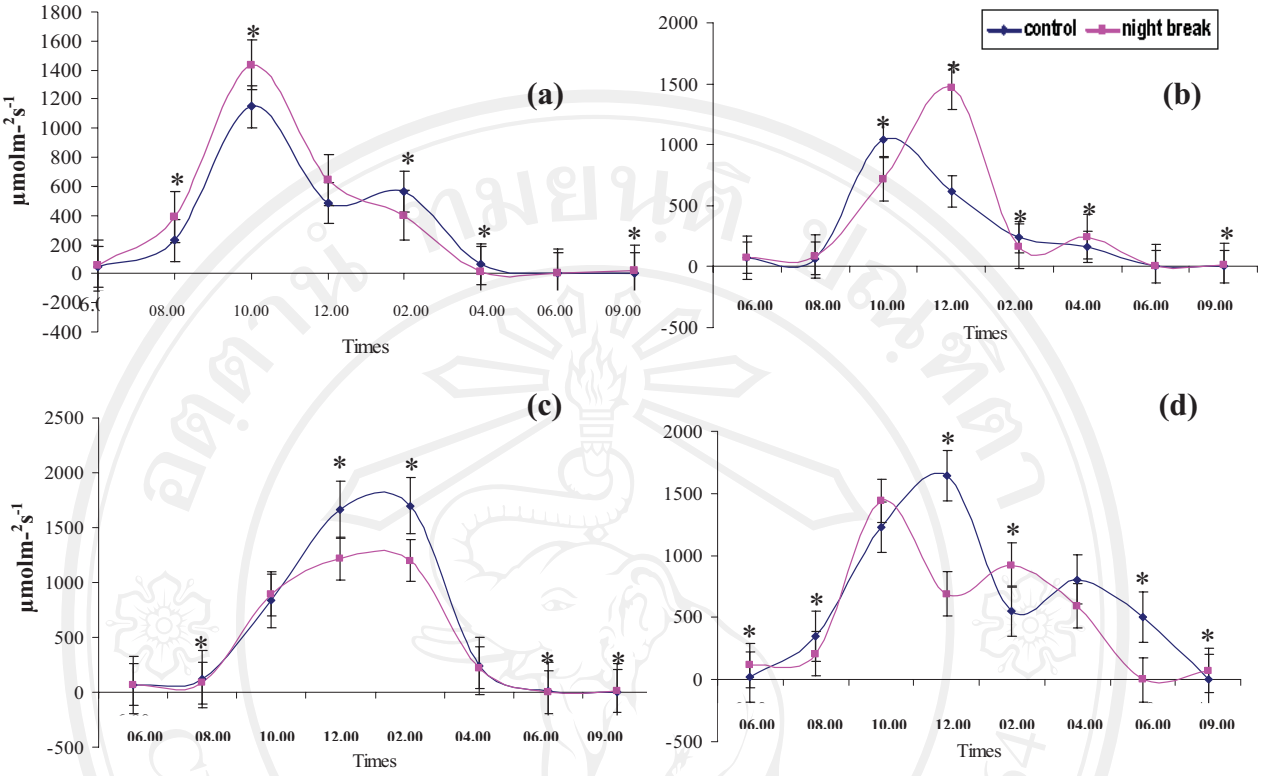


**Figure 4.7** *PAR* of *C. alismatifolia* Gagnep. at L1 (a), L2 (b), L3 (c) and L4 (d) growth stages as affected by night break treatment compared with control. (*: significantly different between treatments)

On the determination of the stomatal resistance (*Rs*) of *C. alimatifolia* Gagnep. the results showed that stomatal resistance at L1 stage presented a bimodal curve pattern with an obvious midday depression phenomenon. The first peak value of the *Rs* was at the highest about 12.00 pm, and it was not different between treatments. The second peak of *Rs* was found to increased at 06.00 pm in control treatment (Fig. 4.8 a). At L2 stage, the *Rs* peak of the night break plant reached the highest at 14.00 am, as well as, that in control plant, and then gradually decreased until at 09.00 pm (Fig. 4.8 b). The *Rs* peak at L3 stage was the highest at 12.00 pm similar to that in control plant and gradually decreased until at 09.00 pm (Fig. 4.8 c). At L4 stage, a bimodal curve of the night break

treated plant reached a maximum at 10.00 am with its value of 86.66 molm$^{-2}$s$^{-1}$ and at 16.00 pm with 72.28 mol.m$^{-2}$.s$^{-1}$. However, the *Rs* of both treatments were comparable (Fig. 4.8 d).

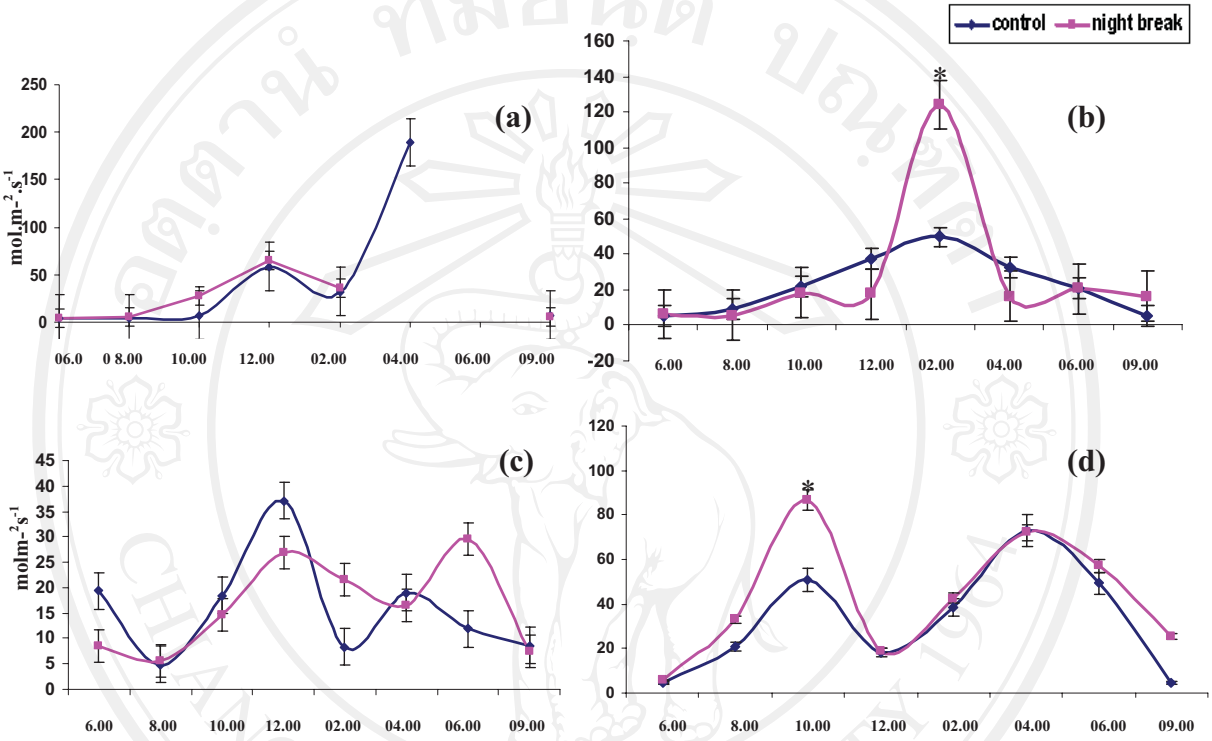


**Figure 4.8** Stomatal resistance of *C. alismatifolia* Gagnep. at L1 (a), L2 (b), L3 (c) and L4 (d) growth stages as affected by night break treatment compared with control.
(*: significantly different between treatments)

In general, the chlorophyll fluorescence at L1-L4 stages of *C. alismatifolia* Gagnep. tended to be the greatest at 03.00 am and it decreased continuously during the afternoon and started to increase gradually to 09.00 pm, but at night time the *Fv/Fm* increased to 0.80 (Fig. 4.9).

The chlorophyll fluorescence of curcuma at L1, L2 and L3 of the two treatments were not different, except that at 02.00 pm of the L3 growth stage (Fig. 4.9 a-c).

At L4 growth stage, chlorophyll fluorescence was greatest at 03.00 am. However, it was significantly higher than that of control treatment when compared with that of the night break treatment. The values decreased continuously from 06.00 am to 02.00 pm and started to increase from 06.00 pm to 09.00 pm, but it was similar for both treatments (Fig. 4.9 d).

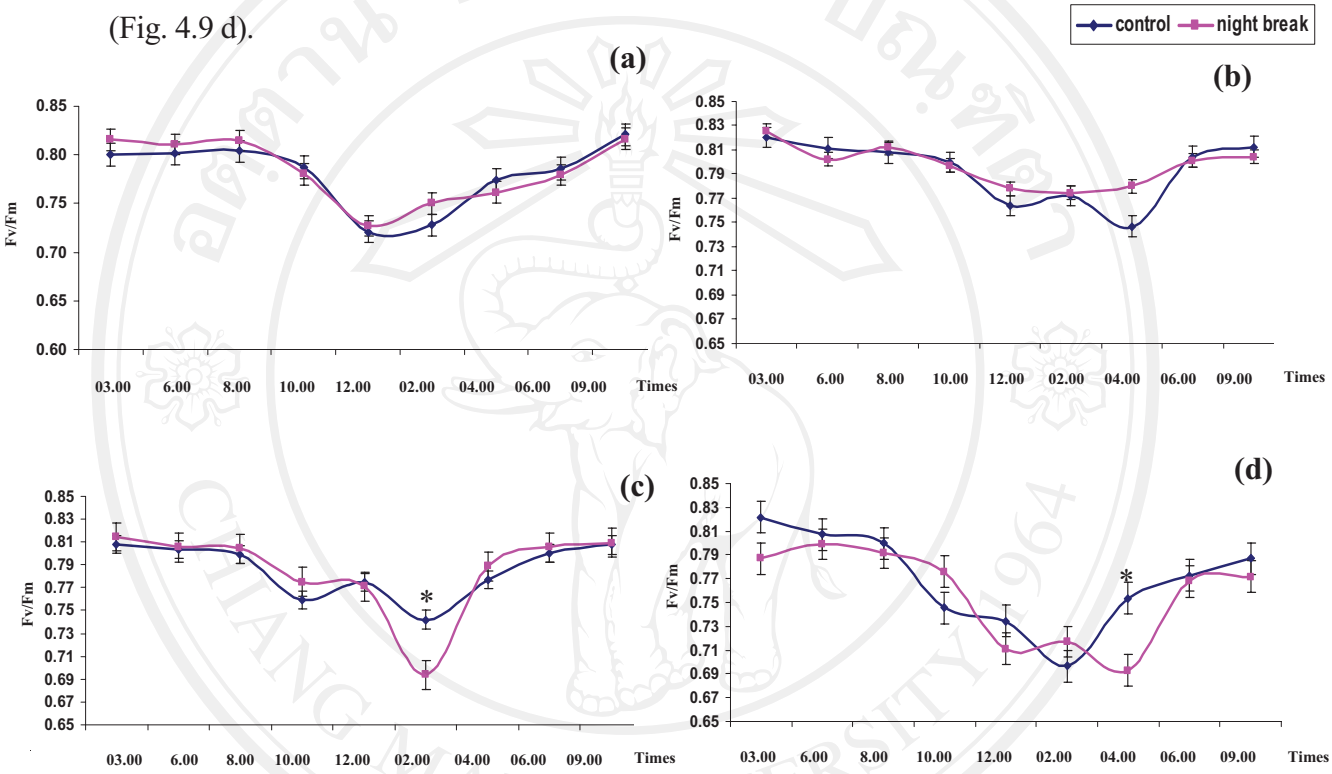


**Figure 4.9** Chlorophyll fluorescence of *C. alismatifolia* Gagnep. at L1 (a), L2 (b), L3 (c) and L4 (d) growth stages as affected by night break treatment compared with control.
(*: significantly different between treatments)

Given night break treatment in rainy season increased the *Pn* at night may bring about the increase in plant height at flowering and leaf area at L2 growth stage of *C. alismatifolia* Gagnep. Nevertheless, the other growth parameters of curcuma under study were not different between treatments.

## 4.4 Discussion

### 4.4.1 Plant growth

The plant height of *C. alismatifolia* Gagnep. grown under night break treatment was significantly higher than that of control at 13 WAP (Fig. 4.2 a and Table 4.1). However, the number of leaves per plant, number of shoots per clump and total leaf area were not different from control (Table 4.1 and Fig. 4.2). Hurd (1973) reported that the additional light or night-break lighting was often assumed to have a negligible impact on net canopy photosynthesis, which affected on vegetative growth. On the other hand, in some plants, such as tomato, lettuce and *chrysanthemum*, the results indicated that growing condition under supplemental lighting increased in plant growth when compared with the control plants (Erhioui, *et al.,* 2002; Fukuda, *et al.,* 2000). In *C. alismatifolia*, total leaves area and leaf color (SPAD unit) of the night break treated plants were not different compared with those of control treatment, except at L2 growth stage (Table 4.2 and Table 4.3). It should be noted that the experiment was carried out in rainy season, in which the weather was at optimum condition for stimulating maximum growth of *Curcuma*. Therefore, night break treatment did not affect on growth parameter, except plant height at flowering stage (F) and leaf area at L2 growth stage. Since plant growth and bioproductivity were ultimately dependent on leaf photosynthesis (Gutiérrez and Meinzer, 1994). Indicating that the increase of photosynthesis by night break was not sufficient to promote growth of *C. alismatifolia* at all growth stages (L1-L4). The response was also depended on plant species. Carpenter and Carlson (1974) researched on *Petunia* and found that photoperiod played an important role in development, such that a short photoperiod promoted branching and vegetative growth, while a long photoperiod

produced taller plants and hastened flowering. In *chrysanthemum*, when photoperiod extension was given during the natural SD period, it was observed that its effect on stem elongation depended on the timing that the plant being exposed to the light (Susana *et al.,* 2008). Given a night interruption for 4 hours, *chrysanthemum* showed a typical long day response that resulting in longer internodes (Cathey, 1974).

Plant growth was the result of photosynthesis, where plants used the energy from light to convert gaseous carbon dioxide into simple sugars and, ultimately, plant tissues. The rate of photosynthesis increased as light intensity increased up to a certain point (light saturation point), therefore plant growth also increased as light intensity increased. Adding supplemental lighting from incandescent light bulbs could greatly increase the amount of light available for plant growth during low light periods of the year (winter season) (Warner, 2006). Besides, supplementary lighting affected stomatal opening during the day, but did not affect the mechanism of stomatal closure. However, the rate of stomatal closure depended on the duration of the light period and might be affected by endogenous factors (Blom-Zandstra *et al.,* 1995).

**4.4.2 Inflorescence quality**

Inflorescence quality attributes of *C. alismatifolia* were not different between treatments (Table 4.4). Similarly, Ruamrungsri *et al*. (2007) also revealed that the plant growth and flower quality were not different when the given night break was conducted before October. This indicated that the other environment conditions might also have the influence on the night break response of the plant. Due to the weather in winter at Lampang, Thailand, having the average temperatures 33/28 $^{o}$C (day/night), with 13 hours of sunshine duration, 61 % RH and rain fall of 2.0 mm, was different

from that in rainy season (Appendix 16). This could probably be the reason of the different response of flower quality on night break treatments for different seasons.

### 4.4.3 Dry weight accumulation

The assimilation of dry matter and its distribution within the plant were important processes that determining the crop productivity. Photosynthesis was the source of organic carbon and energy for plants. It was the source for the growth, production of biomass and yield formation (Van Heemst, 1986). The present experimental results showed that dry weight of major organs were not affected by treatments applied. Zhang *et al.* (1995) reported that photoperiod did not affect dry weight of *Lysimochia congestiflara.* Similar result was found in pepper in which given supplemental light did not increase dry weight of shoot (Dorais, *et al.,* 1996). After harvest, dry weight of new storage roots and the total dry matter of plant grown under night break were lower than that of control treatment. The dry matter of storage roots under night break was significantly lower than that under control and the terminal of contractile roots did not swell normally (Fig.4.4 b). Indicating that the formation of storage roots in *C. alismatifolia* was strongly influenced by the day length. None formation of storage roots were recorded under the long day with vigorous growth of the above ground parts from spring to summer. In potato species, tuberization was inhibited by night break treatment (Jackson, 1999). This was indicated that night break might interrupt the translocation of food reserves for storing in the new storage roots. Changjeraja *et al.* (2008) found that the curcuma plant grown under continuously lighting for 14 hrs delayed the formation of new storage roots at 8 weeks after planting, compared with those at 6 and 10 hrs. Kuehny *et al.* (2002) also

reported that *C. alismatifolia* 'Siam Tulip White' grown under the photoperiod at 16 and 20 hours produced new storage roots less than those at 8 and 12 hours. There were other factors that affected tuber formation, such as nitrogen levels, temperature and light (Van den Berg *et al.,* 1996). The dry weight accumulation of major organs and whole plant were linearly related to variable stages of growing period. (Fig. 4.5). Dry weight of old rhizome and old storage roots were negatively correlated with growing period, which meant that the dry matters of these organs gradually decreased with the progress of growing period. It was assumed that, during sprouting they were acted as sources of sugars and starch involved in activities of enzymes and carbohydrate metabolism to promote plant growth. However, there were not different between control and night break treatments. Conversely, dry weight of leaves, sheath leaves, new rhizome, fibrous roots and total dry weight were positively and linearly related to variables of growing period. Vegetative storage organs, such as bulbs, tubers, corms, rhizomes and bark, performed as sinks for soluble nitrogen compounds (mainly amino acids) generated from the leaf proteins when the plant entered a senescing phase (Van Damme *et al.,* 2000). These storage organs became a source of nitrogen when the plant resumed growth after a resting or dormancy period (Shewry, 2003).



**4.4.4 Photosynthetic rate and chlorophyll fluorescence**

In present results, the diurnal photosynthetic rate of *C. alismatifolia* Gagnep. reached the highest at 10.00 am then decreased until 06.00 pm. The results showed that in both control and night break conditions, diurnal course of net photosynthetic rate (*Pn*) in *C. alismatifolia* leaves presented two peaks and related to the variation of stomatal resistance (*Rs*), photosynthetically active radiation (*PAR*) and chlorophyll

fluorescence (*Fv/Fm*). The rate of *Pn* increased with enhanced *PAR* and stabilized when *PAR* reached a certain level from sunrise (Chengguo *et al.,* 2009). At 10.00 am, *Pn* appeared to be at the highest peak when the environmental factors occurred to be the most proper combination. However, *PAR* and temperature increased gradually with increasing light intensity, and the high temperature inhibited *Pn* after 12.00 pm, that might be caused by the high temperature during afternoon which brought about the partially closed of stomata, as indicated by the increase in stomata resistance in Figure 4.8. Similarly, Ribeiro *et al.* (2009) found that photosynthesis of citrus during the summer was not impaired by biochemical or photochemical reactions, as $CO_2$ assimilation was only limited by stomatal conductance due to high leaf-to-air vapor pressure difference (VPD) during the afternoon. Heber *et al.* (1987) suggested that the main cause of midday depression of photosynthesis was due to higher light intensity which caused an increase in photorespiration and a decrease in *Pn*. The major factor that caused the depression of photosynthesis in the afternoon was due to higher light intensity which inhibited photosynthesis and promoted photorespiration, and the changes of photosynthesis caused by high irradiation differed among species and temperature regimes (Pandey *et al.,* 2003; Pastenes and Horton, 1996). During the leaf development, the increase of maximum net photosynthetic rate was related to the change of stomatal conductance and the leaf maturation period (Cia *et al.,* 2005).

The *Pn* rate of night break treatment at nighttime presented the slightly increased of *Pn* rate at 09.00 pm, which was indicated that photosynthesis process was promoted by supplemental lighting that was given at this time. It was similarly found that supplemental lighting increased photosynthetic rate and chlorophyll concentrations of lettuce, garland chrysanthemum and tomato plants (Fukada *et al.*, 2000).

In this experiment, the change of *PAR* at the different leaf growth stage was the highest at 12.00 – 02.00 pm during the daytime and then decreased gradually until 06.00 pm. The increase of *PAR* was appeared again at 09.00 pm under the night break treatment. Plants utilized solar radiation in visible ranges for photosynthetic process. In order to estimate the net primary production of vegetation, the ratio of *PAR* to solar irradiance was one of the important factors (Muramatsu *et al.,* 2009).

The function of stomata in plants was to control gas exchange and to modulate water balance, stomatal aperture, and the stomatal resistance played important roles in water status and $CO_2$ assimilation. The *Pn* decreased as stomatal aperture decreased or the stomatal resistance increased and reducing stomatal opening status led the decrease in transpiration rate and the reduction of water loss (Chengguo *et al.,* 2009).

The results showed that stomatal resistance (*Rs*) of *C. alismatifolia* Gagnep. presented a bimodal curve pattern and an obvious midday depression phenomenon occurred at L1 stage of plant growth. At L2 stage, the *Rs* peak of night break treatment plant reached the highest at 02.00 pm, the same as that in control plant, and then gradually decreased until at 09.00 pm. The *Rs* peak at L3 stage was the highest at midday, as well as that in control plant, and gradually decreased until at 09.00 pm. At L4 stage, a bimodal curve of night break plant reached a maximum at 10.00 am and 06.00 pm. The decreased of *Pn* after midday might be caused by the high temperature during the afternoon that brought about the partially closed of stomata which indicated by the increase of stomata resistance.

Chlorophyll fluorescence, *Fv/Fm* ratio, indicated the effect of outside factors to chlorophyll efficiency and stress (Krause and Weis, 1991). Chlorophyll fluorescence of L1-L4 growth stages tended to be the greatest at 03.00 am and

continuously decreased during afternoon and then started to increase to 09.00 pm. The *Fv/Fm* of plants was decreased at midday in both conditions, indicating that plants were stressed under these conditions as environmental stress affected PSII efficiency that led to a characteristic decrease in *Fv/Fm* (Baker *et al.,* 2007; Krause and Weis, 1991). But at night time, *Fv/Fm* increased to the value of 0.80, indicating that plants under these conditions were not under stress.

**4.5 Conclusion**

Effects of night break treatment on photosynthesis and growth of *C. alismatifolia* Gagnep. was carried out in rainy season, with average temperatures 33/28 $^{o}$C (day/night), relative humidity (RH) 61 % and 13 hrs of day length. The night break treatment increased photosynthetic rate and chlorophyll fluorescence at 09.00 pm and that influenced on stimulating the plant height at flowering and leaf area at L2 growth stage. However, it decreased dry weight of storage roots and total dry weight of plants compared to that in the control treatment. Moreover, night break treatment inhibited storage roots formation, which might be caused by the changes of sink-source function between inflorescence and storage roots. Photosynthetic rate, *PAR* and chlorophyll fluorescence of control treatment and night break treatment were greatest at 10.00 am - 12.00 pm and fluctuated at different times.