

Effects of Relative Light Intensity on the Growth, Yield and Curcumin Content of Turmeric (*Curcuma longa* L.) in Okinawa, Japan

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Abstract : The effects of relative light intensity (RLI) on the growth, yield and curcumin content of turmeric (*Curcuma longa* L.) were examined in Okinawa, Japan. The plants were shaded with white nets with different mesh sizes for maintaining respective RLI. Five RLI, 100 (without shading), 82, 79, 73 and 59% in 2004–2005 and four RLI, 100, 68, 52 and 48% in 2005–2006 were evaluated. In the first experiment, plant height increased markedly, but the number of leaves and tillers, and SPAD value increased slightly in the plants grown at 59–82% RLI compared with control (without shading). Turmeric shoot biomass and yield increased significantly at 59–82% RLI and they were highest at 73% RLI in the first experiment. Curcumin content of turmeric increased markedly at 59–73% RLI as compared with the control in the first experiment. Similar results in plant growth, shoot biomass, yield and curcumin content were obtained in the second experiment, but the effects of RLIs were smaller than in the first experiment because of late planting. This study indicates that turmeric is a partial shade-tolerant plant that could be cultivated at around 59–73% RLI for higher yield and curcumin content in Okinawa. However, the degree of RLI required for better turmeric cultivation may vary with the place, year and irradiance level.

Key words : Curcumin, Irradiance effect, Medicinal plant, Root crop, Turmeric yield.

Growth, yield and quality of a plant species are influenced by environmental factors such as water, temperature, photoperiod, radiation, shading and soil nutrient status (Chapman et al., 1993; Miller et al., 1993; Kobata et al., 2000; Kakiuchi and Kobata, 2004; Cohen et al., 2005; Hossain and Ishimine, 2005; Sharma et al., 2006; Akamine et al., 2007; Kasajima et al., 2007). Mirdehghan and Rahemi (2007) reported that the concentrations of minerals and phenolics in pomegranate vary with the season. Light is an important environmental factors that influences phenological characteristics including growth, yield and quality of plant (Knake, 1972; Deen et al., 1998a, 1998b; Kobata et al., 2000; Kakiuchi and Kobata, 2004; Kasajima et al., 2007). Clemente and Marler (1996) reported that physiological function of a plant species changes with the change in irradiance level. Kobata et al. (2000) reported that rice can grow well with partial shading, but heavy shading reduces yield. Joscelyne et al. (2007) reported that brix%, pH level and phenolics content of grape vary with the light intensity.

Turmeric (*Curcuma longa* L.) is increasingly being used in many countries as a spice, cosmetic and natural medicine (Ishimine et al., 2003; Hossain et al., 2005a, 2005b). It is now a popular medicine

worldwide. Curcumin is the principal component of turmeric, which has anti-inflammatory, anti-cancer, anti-tumor, anti-bacterial, anti-oxidant, anti-fungal and anti-parasitic properties (Hermann and Martin, 1991; Osawa et al., 1995; Sugiyama et al., 1996; Nakamura et al., 1998). However, the efficacy of turmeric appeared to vary with the level of curcumin in the turmeric used in the studies. Our previous studies showed that growth, yield and curcumin content of turmeric differ with the soil type and fertilizer (Hossain and Ishimine, 2005; Akamine et al., 2007). It is assumed that growth, yield and curcumin content of turmeric vary with the sunlight level. Most farmers in India and Bangladesh cultivate some turmeric in orchards and fallow lands shaded with different trees around their houses for their own consumption. It is also commercially cultivated in open fields. A comprehensive study on yield and quality of turmeric growing in open and shaded fields has not yet been conducted. It is important to evaluate growth and development responses of a plant species to the local climatic and edaphic factors for understanding proper cultivation practices (Ishimine et al., 2004; Hossain and Ishimine, 2005). Turmeric is commercially cultivated in Okinawa where maximum solar radiation in July-August is around 23 MJ m⁻² d⁻¹.

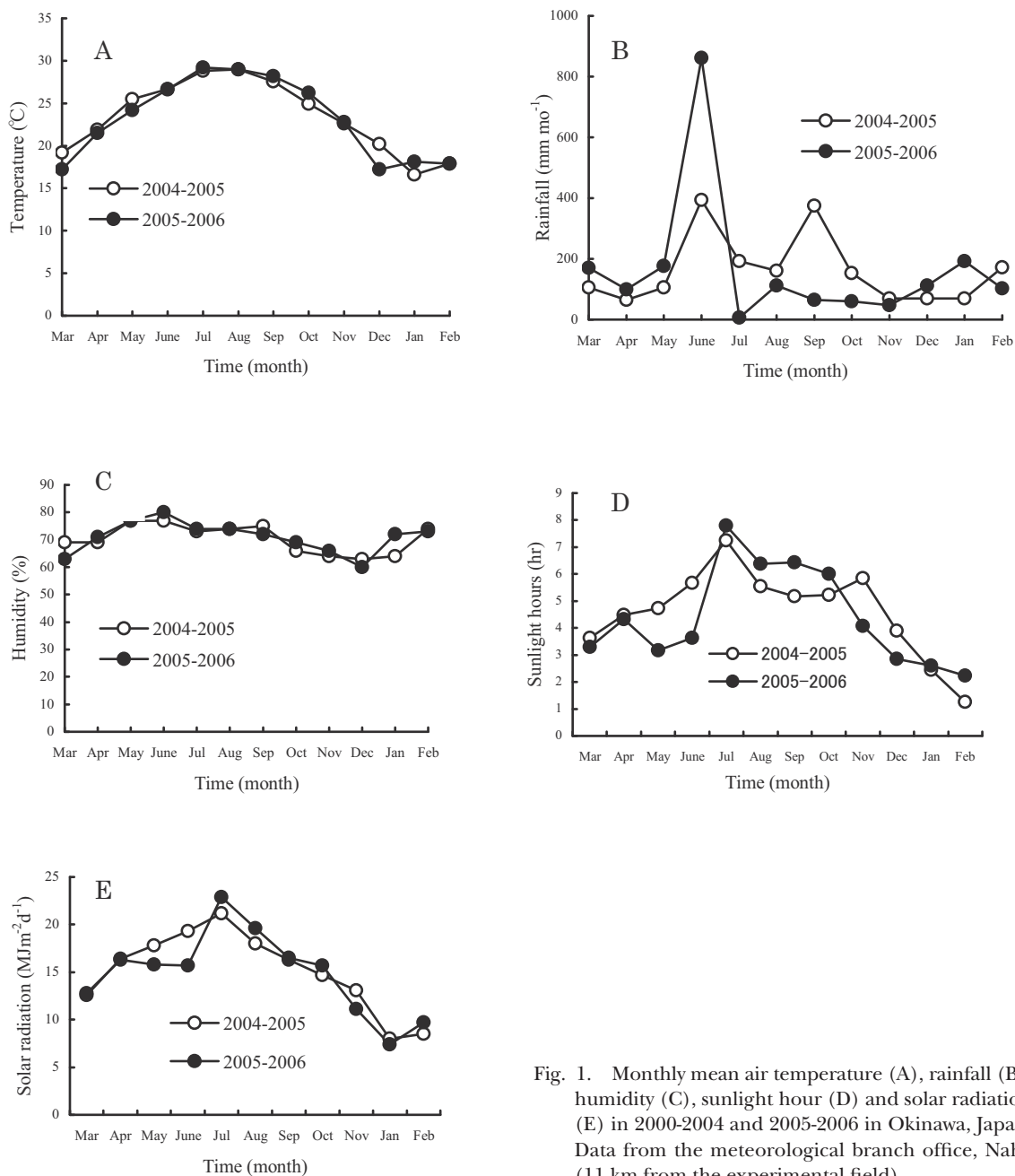


Fig. 1. Monthly mean air temperature (A), rainfall (B), humidity (C), sunlight hour (D) and solar radiation (E) in 2000-2004 and 2005-2006 in Okinawa, Japan. Data from the meteorological branch office, Naha (11 km from the experimental field).

In our previous studies, the effects of planting depth, planting time, planting pattern, seed size, soil types, chemical fertilizers and farmyard manure on the growth, yield and quality of turmeric were examined in Okinawa (Ishimine et al., 2003, 2004; Hossain et al., 2005a, 2005b; Hossain and Isimine, 2005, 2007). The present study was undertaken to evaluate the effects of relative light intensity of sunlight on the growth, yield and curcumin content of turmeric in Okinawa, Japan.

Materials and Methods

1. Experiment 1 (2004–2005)

The experiment was conducted from April 18, 2004 to January 10, 2005 at the Subtropical Field

Science Center, University of the Ryukyus, Okinawa, Japan (26.2° N and 127.8° E). Meteorological data are presented in the Fig. 1. Each Wagner pot (size : 25 cm diameter×30 cm height) was filled with 10 kg of air-dried soil (dark-red soil, Shimajiri maaji, pH 6.2) uniformly mixed with 0.5 kg of compost fertilizer (cow dung). One seed-rhizome (30 g each) of Okinawa cultivar (*Curcuma longa* L. cv. Autumn turmeric) was planted 8 cm deep in a pot. Steel frame (size : 2.5 m length×2.0 m width×2.5 m height) was covered with the white nets (Wind-Break net, Dio Chemicals Co. Ltd., Fig. 2) with different mesh sizes for maintaining respective relative light intensity (RLI). There were five treatments with four replications (4 pots) : (1) 100%

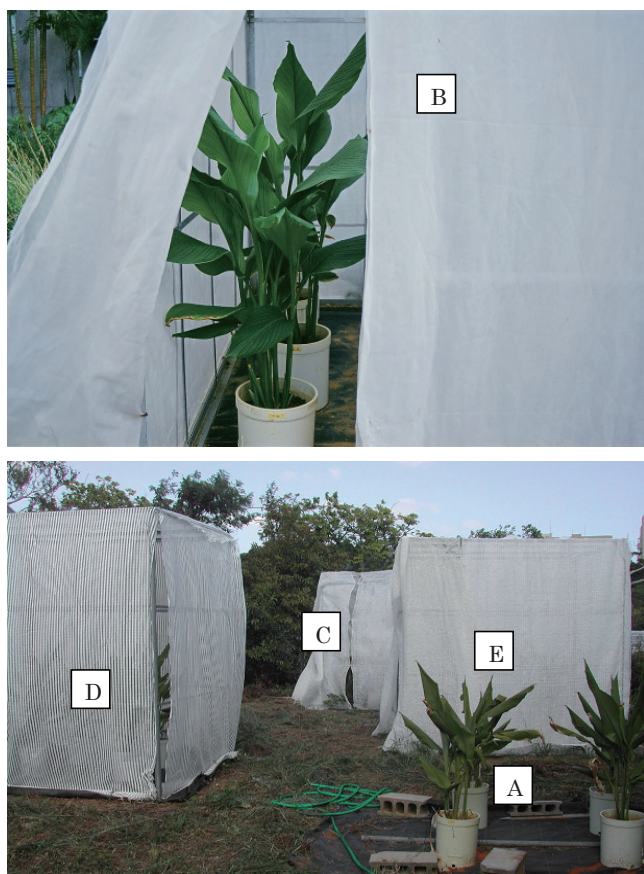


Fig. 2. Turmeric growing under different relative light intensities (RLI). A, 100% RLI (without shading); B, 73% RLI; C, 68% RLI; D, 52% RLI; E, 48% RLI.

RLI (without shading), (2) 82% RLI (through 3 mm mesh net), (3) 79% RLI (2 mm mesh net), (4) 73% RLI (1 mm mesh net) and (5) 59% RLI (two sheets of 1 mm mesh net). Ambient light intensity was measured three times a month at a 10-d interval using a 510 Illuminance Meter (Yokogawa Meters & Instruments Corporation). Five sunlight intensity readings outside and inside of the nets were taken at noon (1130–1230, sunny day), and RLI in the nets was calculated according to the following formula.

$$\text{Relative light intensity (RLI) \%} = \frac{\text{Light intensity inside net}}{\text{Light intensity outside net}} \times 100 \quad [1]$$

Turmeric was grown at different RLIs. Nitrogen, P_2O_5 and K_2O at 3.15, 2.25 and at 2.25 g pot^{-1} , were applied on July 18 (two- to three-leaf stage), August 30 (vegetative and rhizome growth stage) and September 30 (vegetative and rhizome growth stage), 2004. Nitrogen, P_2O_5 and K_2O at 210, 150 and 150 kg ha^{-1} respectively, are usually applied in the turmeric field, and one turmeric plant requires around 0.15 m^2 in the field condition for better growth and yield (Hossain et al., 2005b), therefore the fertilizers were applied

considering this area (0.15 m^2). Water was applied as required everyday for proper seedling emergence and plant growth.

2. Experiment 2 (2005–2006)

Generally climatic factors vary with the year, and many kinds of net are available. In addition, yield and curcumin content increased significantly at 59–73% RLI in the previous study, which indicates that they may increase at a lower RLI. Therefore, this experiment was conducted from June 26, 2005 to January 15, 2006 at the Subtropical Field Science Center of the University of the Ryukyus, where RLI and nets were different from those used in 2004–2005 study. The second experiment was started late because temperature and solar radiation are high in June, July, August and September in Okinawa, Japan (Fig. 1), and farmers do not plant turmeric at the same time.

The same Wagner pot, soil, compost, seed-rhizome, steel frames and plantation procedures were used in this experiment. There were four treatments with four replications (4 pots) : (1) 100% RLI (without shading), (2) 68% RLI (Cool White, 620SW net, Dio Chemicals Co. Ltd.), (3) 52% RLI (Hakureisha #22 net, Hasegawa Tateami Kougyou Co. Ltd.) and (4) 48% RLI (Cool White, 1020SW net). The nets were white in color (Fig. 2). Ambient light intensity and RLI in nets were measured according to the previous experiment. The same fertilizers were applied on July 30 (two- to three-leaf stage), September 15 (vegetative and rhizome growth stage) and October 30 (vegetative and rhizome growth stage), 2005. Water was applied as required everyday for proper plant growth.

3. Data collection and statistical analysis

In experiment 1, plant height and the numbers of leaves and tillers were measured on July 20, August 20, September 20, October 20 and November 7, 2004. The SPAD value was measured on the top three leaves by using SPAD-502 (Minolta Co. Ltd.) on July 20, August 20, September 20 and October 20, 2004. The green period (d) of shoot was counted as the period from planting to shoot yellowing. Turmeric was harvested on January 10, 2005 when shoots withered completely. In experiment 2, plant height and the numbers of leaves and tillers were measured on August 25, September 26, October 26 and November 26, 2005. The SPAD value was measured on August 25, September 26 and October 26, 2005. Turmeric was harvested on January 15, 2006 when shoots withered completely. Leaves, shoots, roots and rhizomes were collected, and the plant parts were oven-dried at 80°C for 48 hr and weighed. For curcumin analysis, rhizomes were sliced and dried at 50°C for 48 hr, and then the slices were ground to a fine powder. The powder of four plants was mixed together for each treatment, and curcumin content was measured three times by HPLC (Shimadzu

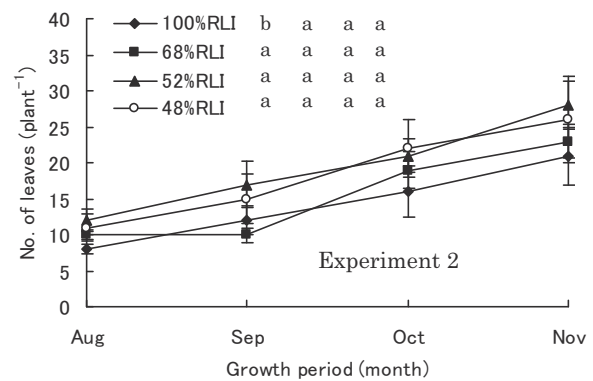
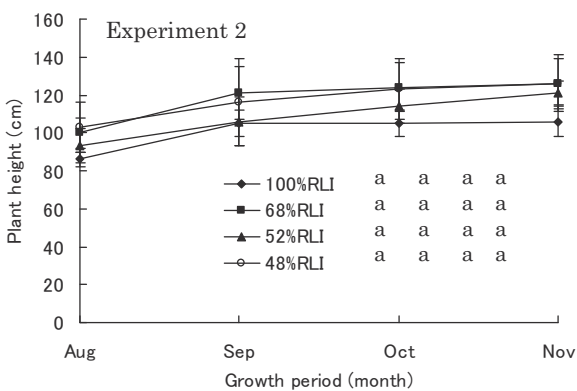
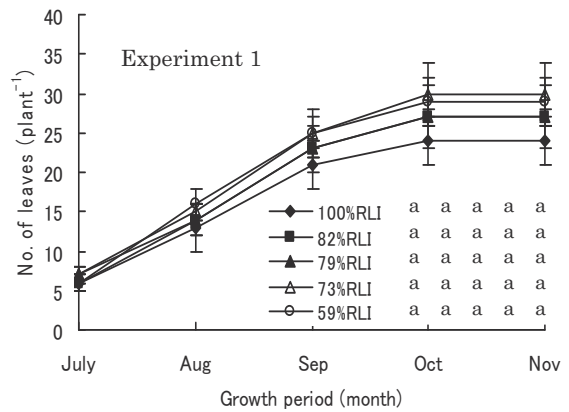
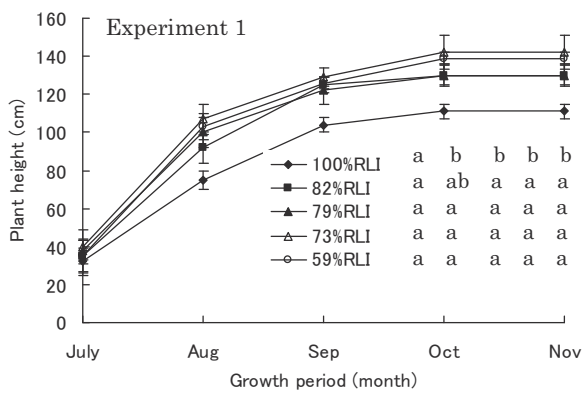


Fig. 3. Plant height of turmeric grown under different relative light intensities (RLI). Data are means \pm SD of four replications. Data with the same letter within each month (from left : July, August, September, October and November in the experiment 1 (2004–2005); August, September, October and November in the experiment 2 (2005–2006)) are not significantly different at the 5% level, as determined by Tukey's multiple range test.

Fig. 4. Effects of relative light intensity (RLI) on leaf number of turmeric. Data are means \pm SD of four replications. Data with the same letter within each month (from left : July, August, September, October and November in the experiment 1 (2004–2005); August, September, October and November in the experiment 2 (2005–2006)) are not significantly different at the 5% level, as determined by Tukey's multiple range test.

Co. Ltd.). Mean and standard deviation (SD) of four replications were calculated. The mean values were compared using one-way ANOVA followed by Tukey's multiple range test at the 5% level.

Results

1. Effects of relative light intensity on the growth and yield of turmeric

Relative light intensity (RLI) influenced shoot elongation of turmeric throughout the observation period, and a significant effect was observed from August to November only in the 2004–2005 cropping season (Fig. 3). The plant height was statistically the same at 59, 73, 79 and 82% RLI, however was the highest at 73% RLI. Plant height in 2005–2006 increased non-significantly at 48–68% RLI, as compared with the control. The number of leaves did not significantly vary with the RLI, but it tended to increase at a lower RLI in both experiments (Fig. 4). The number of tillers was statistically the same at all the RLI, but it tended to increase at 59–82% RLI in 2004–2005. The number of

tillers increased slightly at 48–52% RLI in September–October but significantly in November of 2005–2006 (Fig. 5). In the first experiment (2004–2005), a lower RLI increased the SPAD-value of turmeric leaf significantly or non-significantly in September and October, but 82, 79, 73 and 59% RLI showed similar effects. In the second experiment, SPAD-value was not influenced by the RLI (Fig. 6).

Turmeric shoot biomass increased significantly or non-significantly at a lower RLI in both the cropping seasons (Table 1). The shoot biomass was statistically the same at 59, 73, 79 and 82% RLI, but it was 15–18% larger at 73% RLI than at 59 and 79–82% RLI in the first experiment. In the second experiment, the shoot biomass at 48, 52 and 68% RLI was similarly larger than that in the control without shading (Table 1). Turmeric grown at a lower RLI resulted in a significantly higher yield as compared with the control (Table 1). The yield was highest at 73% RLI followed by 79, 59 and 82% RLI in 2004–2005, whereas in 2005–2006 the yield increased similarly and

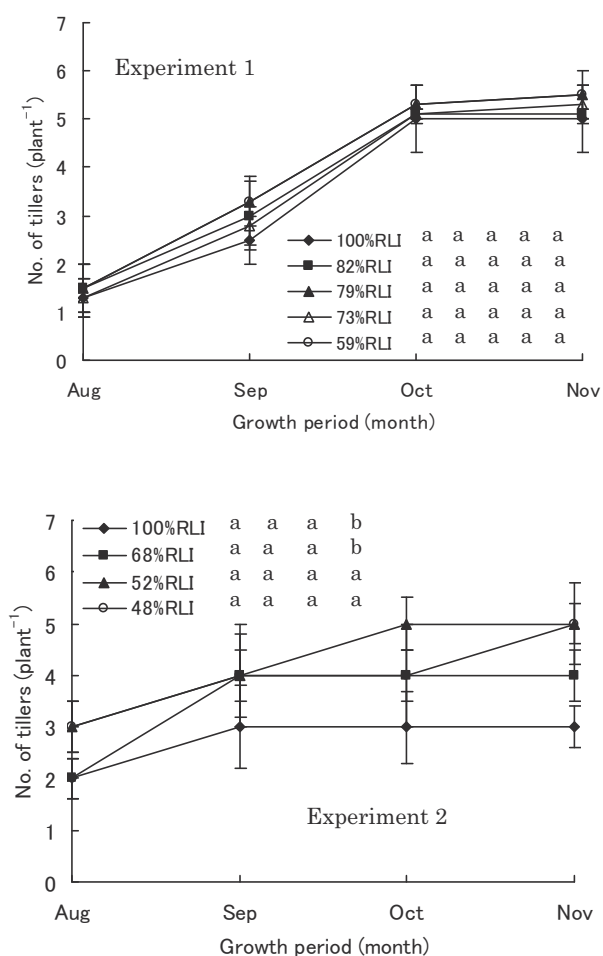


Fig. 5. Effects of relative light intensity (RLI) on tiller number of turmeric. Data are means \pm SD of four replications. Data with the same letter within each month (from left : August, September, October and November in the experiment 1 (2004–2005); August, September, October and November in the experiment 2 (2005–2006)) are not significantly different at the 5% level, as determined by Tukey's multiple range test.

significantly at 48, 52 and 68% RLI, as compared with that in the control (100% RLI).

2. Effects of relative light intensity on curcumin content of turmeric rhizome

The curcumin content increased significantly under 59% RLI and non-significantly under 73, 79 and 82% RLI as compared to that under 100% RLI in 2004–2005 (Table 1). In 2005–2006, however turmeric grown at 52, 68 and 100% RLI obtained a similar curcumin content, and the curcumin content tended to reduce under 48% RLI.

Discussion

1. Effects of relative light intensity (RLI) on the growth and yield of turmeric

Plant height and number of leaves and tillers increased when turmeric was grown at a reduced RLI (Figs. 3, 4, 5). It is assumed that some physiological

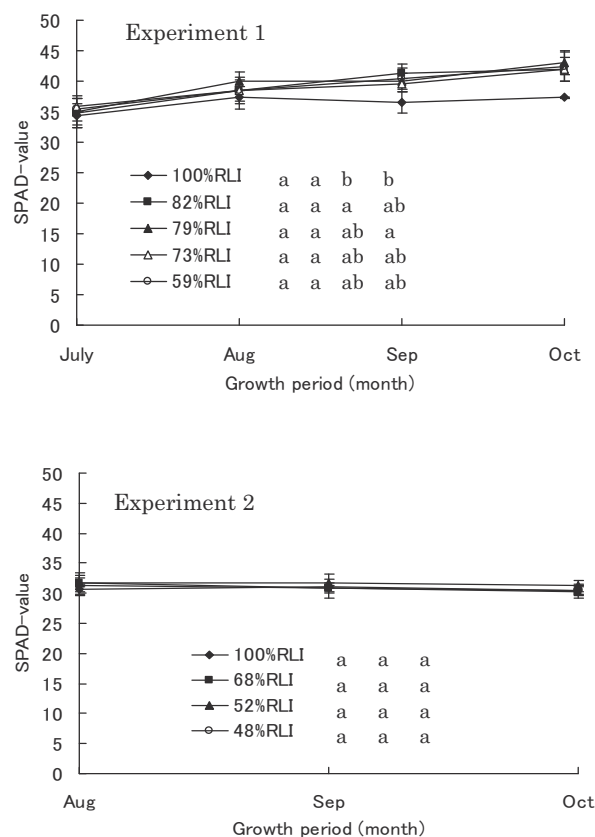


Fig. 6. Effects of relative light intensity (RLI) on SPAD-value of turmeric. Data are means \pm SD of four replications. Data with the same letter within each month (from left : July, August, September and October in the experiment 1 (2004–2005); August, September and October in the experiment 2 (2005–2006)) are not significantly different at the 5% level, as determined by Tukey's multiple range test.

process function properly at a reduced RLI. Similarly, Kobata et al. (2000) reported that rice can grow well with partial shading. Other studies revealed that plant height, leaf area development and leaf life are influenced by climatic and edaphic factors (Tworkoski, 1992; Ghera and Holt, 1995; Deen et al., 1998a). The SPAD-value was increased by the reduced RLI in September and October in 2004–2005, whereas it was not influenced by the RLI in 2005–2006 (Fig. 6). It is assumed that the efficacy of RLI varied with the daylight length, light intensity level, humidity and rainfall in 2004–2005 and 2005–2006 (Fig. 1). As a result, light influenced the SPAD-value of turmeric differently with the cropping seasons (Fig. 6). A higher SPAD-value may result in a better photosynthesis which contributed to higher yield in turmeric. Higher SPAD-value is the indication of higher chlorophyll content in leaf, which ultimately results higher photosynthesis. There are positive correlations among the SPAD-value, chlorophyll content, photosynthesis and plant growth parameters (plant height, leaf number, tiller number, shoot biomass, yield, etc.). Cohen et al.

Table 1. Effects of relative light intensity (RLI) on shoot green period (shoot green period was counted from planting to shoot yellowing), shoot biomass, rhizome yield and curcumin content of turmeric cultivated in experiment 1 (2004–2005) and experiment 2 (2005–2006) in Okinawa, Japan.

Experiments (year)	RLI (%)	Shoot green period (Day)	Shoot biomass (g plant ⁻¹)	Rhizome yield (g plant ⁻¹)	Curcumin content (%)
Experiment 1 (2004–2005)	100(Cont)	235	50±7 b	126± 6 d	0.126±0.000 b
	82	252	71±8 a	157± 5 c	0.140±0.008 b
	79	252	71±6 a	200±13 b	0.140±0.007 b
	73	252	84±3 a	232±24 a	0.155±0.011 ab
	59	252	73±6 a	171±14 c	0.194±0.022 a
Experiment 2 (2005–2006)	100(Cont)	170	46±4 b	80± 5 b	0.124±0.002 ab
	68	185	55±5 ab	111±10 a	0.129±0.005 a
	52	185	56±4 ab	112± 6 a	0.122±0.005 ab
	48	185	57±6 a	108± 7 a	0.111±0.011 b

Data are means±SD of four replications. Cont, without shading. Data with the same letter within each column for each experiment are not significantly different at the 5% level, based on the Tukey's multiple range test.

(2005) reported that chlorophyll content of grape fruit trees was increased by shading resulting in larger grapefruits. Similarly, Sarker et al. (2002) reported that a higher chlorophyll content of leaves caused a higher rate of photosynthesis and higher yield in rice plant.

Turmeric grown under lower RLI had increased vegetative parameters, and a higher shoot biomass. We previously reported that shoot biomass increased with the increasing plant height, leaf number and tiller number of turmeric (Hossain et al., 2005a, 2005b; Hossain and Ishimine, 2005). The plants grown under lower RLI remained green 15–17 ds longer, which contributed to a longer period of photosynthesis and resulted in a higher shoot biomass of turmeric (Table 1). Temperature was slightly higher (0.5–1.0°C) in the plants without shading (data not presented, Cohen et al., 2005). It was assumed that leaf stomatal functions in the plant grown without shading were affected by strong irradiance. Similarly, Clemente and Marler (1996) reported that stomatal conductance in papaya was influenced by the irradiance level. Cohen et al. (2005) reported that CO₂ uptake and conductance increased in grape leaf when grown under a shading condition. The leaves were found to be bended and leaf burn symptom was appeared on the plants grown without shading. The highest yield was obtained in the turmeric grown with the 73% RLI (Table 1) because the plants remained green longer and had a larger shoot biomass, which is in agreement with the results of previous studies (Ishimine et al., 2003, 2004; Hossain et al., 2005b; Hossain and Ishimine, 2005, 2007). Yield tended to reduce when RLI was less than 59% due to reduced shoot biomass. Other studies revealed that low light increases plant yield, though exceedingly low intensity light decreases the yield (Kobata et al., 2000; Sharma et al., 2006).

Effects of RLI on growth and yield of turmeric varied

with the year (Table 1). In the outdoor condition, it is difficult to clarify the reasons why the responses of growth and yield of turmeric to RLI vary with the cultivation year. However, it is assumed that RLI efficacy is influenced by rainfall, humidity, wind and plant growth stage, which varied with the year and resulted in variable growth and yield of turmeric. Similarly, Cohen et al. (2005) reported that growth and yield responses of grapefruit to sunlight levels vary with the year, which might be due to the differences in plant growth stage.

2. Effect of relative light intensity (RLI) on curcumin content of turmeric rhizome

Curcumin content of turmeric rhizome increased markedly at 59–73% RLI in 2004–2005 (Table 1), whereas it tended to increase at 68% RLI and decrease at 48% in 2005–2006, indicating that reduced RLI increases curcumin content but too much reduced RLI results antagonistic effect on curcumin accumulation. It is assumed that some physiological properties function in turmeric properly at 59–73% RLI in Okinawa, which probably resulted in a higher curcumin content. Cohen et al. (2005) and Joscelyne et al. (2007) reported that sugar content, pH level and phenolics content in grapes vary with the light exposure level.

The effects of RLI on curcumin content varied with the cultivation year (Table 1), which may be due to the variations of other factors such as rainfall, humidity and wind. It is assumed that environmental factors influence each other, and the efficacy of a factor changes with the change of any other factor, which influences the physiological functions in plants.

In the experiment in 2004–2005, shoot biomass and rhizome yield increased by reducing RLI to 73% and decreased at a lower RLI, but curcumin content

increased by the reducing RLI to 59%. This result indicates that curcumin correlates with shoot growth and/or rhizome yield positively at 73–100% RLI, but not at a lower RLI. In the experiment in 2005–2006, shoot biomass and rhizome yield increased similarly at 48, 52 and 68% RLI, but curcumin content tended to decrease at 48% RLI. Therefore, it is assumed that curcumin content (%) is not influenced by the amount of shoot biomass and/or rhizome yield but by the some unknown physiological functions that are influenced by RLI.

Conclusion

In the first experiment, turmeric shoot biomass and yield increased with the reducing relative light intensity (RLI) of up to 73%, and they tended to decrease with the lower RLI of 59%. In the second experiment, turmeric grown at 48, 52 and 68% RLI had a similar shoot biomass and yield, which were markedly higher than those in the control plant (100% RLI). In the first experiment, curcumin content in turmeric rhizomes increased markedly at 73 and 59% RLI, whereas in the second experiment curcumin content was not influenced by RLI, though it tended to increase at 68% RLI and decreases at 48% RLI. This study indicates that turmeric is a partial shade-tolerant plant, and has a higher yield and curcumin content at 59–73% RLI in Okinawa. The RLI required for better turmeric cultivation may vary with the place and year. This study also indicates that turmeric can be cultivated under trees and in orchards, which should be evaluated in future studies.

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