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Original Research Article

Effect of Shading on Rice Growth Characteristics Under Different Temperature Conditions

Zun Phoo Wai[1], Min-Ji Lee[2], and Woon-Ha Hwang[3,†]

ABSTRACT Environmental factors play an important role in crop growth and development. In recent years, climate change has become a challenge that limits environmental factors. Light is an important environmental factor for photosynthesis in rice. In addition, temperature is one of the most important factors for rice production; thus, a 1°C increase in temperature because of climate change can affect rice growth and development. Therefore, we investigated the effect of shading on the growth characteristics of rice under different temperature conditions from the vegetative stage to the flowering stage. Plants were grown at three different temperatures: 26°C/16°C for 21°C, 29°C/19°C for 24°C, and 22°C/32°C for 27°C in a phytotron. A 55% shade treatment was applied after 10 days of transplanting until the flowering stage. Plant height was not affected by the shading treatment. In the maximum tiller number response to shading, a lower tiller number and growth speed of tiller was found in the 27°C condition. Among leaf characteristics, shading increased the flag leaf area, length, width, and effective leaf area; however, it decreased the leaf number on the main stem, especially at 27°C. In terms of stem characteristics, shading affected culm wall thickness in both varieties. Finally, regarding the panicle characteristics, lower panicle numbers, spikelet numbers per panicle, primary numbers, and secondary numbers per panicle were found under the shading treatment. Most of the desirable characteristics were affected by the shading treatment at 27°C. Overall, these results indicated that shading had a greater effect on rice plant growth at high temperature.

Keywords : growth speed, response, rice, shading, temperature

Rice serves as staple crop for more than half of the world's population. Rice supplies 21% of energy and 15% of protein for capita human (Gnanamanickam, 2009). It is also economically important crop. It is grown in over 100 countries coming from all continents except Antarctica (USDA, 2017). Global rice production decreased 1% and most of rice production declines are because of adverse weather (USDA, 2023).

Rice is a short-day sunshine crop and it requires 1500 bright hours from transplanting to maturity. Growth and development of rice plant depends on environmental factors such as light, temperature, humidity and rainfall. In addition, rice yield stability is attributed by environmental factors. Light is one of important environmental factors and it serves critical natural source for photosynthesis of rice and it regulates the carbon metabolism processes. Low light intensity reduced yield and quality of rice.

Nowdays, climate change is being challenged and it has become a serious problem in rice production in globally (Wang *et al*., 2015). The occurrence of overcast, rainy sky and low light intensity and environmental pollution caused by climate change and industrial development enhances shade stress to rice production (Deng *et al*., 2018). In intercropping system, tall plant covers short plant and that fact supplies for shade stress. In crop production, high plant density results mutual shading affect each other. Shade stress effected rice plant in imbalance metabolic process and contributes changes in agronomical, morphological, physiological, quality and gene expression as well.

1)Scientist, Rice Research Center, Department of Agricultural Research, Yezin, Myanmar
2)Master Degree Student, National Institute of Crop Science (NICS), RDA, Jeon-ju 55365, Republic of Korea
3)Senior Scientist, National Institute of Crop Science (NICS), RDA, Jeon-ju 55365, Republic of Korea

†Corresponding author: Woon-Ha Hwang; (Phone) +82-63-238-5263; (E-mail) hwangwh@rda.go.kr
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In addition, temperature is one of climatic factor and related with other meteorological factors like solar radiation, humidity and light hours (Huang *et al*., 2013). Temperature can influence all growth stages of rice (Yoshida, 1981). However, the response of rice vary based on the genotypes, growth stage, intensity and duration of the temperature (Fahad *et al*., 2018). The rice growth and development can be changed with the increasing of 1°C temperature. Therefore, this experiment was conducted to understand shading effect on changes of rice plant under different temperature conditions.

MATERIALS AND METHODS

Plant Materials and Treatments

The experiment was carried out in the phytotron at National Institute of Crop Science (NICS) of Rural Development Administration (35°N, 127°E). Two Korean varieties, Hopyeng (high tller, less grain) and Sindonjjin (Low tiller, much grain) were use a plant material. Firstly, the seeds of two varieties were germinated and then 21-day-old seedlings were transplanted into the wagner pots (1/5000a). Plants were grown in the phytotron during the whole experiment. The growing environmental condition inside the phytotron during experiment were artificially made in three temperature conditions. The highest and lowest temperature were created into 26/16°C for 21°C, 29/19°C for 24°C and 32/22°C for 27°C conditions. The temperature inside the phytotron was changed every hour just as the natural condition. Shading treatment was started two weeks after transplanting. The photosynthetically active radiation (PAR, wavelength in the range of 350-650 nm) under normal light and shading treatment were measured with a quantum sensor (SQ-110, Apogee, USA) in every hour between 7:00AM and 6:00PM. The sum of PAR values for 7 days were 15,597 $\mu molm^{-2}s^{-1}$ under control condition and 7,018 $\mu molm^{-2}s^{-1}$ under shading condition. There was 55% less light radiation in shading treatrment compared to control condition. This experiment was started in March, 2023 and ended in early August, 2023. Fertilizer application and irrigation were used as necessary.

Growth Character

Growth characters such as plant height, leaf number and tiller number of each variety from each temperature treatment were measured with three replications. The plant height was measured from the ground surface to the tip of the longest leaf and panicle expressed in centimeter (cm) and the number of tillers and leaf number on main stem were counted. Plant height, tiller number and leaf number on the main culm were collected with ten-day interval from days after transplanting (DAT) to flowering stage. Leaf area was measured by using (LI Cor, LI-3100C). Stem internode diameter and culm wall thickness were measured by using digital clipper and expressed in millimeter (mm).

Statistical Analysis

The data were analyzed using STAR software (Statistical Tools for Agricultural Research, version 2.0.1, IRRI, Philhellenes) to test the significant of shade and shading and temperature interaction effect on growth of rice. The means were separated using Least significant different (LSD) at an alpha level of 0.05. In this study, we mainly focused on shading effect and interaction effect of shading and temperature. If there was no significant difference shading and temperature interaction effect for a parameter, then the values for that parameter were used to mean and error. T-test was also used to show significant shading effect with the mean data for all temperature regimes. The standard errors of the mean were also calculated and present in the graphs. Microsoft excel (2019) was used for graphs.

RESULTS AND DISCUSSION

Shading effect on plant height and tiller under different temperatures

Shading, temperature and their interaction did not show significant difference on plant height (Table 1). For tested varieties, shading has no effect on plant height at flowering stage at 21, 24 and 27°C. The average plant height of Sindonjjin and Hopyeng were 82.36 and 83.44 cm in control where as 86.18 and 82.01 cm in shading condition, respectively. Previous study reported that plant height in shading is significantly higher than that of normal condition (Hairmansis *et al*., 2017). In this study, the reason for non-significant effect of shading on plant height may be due to genetic factor. The variation in plant height was observed due to the variation in genetic variability and adaptability in studied area (Hossain *et al*., 2014).

There was significant difference shading, temperature and their interaction effect on tiller number at the maximun tillering stage (Table 1). In all temperature conditions, the tiller number at

Table 1. Effect of shading on plant height and tiller number at different temperature.

Treatment	Temperature (°C)	Plant height (cm)		Tiller number (No.)	
		Sindongjin	Hopyeng	Sindongjin	Hopyeng
Control	21	79.11a	81.27a	13.00a	15.00a
	24	79.39a	88.61c	11.11ab	13.05ab
	27	88.57c	80.44a	11.78ab	12.56b
	Mean	82.36	83.44	11.96	13.53
Shading	21	87.89c	81.40a	9.22bs	11.56bc
	24	84.27b	80.36a	7.33cd	9.44c
	27	86.38bc	84.26bc	4.34d	5.56d
	Mean	86.18	82.01	6.96	8.85
Shading		NS		**	
Temperature		NS		**	
Shading×Temperature		NS		**	

NS indicates non significant difference.
Different letters (a-d) within the same column represent significant difference ($P<0.05$) among the six treatments for the same rice variety. ** indicates a significant difference at the 0.01 level.

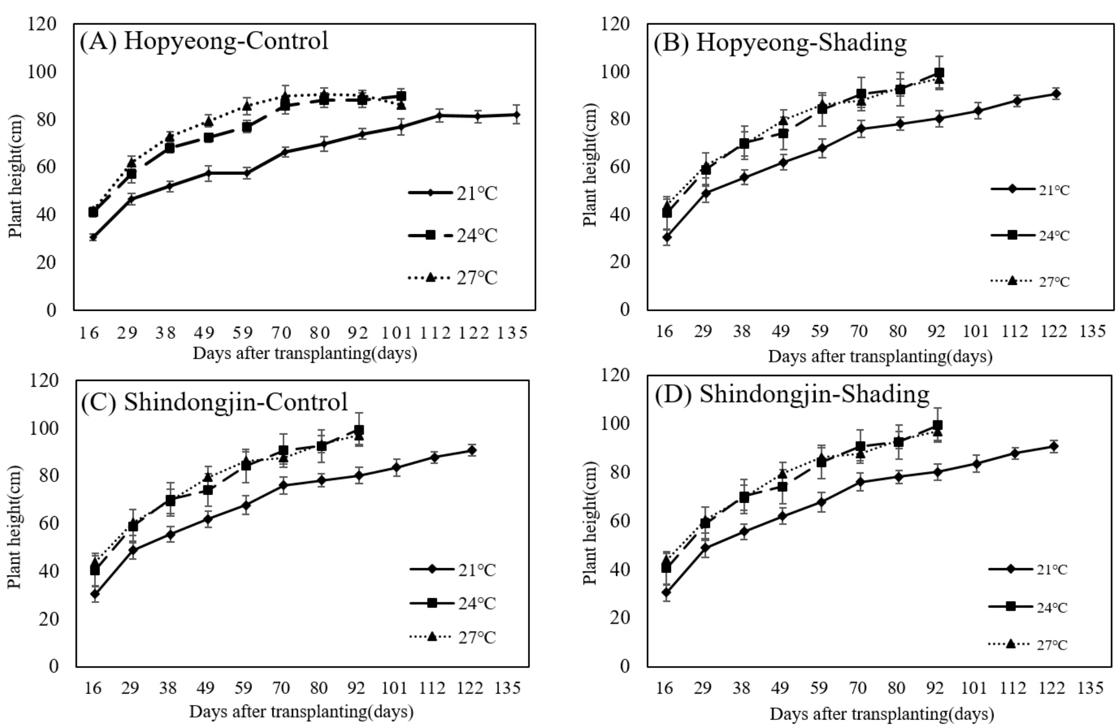

Fig. 1. Change in plant height during the growth period after transplanting under different temperature and shading condition.

the maximun tillering stage was fewer in shading than in control condition. Among temperature conditions, the tiller number at the maximun tillering stage showed the highest at 21°C for control condition and the lowest at 27°C for shading condition in both varieties. Therefore, combination of shading and high temperature (among tested temperature conditions) depressed on tiller bud emergence and also reduced tiller numbers.

We studied changing pattern of plant height and tiller number per plant (Figs. 1 and 2). In plant height, more days needed to reach the maximun plant height in 21°C among all treatments. In

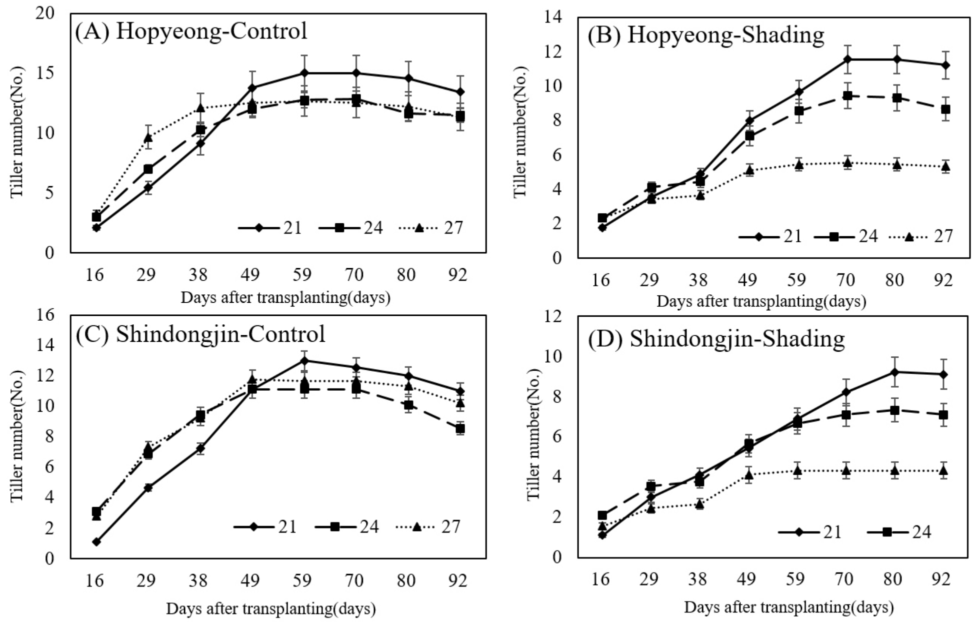

Fig. 2. Change in plant tiller number during the growth period after transplanting under different temperature and shading condition.

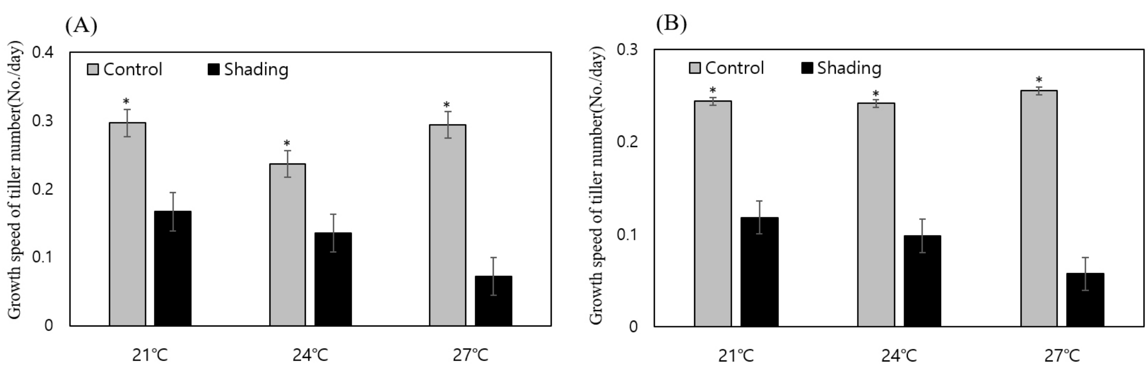

Fig. 3. Analysis of growth speed of tiller number per day according to different temperatures in the shading and control conditions (A) Hopyeng and (B) Sindongjin. The error bars indicate the standard error. * indicate a significant difference at the 0.05 level.

tiller number, it declined after reaching maximum tiller number in all temperature under control condition (Fig. 2A, C). However, under shading condition, tiller number could not change after reached maximum tiller (Fig. 2B, D). Increase in tiller number has high competition for nutrient and photosynthate intake within tillers in the same hill that leads to lack of ability to young tiller or late tillers and gradually to wither. Ahmad *et al*. (2005) reported that excessive tiller caused high tiller abortion. In shading condition, less tiller number has less competition for nutrient and that advantage support tiller number to stable. On the other hands, less tillers produced less panicle is undesirable character.

As shown in Fig. 3, growth speed of tiller formation per day in control was 2~3 time higher than in shading in all temperature conditions. In shading condition, 27°C showed the lowest growth speed of tiller formation per day. High value difference of tiller growth speed between control and shading was found in 27°C. It revealed that shading in high temperature exhibit reducing of tiller growth speed. In addition, it enhances reduction source activities like less in tiller number and low growth speed of tiller number.

In rice plant, tiller number is the most important agronomic trait and determines the panicle number which is a key component in grain yield (Liu *et al*., 2011) and main source of dry matter accumulation (Wu *et al*., 1998). Thus, it could be said that combination of shading and high temperature enhances grain reduction through reduction of source activities.

Effect of shaded on leaf characters under different temperatures

Leaves are the primary source of photosynthesis in plants. The analysis of leaf characters showed that shading, temperature and their interaction effect was found on leaf number on main stem, flag leaf area and flag leaf length while only shading effect was found on flag leaf width and effective leaf area (Table 2). For each variety within six treatments, maximum leaf number on main stem was found under control whereas minimum leaf number was found under shading condition in 27°C. This result pointed out shading treatment under high temperature stressed leaf formation and lower leaf number tends to reduce photosynthetic intakes. Maximum flag leaf area and flag leaf length were found under shading treatment and 27°C. Thus, limiting light irradiation and high temperature promote decrease leaf number, however, increase leaf expansion by increasing length and width (Table 2 and Fig. 4).

Among leaf length and width, leaf length showed higher positive correlation with leaf area then leaf width (Fig. 5). Based on resulted in this study, there is parallel increasing in one unit of leaf length, width and leaf area, especially in shading condition. In general, we can expect that increase leaf area give a result of increasing leaf activities such as chlorophyll content and photosynthetic activity.

Flag leaf and its penultimate leaves greatly influenced carbo-

Table 2. Effect of shading on leaf characteristics under different temperature conditions.

Treatment	Temperature (°C)	Leaf number on main stem (No.)		Flag leaf area (cm^2)		Flag leaf length (cm)		Flag leaf width (cm)		Effective leaf area (cm^2)	
		Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong
Control	21	13.22b	16.33a	24.20b	15.27c	24.00c	19.27c	1.37ab	1.00c	98.91bc	62.66c
	24	13.56b	16.11ab	24.75b	18.12bc	23.33c	21.67ac	1.37ab	1.10c	101.02bc	89.05abc
	27	15.89a	17.00a	24.04b	16.21c	24.67c	23.33bc	1.30b	1.00c	88.56c	76.46bc
Shading	21	12.89b	14.11b	29.79ab	19.56bc	29.33bc	22.00bc	1.43ab	1.23ab	112.36abc	92.33abc
	24	12.56bc	14.11b	40.64ab	26.26b	38.00a	28.00b	1.60ab	1.23ab	132.23ab	100.23ab
	27	11.11c	11.44c	43.61a	39.48a	35.67c	40.17a	1.73a	1.33a	147.29a	111.67a
Shading		**		**		**		**		**	
Temperature		**		**		**		NS		NS	
		**		**		**		NS		NS	

Different letters (a-d) within the same column represent significant difference ($P<0.05$) among the six treatments for the same rice variety. NS, *and ** indicates non-significant difference, significant difference at the 0.05 level, and significant difference at the 0.01 level, respectively. The effective leaf area represents the sum of the top three leaf areas.

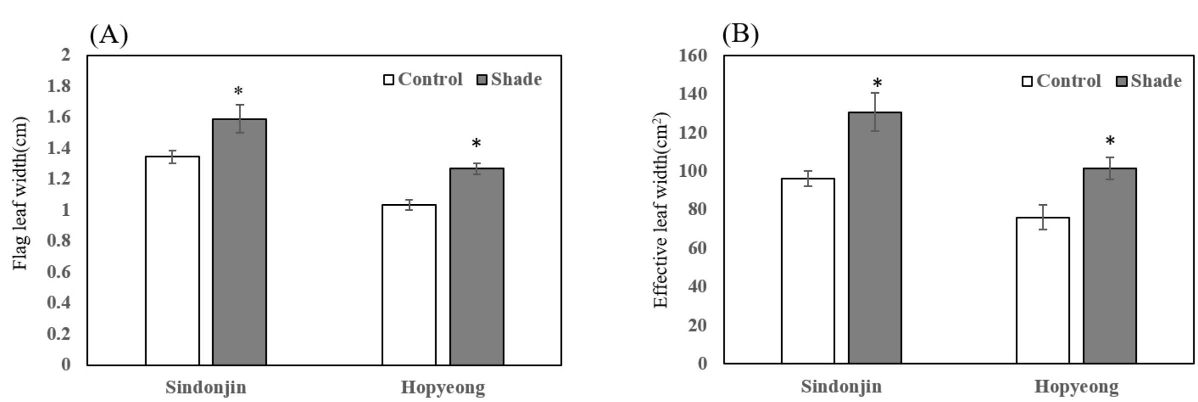

Fig. 4. Effect of shading on leaf width (A) and effective leaf area (B). The error bars indicated the standard error. * indicates a significant difference at the 0.05 level.

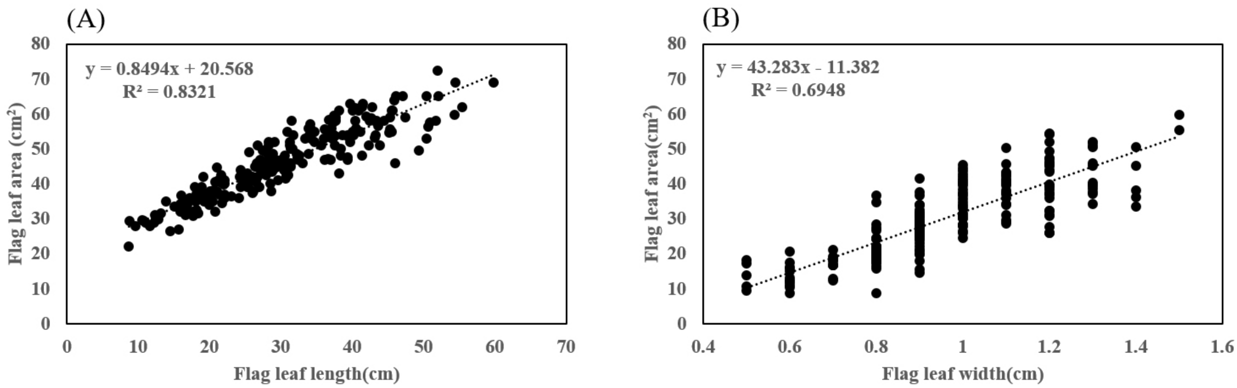

Fig. 5. Correlation of the flag leaf area with the flag leaf length and width.

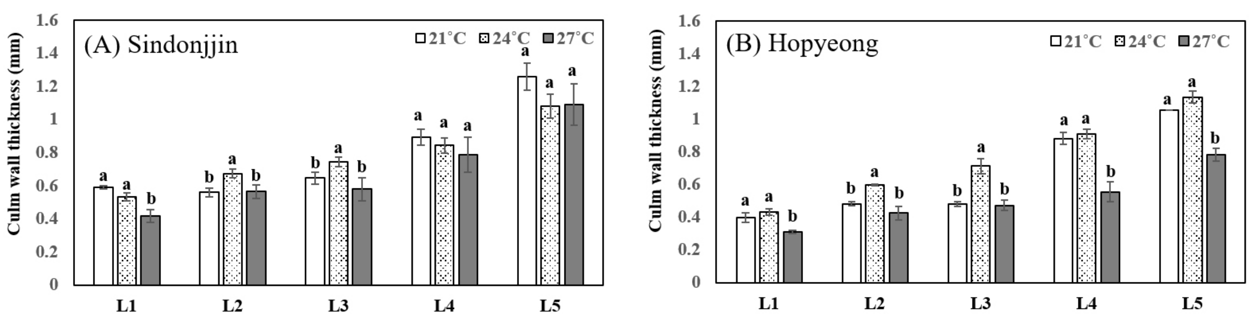

Fig. 6. Culm wall thickness under different temperature conditions. The error bars indicated the standard error. "a" and "b" indicate a significant difference at the 0.05 level. L1, L2, L3, L4, and L5 indicate internode numbers 1 to 5 (from the top to the base), respectively.

hydrate production (Al-Tahir, 2014) and provides photosynthetic products to the panicle. However, short and erect leaves reduced mutual shading and efficient light interception (Vangahun, 2012). The flag leaf must be wide and upright to meet the purpose of increase rice grain yield (Tari *et al*., 2009). Top three leaves are considered as photosynthetically active leaves and important for growth of the whole plant and are called physiologically active centers (Tanaka, 1961). Based on our result, high flag leaf area, wider flag leaf and high effective leaf area were found in shading and it could be considered as desirable characters. However, longer flag leaf length compare with control is not ignorable. Longer flag leaf promotes mutual shade which could be decrease lower leaf activities like photosynthesis, stomatal conductance and chlorophyll content. However, apart from this issue, shading has desirable leaf characters like flag leaf area and width.

Shading effect on stem characters under different temperatures

In rice, stem strength is important character as stem serve not only as a medium for water and nutrient but also as a stand for panicle. Also stem strength is one of the main factors for lodging resistant (Zhang *et al*., 2014). Stem physical strength of the rice plant could be increased with the increase in culm diameter and culm wall thickness (Kashiwagi, 2022). Also the length of elongated internode of basal stem, culm wall thickness and culm diameter greatly influence the lodging resistance capacity in rice (Kashiwagi *et al*., 2008; Ookawa *et al*., 2010). Higher outer diameter and culm wall thickness are desirable traits of physical strength (Zhang *et al*., 2016; Chen *et al*., 2021). In previous study reported that although the culm diameter is smaller, culm wall thickness and dry weight cm^{-1} of culm and leaf sheath are the important traits that determine lodging resistance of rice plant (Zhang *et al*., 2013). Zhang *et al*. (2013) also reported that culm wall thickness and dry weight cm^{-1} of culm and leaf sheath are the important traits that determine lodging resistance of rice plant, in spite of the smaller culm diameter.

Based on that report, firstly, we checked culm wall thickness in control group in different temperature condition (Fig. 6). Culm wall was thickest at 24°C condition in most of internode in

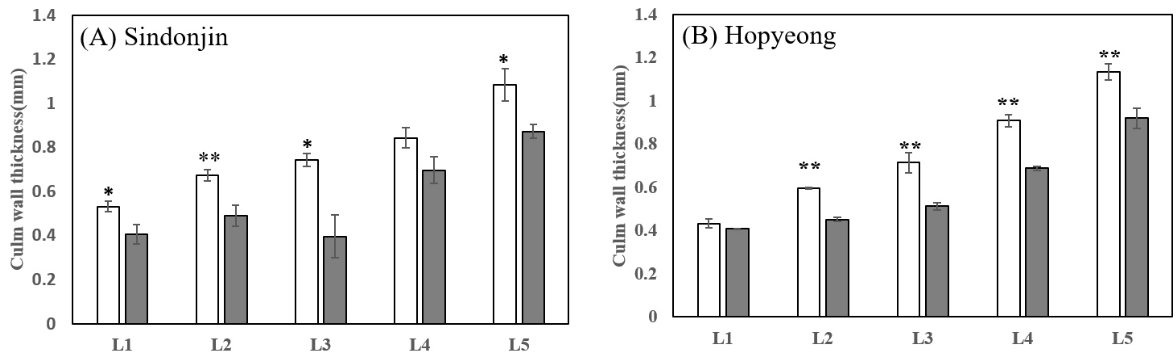

Fig. 7. Culm wall thickness in the internodes at 24°C under shading and control conditions. Internode numbers 1 to 5 indicate internode positions from the top to bottom.

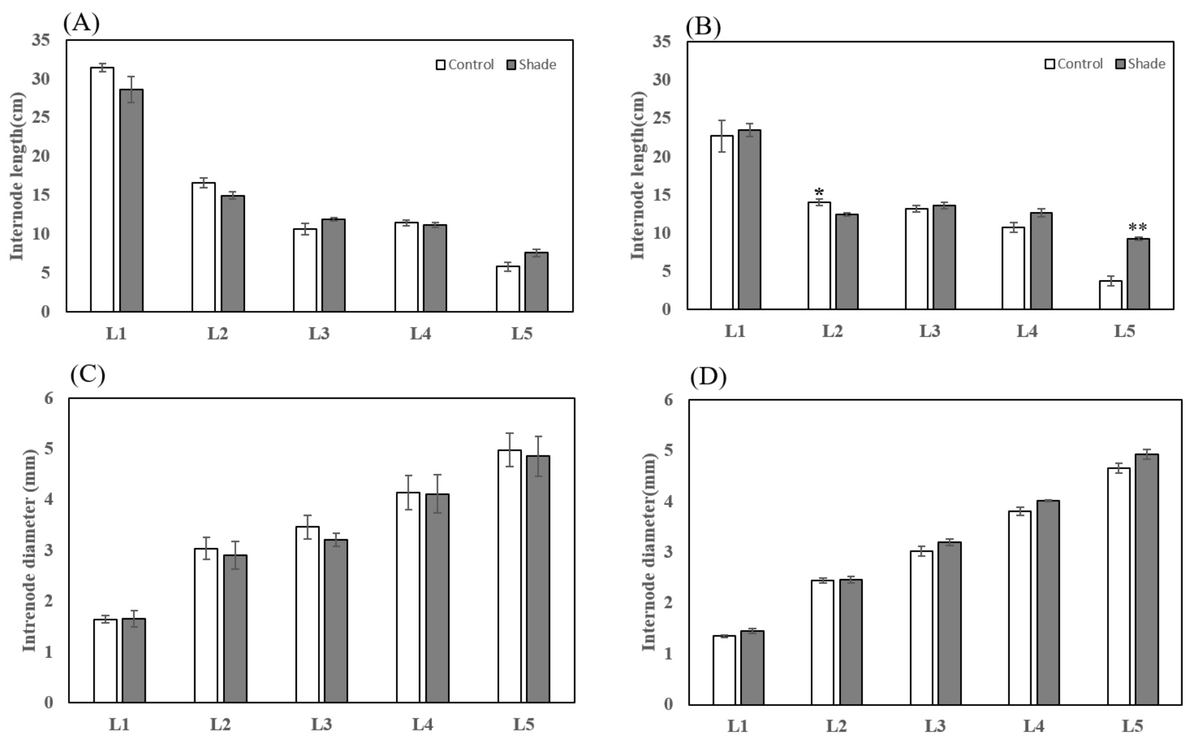

Fig. 8. Effect of shading on stem internode length and culm diameter (A, C for Sindonjin, and B, D for Hopyeng). The error bars indicated the standard error. * indicates a significant difference the at 0.05 level.

Sindongjin and Hopyeong. Based on this result, we checked shading effect on culm wall thickness in internode at 24°C with t-test analysis (Fig. 7). Results showed that the culm wall thickness in most of internode was decreaed in shading treatment compared to control condition.

We checked the Internode length and diameter at 24°C (Fig. 8). Internode diameter and length did not showed significant difference in control and shading condition in all internode. All of results confirmed that shading effect on internode length was unclear, but shading decrease culm wall thickness in both varieties. This result consistent with the report of Wu *et al*. (2017). Therefore, shading could be one of lodging susceptible risks through promote thin culm wall thickness and reduce stem strength.

Effect of shaded on panicle characters under different temperatures

Shading and temperature condition effected on panicle characters such as panicle number per plant, spikelet number per plant, primary branches per panicle and secondary branches per panicle (Table 3). Under control conditions, maximum value of

Table 3. Effect of shading on panicle characteristics under different temperature conditions.

Treatment	Temperature (°C)	Panicle number per plant (No.)		Panicle length (cm)		Spikelet number per panicle (No.)		Primary branches number per panicle (No.)		Secondary branches number per panicle (No.)	
		Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong	Sindongjin	Hopyeong
Control	21	8.89ab	12.11a	15.31ab	14.39b	62.94b	58.7b	7.67b	7.27a	6.06ab	5.33ab
	24	7.89abc	10.67a	16.4b	13.8ab	72.04a	57.44ab	9.04a	7.28a	7.83a	5.83a
	27	9.22a	10.78a	16.56b	14.38b	57.79ab	55.02ab	7.06b	7.11a	4.45bc	4.24ab
		8.67	11.20	16.09b	14.19b	66.26	57.05	7.92	7.22	6.11	5.13
Shading	21	7.44bc	10.33ab	15.42a	12.51a	41.58c	46.38b	5.41c	6.54ab	2.47cd	2.75bc
	24	6.44c	8.22b	14.26a	12.01a	41.77c	33.22c	6.13c	5.11c	1.62d	0.22c
	27	4.33d	5.33c	15.67ab	14.7c	42.95c	52.23ab	5.48c	5.92bc	1.92d	4.35ab
		6.03	7.93	15.12	13.07	42.1	43.94	5.67	5.86	2	2.44
Shading		**		**		**		**		**	
Temperature		**		**		NS		NS		NS	
		**		NS		**		**		**	

Different letters (a-d) within the same column represent significant difference (P<0.05) among the six treatments for the same rice variety. NS, *and ** indicates non significant difference, significant difference at the 0.05 level, and significant difference at the 0.01 level, respectively. The effective leaf area represents the sum of the top three leaf areas.

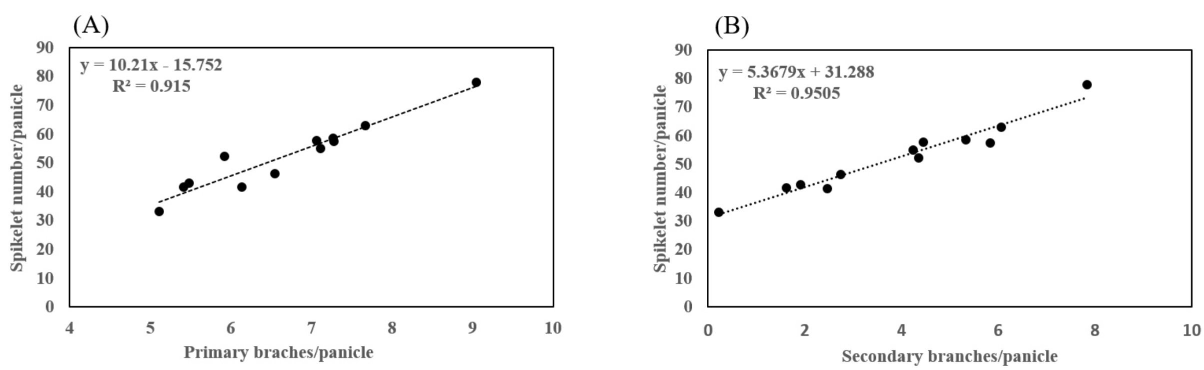

Fig. 9. Correlation of the spikelet number per panicle with the primary and secondary branches numbers.

panicle number was found in 21°C and in 27°C for Hopyeng and Sindonjin, respectively. Under shading condition, the minimum panicle number was found in 27°C in both varieties. It could be assumed that shading in high temperature could be imbalance carbohydrate distribution from plant organs to form panicle.

Among three temperature conditions, shading effect on spikelet number, primary branches and secondary branches per panicle were found in 24°C and 27°C (Table 3) in both varieties. Thus, shading resulted decline spikelet number, primary branches and secondary branches per panicle. Our result confirms with the previous report (Wang *et al*., 2018). The reason for reduced spikelet per panicle may be due to spikelet degeneration in booting stage. Spikelet per panicle has strongly positive relationship with primary branches and secondary branches (Fig. 9). That result showed that increase primary and secondary branches per unit area give a chance to increase spikelet number per unit area.

In general, panicle number and spikelet number are considered as yield attribute characters and they are determined at the panicle differentiation stage. the previous studies reported that shading reduced number and spikelet and yield (Chaturvedi *et al*., 1989) and panicle member (Deng *et al*., 2009). Therefore, it could be concluded that shading reduce yield of rice through reduction of panicle number, spikelet number, primary and secondary branches per panicle.

CONCLUSION

In conclusion, we found that shading effected tiller number and tiller growth speed. In shading condition, it enhances increase in flag leaf area, flag leaf length, flag leaf width and top three leaf area, however, decrease in leaf number on main stem. Furthermore, shading reduce culm wall thickness, especially basal internode. In addition, shading promotes reduce in panicle number, spikelet number, primary branches and secondary branches. Among three temperature, undesirable shading effect was found mostly in 27°C. Therefore, shading and high temperature combination seriously effect rice pant growth characters. In addition, our findings could be become one of considerations in finding solution of adaptation rice cultivation with climate change in future.

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