Effect of Red, Blue, Green LEDs on the Germination and Seedling Growth of Rice

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Abstract

The present investigations attempted to study the effects of red, blue and green LEDs effect on seed germination, first leaf length, first leaf blade length, root length, seedling fresh and dry weight. Seeds of five rice varieties were germinated and seedlings were grown under dark and red, blue, green LEDs lighting system (6 h photoperiod and 18 h dark) set at 20 to 24 ± 2 °C for day and night respectively and 70 ± 2 % relative humidity in a control chamber for 14 days (starting 3 days after plated for germination). The result showed that germination percent increased significantly in BRRIdhan52 and BRRIdhan75 under red-blue-green LEDs than dark. First leaf length increased in dark than LEDs treatment. Longest leaf (10.42 cm) was recorded in BRRIdhan86 in dark and under LEDs in BRRIdhan75 (5.70 cm). First leaf blade length was highest in BRRIdhan52 (2.56 cm) under LEDs treatment and in dark BRRIdhan67 had the longest (2.48 cm). Root length was also increased significantly in studied rice varieties. Though, longest root was found in dark in BRRIdhan71 (6.69 cm) and under LEDs, BRRIdhan71 had the longest root (6.35 cm). Seedling fresh and dry weight were highest under red-blue-dark LEDs treatment. BRRIdhan86 had the highest and BRRIdhan67 had the lowest seedling fresh and dry weight with a range of 0.323 g to 0.451 g and 0.037 g to 0.052 g respectively than dark condition. Root length showed positive significant correlation with seedling fresh weight (r = 0.876) and seedling dry weight (r = 0.873). Whereas seedling fresh weight showed complete correlation (r = 1) with seedling dry weight. Response index was negative for first leaf length in the studied rice varieties. Highest response index (35.93) was observed for seedling fresh and dry weight in BRRIdhan75 and BRRIdhan86.

Key words: Germination, LEDs, Rice, Response index, Seedlings

Introduction

Light is used by plants as an energy source for photosynthesis. Plants also use light as an environmental signal, and respond to its intensity, wavelength, and direction. Plant photoreceptors, which include phytochromes, cryptochromes, and phototropins, detect light and trigger a variety of physiological reactions. Providing appropriate amount and quality of light intensities from light source to photosynthetic organ is a major challenge for plants (Dong et al., 2014; Samuoliene et al., 2013).

Visible light wavelength ranges from 380 to 780 nm. The most absorbed light by chlorophylls and other pigments in higher plants is red light (640 - 660 nm) and blue light (430 - 450 nm), whereas green light (500 - 600 nm) is the least (Abboud et al., 2013). Many researchers have demonstrated the beneficial effects of red, blue, green light alone or mixed lighting, but rarely considering the duration and intensity of green light and the response of cereal crops (Zhang et al., 2016).

The light spectrum of the growth environment has a big impact on plant development and physiology, and blue light is involved in a lot of plant activities as phototropism, photo-morphogenesis, stomatal opening, and leaf photosynthetic functioning (Whitelam et al., 2007).

Plants absorb 90% of blue and red light (LEDs) (Terashima et al., 2009), indicating that blue and red light have a major influence on plant development and physiology (Olle et al., 2013). On the other hand, Green light has been shown to be harmful to physiological and developmental functions (Folta et al., 2007). Many research on plant growth and development have been published on a variety of crops grown in deficiency/efficiency or with a combination of red and blue light at different wavelengths (Fan et al., 2013; Lin et al., 2013). Photosynthesis is more similar in plants cultivated under blue light than in plants grown under red light (Buschmann et al., 1978; Leong et al., 1984).

Light emitting diodes (LEDs), because of its desirable properties such as minimal mass, safety, and durability, have been proposed as a light source for controlled environment agriculture facilities and space-based plant growth chambers (Yano et al., 2012; Kim et al., 2013; Yori et al., 2001).

The majority of studies examining the effects of blue light (blue LEDs) on the leaf or whole plant have compared the response to a broadband light source with the response to blue deficient light (Matsuda et al., 2008) or compared plants grown under red light alone (Yori et al., 2001; Matsuda et al., 2004). On the other hand, red LEDs emit a narrow spectrum of light (660 nm) that is close to chlorophyll and phytochrome...
maximum absorbance. Plants have evolved to use a wide spectrum of light to drive photosynthesis, despite the fact that red light components have a lot of potential for use as a light source to drive photosynthesis (Kang et al., 2013). Photosynthesis has been hindered by green LEDs (Sun et al., 1998). Several studies have evaluated the effectiveness and ineffectiveness of green light on plant growth and development (Frechilla et al., 2000).

The quality of seedlings during growth is therefore an important factor in rice improvement and production, especially when rice variety developed in controlled condition. Rice plants grow better under RB lights than under R alone during the vegetative growth stage (Matsuda et al., 2004; Ohashi et al., 2006). Guo et al. (2011) cultured rice seedlings using RB LEDs, which were more robust in terms of root number, stem diameter, health index, and soluble sugars than when incubated under other LED spectra. Little is known on the integrity of combined effect of green, red and blue LEDs, with no experimental evidence available concerning BRRI developed rice varieties. Therefore, in order to apply the findings of previous research to rice seedling quality and production, this study considered that, it is important to investigate the effects of light quality when provided by red, blue, green LEDs systems to meet different purposes.

The objectives of this study was to determine the efficacy of RBG LEDs radiation source in relation to the growth, development and quality of rice grown under various LEDs together at the same light intensity.

**Material and Methods**

**Plant materials and growth conditions**

Seeds of *indica* rice (*Oryza sativa* L.) cultivar, BRRIdhan52, BRRIdhan67, BRRIdhan71, BRRIdhan75 and BRRIdhan86 were used in this study (Table 1). Seeds were sterilized with 2% sodium hypochlorite for 20 min, washed extensively with distilled water and then germinated in Petri dishes with wetted filter paper at 24 ± 2 °C in the dark and LEDs. The germination test was conducted using the petridish method with three replicates of 100 seeds. Seeds were soaked in distilled water for 36 h at room temperature and placed on Whatman filter paper no.1. The petridishes were observed every day and the numbers of germinated seeds were recorded at 24 h interval up to 14 days from set up of the experiment.

**Table 1. Description of the four rice variety used in the present study**

| Rice variety | Growing season | Special phenotypic feature | Year of Release, Institution |
|--------------|----------------|---------------------------|-----------------------------|
| BRRIdhan52   | Aman           | Submergence tolerant      | 2010, BRRI                  |
| BRRIdhan67   | Boro           | Salinity tolerant         | 2014, BRRI                  |
| BRRIdhan71   | Aman           | Drought tolerant          | 2014, BRRI                  |
| BRRIdhan75   | Aman           | Uptake 25% less nutrient  | 2016, BRRI                  |
| BRRIdhan86   | Boro           | Anther culture derivative | 2017, BRRI                  |

After 48 h of incubation, uniformly germinated seeds were selected and sand cultured in a natural medium with 1:1 (Organic matter: Sand). Rice seedlings were raised in growth rooms with the LED lighting system set at 20 ± 2 °C and 24 ± 2 °C for day and night respectively and 70 ± 2% relative humidity under a 6 h photoperiod and 18 h dark.

**Light treatments**

LED lighting of 12W were used to control light quality. The spectral quality were measured using android apps. Light treatments for rice seed and seedlings included red LEDs (R), blue LEDs (B) and green LEDs (G). Specification of the red, blue and green LEDs light: 12Watt; voltage range 85 – 265 V; Frequency 50 – 60Hz; power factor ≥ 0.5; efficacy ≥ 95lm/W; color rendering index ≥ 80%; total harmonic distribution ≤ 15%; high lumen PF>0.9; 6500k daylight, ambient temperature: -20 °C ~40 °C. Distance between LED lights and seed or seedling were adjusted to get the approximately equal photosynthetic photon flux (PPF). The plants without red, blue and green light irradiation were used as the control i.e., dark.

**Data collection**

The experiment was independently performed three times with a randomized design of growth conditions and measurements representing the means of 15 plants (three replications consisting of five plants each) were taken. Five seedlings for each replication for combined LEDs (red, blue and green) light treatments were randomly selected for growth analysis.

**Germination**

Germination was recorded daily and was considered complete once the radicle protruded about >2 mm in length. The experiments were continued for 14 days (Ellis and Roberts, 1981).
Germination per cent

A seed was considered to be germinated as seed coat ruptured, plumule and radicle came out and were >2mm long. Germination count was expressed in percentage. The germination percentage was calculated using the following formula (International Seed Testing Association, 2006).

\[ \text{Germination (\%) = \left( \frac{\text{Number of seed germinated}}{\text{Total number of seed for test}} \right) \times 100} \]

Measurement of leaf, root and shoot length

Randomly selected five seedlings were taken from each petridish to measure first leaf length, first leaf blade length, root length and shoot length. First leaf length, first leaf blade length, root length and shoot length of the seedlings were measured after 17 days of seed setting (Kouio, 2003).

Measurement of fresh weight and dry weight of the seedling

After 17 days of seed setting 15 seedlings of each petridish was wrapped with brown paper and weighed the fresh weight first and then they were dried in oven at 70° C for 48 hours and weighed the dry weight. These were measured by four digit balance and expressed in gram.

Response index

Response index (RI) was calculated for showing inhibition and stimulation by different lights on seed germination and seedling growth (Tehrani et al., 2016). RI is calculated as: \( \text{RI} = \left( \frac{T}{C} - 1 \right) \times 100 \), where, \( T \) is the parameter under treatment and \( C \) is the parameter under control.

Data analysis

All measurements were evaluated for significance using analysis of variance (ANOVA) followed by the least significant difference (LSD) test at the \( P < 0.05 \) level. Completely Randomized Design was used to test the variation in rice varieties and growth condition. Simple linear correlation coefficient were calculated to find out the inter relation of the studied characters. All statistical analyses were conducted using MSTAT-C (Statistical analysis software) computer package program (Gomez and Gomez, 1984).

Result and Discussion

All of the studied parameters, including germination percent, first leaf length, first leaf blade length, root length, seedling fresh weight, and seedling dry weight, for five rice varieties: BRRIdhan52, BRRIdhan67, BRRIdhan71, BRRIdhan75 and BRRIdhan86 (Table 2).

Seed germination

Germination in the dark ranges from 70 to 99 percent. Highest germination was recorded in BRRIdhan71 and lowest in BRRIdhan75. Under red, blue and green LEDs, germination percentage ranged from 66 to 98 percent. BRRIdhan67 and BRRIdhan71 had the highest and BRRIdhan86 had the lowest percent of seed germination (Table 2). Earlier investigations showed that light spectrum plays an important role in germination (Tehrani et al., 2016). Simpson (1990) also reported that light inducible germination happens in a certain set of environmental conditions in many plant species, those may be dependent or independent to light. Information on effect of red, blue and green light on rice seed germination is very scars till to date.

First leaf length and leaf blade breadth

In dark first leaf length ranges from 7.88 to 10.42 cm. BRRIdhan86 had the longest and BRRIdhan52 had the shortest. First leaf blade length ranges from 1.93 to 2.48 cm (Table 2). BRRIdhan67 had the most and BRRIdhan75 had the least. Under red, blue and green LEDs, first leaf length ranges from 2.59 to 5.70 cm. BRRIdhan75 had the longest and BRRIdhan52 had the shortest. First leaf blade length ranges from 2.12 to 2.56 cm. BRRIdhan52 had the longest and BRRIdhan86 had the shortest (Table 2). Zhang et al. (2016) found highest seedling height in red-blue-green LEDs, which is different in the present study. Rice seedling height inhibition under blue light reported by Xu et al. (2020). In seedling stage, rice plants are short and strong under single-wave blue light, and the quality of seedlings is the best. LED red light promotes the growth of seedlings, and the number of seedlings and uniformity are better (Renliang et al., 2016). In the present study first leaf blade length increased under red-blue-green LEDs which agrees with the findings of Zhang et al. (2016) where, red-blue-green light increase leaf area in rice seedlings.
Table 2. Rice seed germination and seedling morphology as affected by dark and lighting from red, blue, green light-emitting diodes (LEDs)

| Variety    | Germination (%) | First leaf length (cm) | First leaf blade length (cm) | Root length (cm) | Seedling fresh weight (g) | Seedling dry weight (g) |
|------------|----------------|------------------------|-------------------------------|------------------|------------------------|------------------------|
| **Dark**   |                |                        |                               |                  |                        |                        |
| BRRIdhan52 | 82 ±1.14       | 7.88                   | 1.99                          | 5.79             | 0.356                  | 0.041                  |
| BRRIdhan67 | 96 ±1.13       | 10.18                  | 2.48                          | 4.10             | 0.305                  | 0.035                  |
| BRRIdhan71 | 99 ±0.58       | 8.43                   | 2.22                          | 6.69             | 0.405                  | 0.047                  |
| BRRIdhan75 | 70 ±1.15       | 8.46                   | 1.93                          | 4.94             | 0.304                  | 0.035                  |
| BRRIdhan86 | 80 ±1.14       | 10.42                  | 2.25                          | 5.48             | 0.332                  | 0.038                  |
| **RBG LEDs** |              |                        |                               |                  |                        |                        |
| BRRIdhan52 | 90 ±1.15       | 2.59                   | 2.56                          | 5.95             | 0.348                  | 0.040                  |
| BRRIdhan67 | 98 ±0.58       | 4.80                   | 2.38                          | 5.43             | 0.323                  | 0.037                  |
| BRRIdhan71 | 98 ±0.33       | 4.36                   | 1.94                          | 6.35             | 0.385                  | 0.044                  |
| BRRIdhan75 | 92 ±1.15       | 5.70                   | 2.45                          | 4.94             | 0.377                  | 0.043                  |
| BRRIdhan86 | 66 ±1.14       | 5.07                   | 2.12                          | 6.12             | 0.451                  | 0.052                  |

Values show Mean ± SE (n=5). All the values were significantly different at p ≤ 0.0001.

**Root length, seedling fresh weight and dry weight**

In dark root length ranges from 4.10 to 6.69 cm. BRRIdhan71 had the longest and BRRIdhan67 had the shortest root. Under red, blue and green LEDs, root length ranges from 4.94 to 6.35 cm. Longest root was found in BRRIdhan71 and shortest in BRRIdhan75. According to Zhang *et al.* (2016), higher total root length of rice seedlings was found under red-blue-green light, which was not different in the present study (Table 2).

Seedling fresh weight ranges from 0.304 to 0.405 g and seedling dry weight ranges from 0.035 to 0.047 g in dark. BRRIdhan71 had the highest and BRRIdhan75 had the lowest seedling fresh weight and seedling dry weight. Under red, blue and green LEDs, Seedling fresh weight ranges from 0.323 to 0.4051 g and seedling dry weight ranges from 0.037 to 0.052 g. BRRIdhan86 had the highest and BRRIdhan67 had the lowest seedling fresh and seedling dry weight. The findings of the present study agree with the statement of Zhang *et al.* (2016), who found highest shoot dry weight and dry mass of root in rice seedlings in consecutive years under red-blue-green light LEDs treatment.

**Correlation between seed germination and seedling characters**

Correlation coefficient was calculated for germination percent, first leaf length, first leaf blade length, root length, seedling fresh weight and seedling dry weight (Table 3). Germination percent showed non-significant correlation with all the seedling characters, among these association there were two negative and two positive. First leaf blade showed negative significant correlation with root length, seedling fresh and dry weight. Root length showed positive and significant correlation with seedling fresh weight (r = 0.876) and seedling dry weight (r = 0.873). Seedling fresh weight showed complete correlation (r = 1) with seedling dry weight. Zhang *et al.* (2016) also reported positive significant correlation for root shoot characters in rice seedlings, which justified the findings in the present study.
Table 3. Correlation between seed and seedling characters in rice varieties.

|                          | Germination (%) | First leaf length (cm) | First leaf blade length (cm) | Root length (cm) | Seedling fresh weight (g) | Seedling dry weight (g) |
|--------------------------|-----------------|------------------------|------------------------------|-----------------|--------------------------|------------------------|
| Germination (%)          | 0               | -0.277**               | 0.165**                     | 0.129**         | -0.226**                 | -0.208**               |
| First leaf length (cm)   | 0               | 0                      | 0.143**                     | -0.469*         | -0.062**                 | -0.045**               |
| First leaf blade length (cm) | 0          | 0                      | 0.726*                      | -0.849*         | 0.876*                   | 0.873*                 |
| Root length (cm)         | 0               | 0                      | 0.873*                      | 0.876*          | 0                        | 0                      |
| Seedling fresh weight (g) | 0               | 1***                   | -2.23                       | 2.71            | -2.23                    | -2.23                  |
| Seedling dry weight (g)  | 0               | 0                      | 5.76                        | 5.76            | 5.76                     | 5.76                   |

*, ** Indicate significant differences between dark and green LEDs treatment at p ≤ 0.05 and p ≤ 0.01 level, respectively. Ns: Not significant at (n - 2) df.

(a) Germinated seeds of BRRIdhan52 in dark

(b) Seedlings of BRRIdhan52 grown under red, blue, green LEDs (left) and in dark (Right)

Plate 1. Effect of dark (a) and red, blue, green LEDs (b) on germinated seed and seedling of BRRIdhan52.

Table 4. Response index for growth parameters of 5 rice varieties under red-blue-green LEDs lights.

| Variety       | Germination (%) | First leaf length (cm) | First leaf blade length (cm) | Root length (cm) | Seedling fresh weight (g) | Seedling dry weight (g) |
|---------------|-----------------|------------------------|------------------------------|-----------------|--------------------------|------------------------|
| BRRIdhan52    | 9.76            | -67.20                 | 28.68                        | 2.71            | -2.23                    | -2.23                  |
| BRRIdhan67    | 2.08            | -52.89                 | -4.03                        | 32.34           | 5.76                     | 5.76                   |
| BRRIdhan71    | -1.35           | -48.29                 | -12.81                       | -5.08           | -4.97                    | -4.97                  |
| BRRIdhan75    | 31.43           | -32.66                 | 26.58                        | 0.03            | 23.79                    | 23.79                  |
| BRRIdhan86    | -17.50          | -51.39                 | -5.92                        | 11.60           | 35.93                    | 35.93                  |
Response index

Inhibition and stimulation by red, blue and green LEDs on seed germination and seedling growth were assessed through response index in rice varieties (Table 4) (Plate 1). Seed germination was stimulated by red, blue and green LEDs ranging from 2.08 to 31.43 percent. BRRIdhan86 showed highest response and lowest response by BRRIdhan67. Negative response for seed germination was found in BRRIdhan86 and BRRIdhan71. First leaf length was inhibited by red, blue and green LEDs. Response index ranges from -32.66 to -67.20 percent. BRRIdhan52 showed highest and BRRIdhan67 showed lowest negative response to light spectra. First leaf blade length was stimulated in BRRIdhan52 (28.68%) and BRRIdhan75 (26.58%). Negative response for first leaf blade length showed by BRRIdhan67, BRRIdhan86 and BRRIdhan71 with a range from -4.03 to 12.81 percent. Root length was stimulated in all the varieties except BRRIdhan71 (-5.08%). Response index for root length ranges from 0.03 to 28.68 percent. Highest growth response showed by BRRIdhan67 and lowest by BRRIdhan75. Seedling fresh weight and dry weight were stimulated in BRRIdhan86, BRRIdhan75 and BRRIdhan67 with a range from 5.76 to 35.93 percent. Highest response was recorded in BRRIdhan86 and lowest in BRRIdhan71. Negative response was indexed in BRRIdhan71 (-4.97%) and BRRIdhan52 (-2.23%) for seedling fresh weight and seedling dry weight. A number of studies demonstrated that the combination of red and blue light was an effective light source for plant growth (Lian et al., 2002; Nhut et al., 2003; Matsuda et al., 2004; Jao et al., 2005; Ohashi-Kaneko et al., 2006; Johkan et al., 2010). However, it was found that the highest stem width, shoot and root height, dry weight of shoot and root were all observed in RBG (Zhang et al., 2016).

Illuminance is also a key photo-environmental component influencing rice development as well as an important ecological factor influencing photosynthetic rate. Different plants require different levels of illumination. This suggests that combining red and blue LEDs with green light improves stem and root elongation and dry weight accumulation. Kim et al. (2004a) also reported a similar result. This could be due to the fact that green light penetrates the plant canopy more than red and blue light, potentially enhancing plant growth via increasing photosynthesis from the lower canopy leaves (Kim et al., 2004a; Terashima et al., 2009). Alternatively, green light could be reversing the effects of blue wave bands on elongation inhibition, causing the leaves to extend further (Bouly et al., 2007; Wang et al., 2015). Therefore, it is concluded the effect of LEDs lighting treatments on rice seed and seedling may be helpful to obtain higher germination and healthy seedlings in controlled environment.

As a result, the optimal illuminance of different rice varieties suitable for different periods can be studied and determined based on the photo-lightness of rice, and then the illuminating irradiance required for the rice daily cycle can be analyzed based on the daily variation of external environmental illuminance. Using rice as an example, researchers discovered that a balanced mix of light quality, illuminance, and illumination time in an artificial light environment is a significant component in improving rice seedling quality, yield, and nutritional content. The use of novel photoelectric technologies to additional plant physiological types deserves more investigation and discussion.

References

Abboud, T.; Bamsey, M.; Paul, A.-L.; Graham, T.; Graham; S.; Novmeir R.; Berninstain A. and Ferl R. 2013. Deployment of a fully-automated green fluorescent protein imaging system in a high arctic autonomous greenhouse. Sensors, 13: 3530–3548.

Bouly, J. P.; Schleicher, E.; Dionisio-Sese, M.; Vandenbussche, F.; Van Der Straeten; D.; Bakrim, N.; Meier, S.; Batschauer, A., Galland, P. ; Bittl, R. and Ahmad, M. 2007. Cryptochrome blue light photoreceptors are activated through interconversions of flavin redox states. The Journal of Biological Chemistry, 282: 9383–9391.

Buschmann, C.; Meier, D.; Kleudgen, H.K. and Lichtenhaler, H. K. 1978. Regulation of chloroplast development by red and blue light. Photochem. Biol. 27, 195–198.

Dong, C.; Fu, Y.; Liu, G. and Liu, H. 2014. Low light intensity effects on the growth, photosynthetic characteristics, 2 antioxidant capacity, yield and quality of wheat (Triticum aestivum L.) at different growth stages in BLSS. Adv. Space Res., doi:10.1016/j.asr.2014.02.004.

Ellis, R.H., and E.H., Roberts. 1981. The quantification of ageing and survival in orthodox seeds. Seed Science and Technology 9, 373–409.

Fan, X.X.; Xu, Z.G.; Liu, X.Y.; Tang, C.M.; Wang, L. W. and Han, X. L. 2013. Effect of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. Sci. Hort.153, 50–55.

Folta, K.M. and Maruhnich, S.A. 2007. S.A. Green light: A signal to slow down or stop. J. Exp. Bot. 2007, 58, 3099–3111.

Frechilla, S.; Talbott, L.D.; Bogomolni, R.A. and Zeiger, E. 2000. Reversal of blue light-stimulated stomatal opening by green light. Plant Physiol., 41, 71–176.

Gomez AK. and Gomez, AA.1984. Statistical Procedures for Agricultural Research 2nd ed. International Rice Research Institute, Los Banos, Philippines, pp 207-215.

Guo Y.S.; Gu A.S. and Cui, J. 2011. Effects of light quality on rice seedlings grow th and physiological characteristics, Chinese Journal of Applied Ecology, 22(6), 1485-1492.

International Seed Testing Association, 2006. ISTA Handbook on Seedling Evaluation, second ed. International Seed Testing Association, Zurich, Switzerland.

Jao R., C.; Lai C.-C., Fang W. and Chang, S. F. 2005. Effects of red light on the growth of Zantedeschia.
plantlets in vitro and tuber formation using light-emitting diodes. Hortscience, 40: 436–438.

Johkan M.; Shoji K., Goto F., Hashida S. N. and Yoshihara, T. 2010. Blue light-emitting diode light irradiation of seedlings improves seedling quality and growth after transplanting in red leaf lettuce, Hort. science, 45(12), 1809-1814.

Kang, J.H.; Krishnkumar, S.; Sua Atulba, S.L.; Jeong B.R. and Hwang, S.J. 2013. Light intensity and photoperiod influence the growth and development of hydroponically grown leaf lettuce in a closed-type plant factory system. Hort. Environ. Biotechnol. 54, 501–509.

Kim H. H.; Goins G. D.; Wheeler R. M. and Sager, J. C. 2004. Stomatal conductance of lettuce grown under or exposed to different light qualities, Ann Bot, 94(5), 691-697.

Kim, K.; Kook, H.S.; Jang, Y.J.; Lee, W.H.; Kamala Kannan, S.; Chae J.C. and Lee, K.J. 2013. The effect of blue-light-emitting diodes on antioxidant properties and resistance to Botrytis cinerea in tomato. Plant Pathol. Microbiol., 4, 49.

Kouio, A.G. 2003. Chemical and biological changes in seed treatment of rice varieties. Journal of rice Science. International Rice Research Institute, Los Banos, Philippines, pp 207-215.

Leong, T.Y. and Anderson, J.M. 1984. Effect of light quality on the composition and function of thylakoid membranes in Atriplex triangularis. Biochem. Biophys. Acta, 766, 533–541.

Lin, K. H.; Huang, M.Y.; Huang, W.D.; Hsu, M.H.; Yang, Z. W. and Yang, C.M. 2013. The effects of red, blue and white light-emitting diodes on the growth, development, and edible quality of hydroponically grown lettuce (Lactuca sativa L. Var. Capitata). Sci. Hort., 150, 86–91.

Matsuda, R.; Ohashi-Kaneko, K.; Fujiwara, K. and Kurata, K. 2008. Effects of blue light deficiency on acclimation of light energy partitioning in PSII and CO2 assimilation capacity to high irradiance in spinach leaves. Plant Cell Physiol., 49, 664–670.

Matsuda, R.; Ohashi-Kaneko, K.; Fujiwara, K.; Goto, E. and Kurata, K. 2004. Photosynthetic characteristics of rice leaves grown under red light with or without supplemental blue light. Plant Cell Physiol., 45, 1870–1874.

Nht D. T.; Takamura T.; Watanabe H. and Tanaka, M. 2003. Efficiency of a novel culture system by using light-emitting diode (LED) on in vitro and subsequent growth of micropropagated banana plantlets, Acta Hort., 161, 121-127.

Ohashi-Kaneko K.; Matsuda R.; Goto E.; Fujiwara K. and Kurata, K. 2006. Growth of rice plants under red light with or without supplemental blue light, Soil Sci. Plant Nutr., 52(4), 444-452.

Olle, Margit, and Virsile, A. 2013. The effects of light emitting diode on greenhouse plant growth and quality. Agric. Food Sci., 22, 223–234.

Renliang Xu, Guoliang Zhang and Yan. Yuanjing Yan. 2016. Effects of LED Blue, Red and its Combinations on Rice Seedlings Quality[J]. Journal of Huaian University of Technology, 25(5):39-44.

Samueliene, G.; Brazaityte, A.; Jankauskienė, J.; Virsile, A.; Sirtautas, R.; Noviškuvas, A.; Sakalauskienė, S.; Sakalauskaite, J.; Duchovskis, P. LED irradiance level affects growth and nutritional quality of Brassica microgreens. Cent. Eur. J. Biol. 2013, 8, 1241–1249.

Simpson, G.M. 1990. Seed dormancy in grasses. 1st ed. University Press, Cambridge, UK.

Sun, J.D.; Nishio, J.N. and T. C. Vogelmann. 1998. Green light drives CO2 fixation deep within leaves. Plant Cell Physiol., 39, 1020–1026.

Tehrani, P.; Mahmoodzadeh, Homa and T. Satari. 2016. Effect of red and blue light-emitting diodes on germination, morphological and anatomical features of Brassica napus. Advanced Studies in Biology, 8. 173-180. 10.12988/asp.2016.6832.

Terashima, I.; Fujita, T.; Inoue, T.; Chow, W.S. and R. Oguchi. 2009. Green light drives leaf photosynthesis more efficiently than red light in strong white light: Revisiting the enigmatic question of why leaves are green. Plant Cell Physiol., 50, 684–697.

Wang Y.H.; Zhang T.T. and Folta K.M. 2015. Green light augments far-red-light-induced shade response. Plant Growth Regulation,77: 147–155.

Whitelam, G. and K. Halliday. 2007. Light and Plant Development; Blackwell: Oxford, UK.

Xu, Xiaqiao; Chen, Qingchang and Yaming, Cai. 2020. Physiological Effects of Artificial Light Environment on Rice in Ecological Landscape. IOP Conference Series: Earth and Environmental Science. 598. 012001. 10.1088/1755-1315/598/1/012001.

Yano, A. and Fujiwara, K. 2012. Plant lighting system with five wavelength-band light-emitting diodes providing photon flux density and mixing ratio control. Plant Methods. 8, 46.

Yorio, N.C.; Goins, G.D.; Kagie, H.R.; Wheeler, R.M. and Sager, J. 2001. Improving spinach, radish, and lettuce growth under red light-emitting diodes (LEDs) with blue light supplementation. Hort. Sci., 36, 380–383.

Zhang, Shixiu; DD, Huang, XY, Yi; Zhang, Su; Yao, R.; CG, Li; Liang, Aizhen and Zhang, Xp. 2016. Rice yield corresponding to the seedling growth under supplemental green light in mixed light-emitting diodes. Plant, Soil and Environment. 62. 222-229. 10.17221/783/2015-PSE.