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Effect of three specific spectra of LED light on the growth, yield, and fruit quality of Sida tomato

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ABSTRACT

The LED artificial light has been widely applied for greenhouse and indoor plantation. The artificial light generates sole red per blue (R:B) light ratio during plant cultivation from seedling through the fruiting period. The aim of this study is to investigate the fruit quality and the yield of Sida tomatoes under three specific spectra of LED light at different R:B ratios in comparison with the tomato yield and fruit quality under sole R:B light ratio. The experiments were divided into two groups. The 1st experimental group involved applying the LED light at R25:B75R for the seedling stage, R50:B50 for the vegetative growth, and R75:B25R for the fruit stage. The second experimental group involved applying the LED light at R63:B37 for the seedling, vegetative growth, and fruiting stages. Independent t-test was applied to determine the mean difference of the plant height, stem diameter, fruit yield, fruit weight, fruit size, and TSS. The experimental period was for 115 days. The results confirmed that the three specific spectra of LED light for each growth stage could promote the highest fruit weight, fruit yield, marketable fruit weight, and marketable fruit yield when compared to Sida tomatoes treated with one constant spectrum. Moreover, the level of total soluble sugar is also the highest. Sida tomatoes treated with three specific spectra of LED light has contributed to early and increased fruit yield. This method could be applied to produce high quality tomatoes and yield for the indoor plantation system.

1. Introduction

Light is essential to the growth and development of the living things such as animals and plants. The natural sun light consists of a wide range of electromagnetic spectrum from 290 nm to 3200 nm. The light spectrum that supports plant photosynthesis most efficiently lies in the range of 400 to 700 nm according to the 1972 experiment by McCree, hence, the name McCree action spectrum or the PAR spectrum (Photosynthetic Active Radiation) (McCree, 1971). In the PAR spectrum, the B light at 400 nm to 460 nm and the R light of 620 to 660 nm were supplied at the highest quantum flux which subsequently contributed most to the photosynthetic process of the plants (Trouwborst et al., 2016; Yen et al., 2013; Dănilă and Lucache, 2016). It is possible to infer that the B and R light are the most important for supporting plant's photosynthesis. Moreover, two other important quantities in the plant morphological growth and development are the plants (Trouwborst et al., 2016; Yen et al., 2013; Dănilă and Lucache, 2016). It is possible to infer that the B and R light are the most important for supporting plant's photosynthesis. The photosynthetic photon flux Density (PPFD sometime call PPF), and the photoperiod. The PPFD is expressed in terms of moles of photon (energy of light between 400-700 nm of wavelength) per square meter per second or indicated in μmol $m^{-2}s^{-1}$. Usually, the level of the PPFD has to be controlled in order to match with the plants' needs in each growth stage. For example, in the seeding stage, many type of plants require low PPFD such as 50-100 μmol $m^{-2}s^{-1}$ (Johkan et al., 2010; Godo et al., 2011; Rabara et al., 2017), and for the vegetative growth stage, the plants require higher PPFD of about 200-400 μmol $m^{-2}s^{-1}$ (Jishi et al., 2016; Bantis et al., 2016; Amoozgar et al., 2017; Yao et al., 2017; Chen et al., 2017). The level of PPFD could be controlled by adjusting the intensity of the light sources. The photoperiod shows the effect of growth and development of the plants. Some previous studies indicated that longer

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photoperiod could promote the plant stem, height and the number of leave (Yunze and Shuangsheng, 2014; Chen et al., 2017). We can conclude that the most suitable photoperiod for the indoor plantation system should be 12 to 16 hours (Yunze and Shuangsheng, 2014; Chen et al., 2017; Amoozgar et al., 2017).

The use of artificial light gives many advantages. It could generate specific light wavelength as well as maintaining the ease of control of the PPFD, and the timing control of the photoperiod. Nowadays, the LED artificial light is widely used for the residential houses, greenhouses plantation, indoor plant cultivation, growth chamber, and plant factory due to the fact that the LED light is able to produce possible luminous quality with energy efficiency of about 80-90% (Almeida et al., 2014), and is also environmental friendly when compared with the other light technologies.

In Thailand, tomatoes are very popular as they are widely used for side dishes in the spicy paste of the Thai traditional food, especially, the papaya salad (most popular for Thai and foreigner). Moreover, Sida-tomato (*Lycopersiconesculentum Mill*) is widely used for many kinds of Thai food. The taste of Sida-tomato is sour and sweet. Tomato contains many types of vital nutrients that are beneficial for health such as vitamin C, and higher Lycopene content when compared with other fruits (Alda et al., 2009). The artificial LED light could promote tomato growers with a 30%, increase in expected yield, and higher fruit quality (Dzakovich et al., 2015). It was demonstrated that Blight could promote tomato plant's height (Matsuda et al., 2016; Yang et al., 2018) and the R light, when combined with Blight with the same quantity, increases the tomato stem diameter and chlorophyll a, chlorophyll b, and carotenoid content (Yang et al., 2018). Moreover, some of the previous studies about the tomato fruit yield indicated that the R light could promote the fruit number and the fruit yield of the greenhouse tomato (Brazaityte et al., 2009; Jiang et al., 2017).

However, most studies of the R and B light treatment in different ratios were in the seedling stage of the tomato. There are only a few studies about the effect of R and B light during fruit stage such as Brazaityte, and Jiang (Brazaityte et al., 2009; Jiang et al., 2017). Only Brazaityte studied the tomato in two stages: transplants stage and fruit stage. They used the LED light at a higher ratio of R light than B light in combination with UV and FR light. There are no data about the tomato seedling and growth under the other specific spectrum of R:B light ratio. Only one specific spectrum of light for the plantation was studied. Therefore, this lead the Authors to the research question: Are there effects or relationships between the yield and quality of tomato fruit under different types of R and B light ratio in the seedling stage, vegetative growth stage, and fruit stage? If so, which method would give the highest yield? The authors aimed to study the fruit quality and yield of Sida-tomato under three specific spectra, for the seedling state, vegetative growth, and fruit state, of the LED at different R:B light ratio by comparing the obtained values with the tomato yield and fruit quality under sole R:B light ratio.

2. Material and methods

2.1. Plant and growth conditions

2.1.1. Seedling stage

This study was conducted at Rajamangala university of Technology Suvarnabhumi, Nonthaburi Thailand. Seeds of tomato "Sida-tomato" (Known-you Seed Co., ltd, Thailand) were sown into rectangular growing tray with 15 pots (pot diameter is 10 cm) containing loamy soil, compost, paddy husk charcoals, and coconut dust in the same quantity and placed in the growth chamber(60cm×60cm×80cm).The growth chamber is placed at a temperature of a control room. The temperature is maintained at 29/25°C (day/night) and the humidity is at 55/80% (day/night). There are two experimental groups, each group consisting of 15 pots per tray, and within one pot there are 3 tomato seeds. Twenty milliliters of tap water was supplied to each pot once a day in the morning. The seedling period is 25 days (22 February to 18 March, 2018). The tomato seedling plants are shown in Fig. 1.

2.1.2. Vegetative growth and fruit stage

The seedling tomato plants were sampled randomly into three experimental groups. There are two plants for each group. For the transplantation, cuttings on day 25th (0 day of vegetative growth stage) were taken from all the cultivars and rooted in plastic tray filled with mixed soil (loamy soil, compost, paddy husk charcoals, and coconut dust). Each tomato transplants were rooted into the pot with the pot diameter of 25-30 cm. Two pots of tomato transplants were placed into the growth tent (60cm×120cm×180cm) with the ventilation system. The artificial light source was hung over the plants and the photoperiod was controlled by a digital timer switch. Two growth tents were placed in the room with temperature control at 29°C/25°C (day/night), the humidity was around 50%- 80%. The transplants received daily irrigation of 50 ml to 250 ml per day as shown below in the diagram (Fig. 2). The vegetative growth and fruits yield period is 90 days (19 March to 30 June, 2018). The fertilizer (N-15: P-15: K-15 of 5 grams per pot) was applied two times at the day 40th and the day 60th.

2.2. LED lighting and treatments

2.2.1. For the first experiment

For the first experiment (Exp. 1) at seedling period, the artificial LED light at R25+B75 ratio with the PPFD at 150 μmol m^{-2}s^{-1} was applied over the plants (for the first ten days), and subsequently followed by R50+B50 at the same PPFD. On the first 14 days of vegetative growth and fruits period, the LED light were applied at R50+B50 of the PPFD of 200 µmol m^{-2}s^{-1}. For the next two week (15th-30th April, 2018), the LED light was applied at R75+B25 of the PPFD of 200 µmol m^{-2}s^{-1}. Lastly, the LED light was applied at R75+B25 of the PPFD of 300 µmol m^{-2}s^{-1} (60 days) from 30 April to 30 June, 2018 (Fig. 2). The PAR spectrum of the light source is as shown in Fig. 3, and the growth tent of Exp. 1 is shown in Fig. 4.

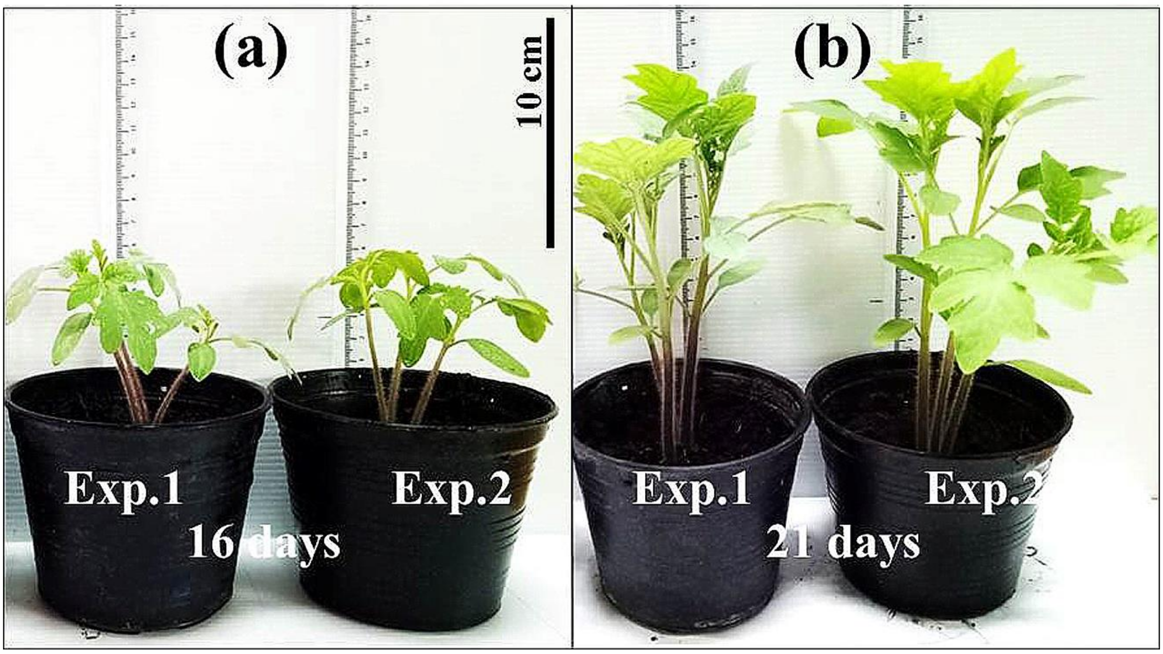

Fig. 1: The growth of tomato in the seedling stage from all experimental groups (a) on the 2nd week, and (b) on the 3rd week

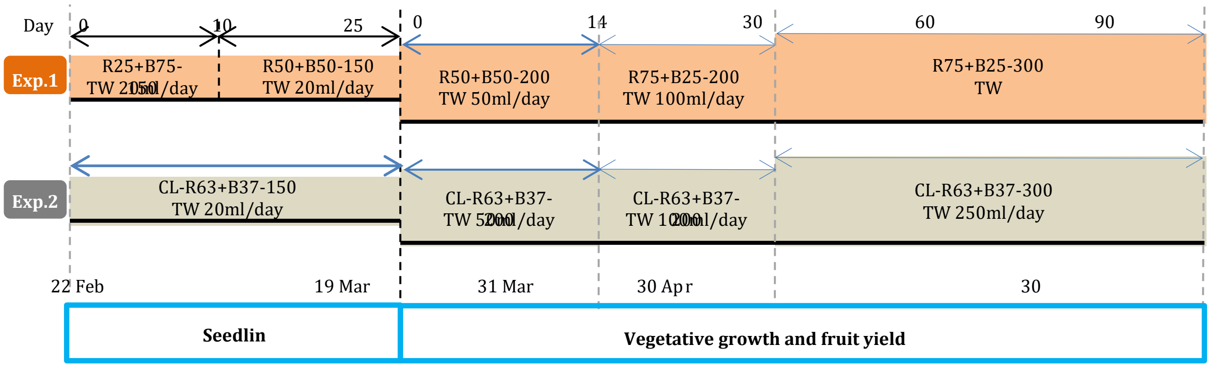

Fig. 2: The experimental design

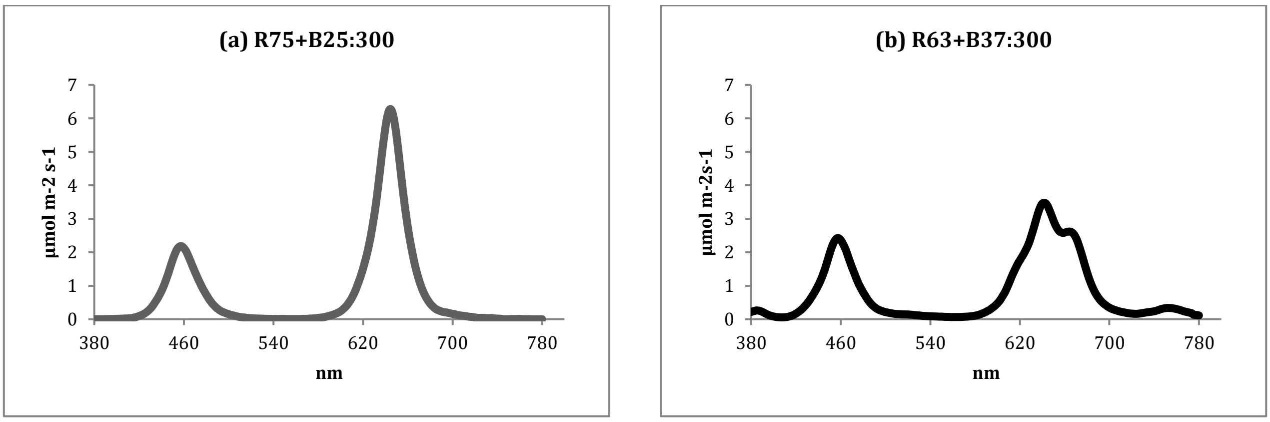

Fig. 3: Spectrum distribution of the experiments showing the fruit stage (a) Exp.1 under R75+B35 at PPFD = 300 µmol m^{-2}s^{-1}, (b) Exp.2 under R63+B37 at PPFD = 300 µmol m^{-2}s^{-1}

2.2.2. The second experiment

The second experiment (Exp. 2) used the LED light treatment from commercial 180W model UFO180 LED growth light (BOSSLED Shenzhen, China). At the seedling period, the plants were treated with the PPFD of 150 µmol m^{-2}s^{-1}. For the early vegetative growth and fruits period, the PPFD was increased to the same value as Exp. 1. The photoperiod of Exp. 1, Exp. 2 in all stage, and the photoperiod of Exp. 1 on seedling stage were applied for 14-h. The measured spectrum distribution of this treatment at PPFD 300 μmol $m^{-2}s^{-1}$ shows the R:B ratio to be around 1.75 or R63+B37 in Fig. 3.

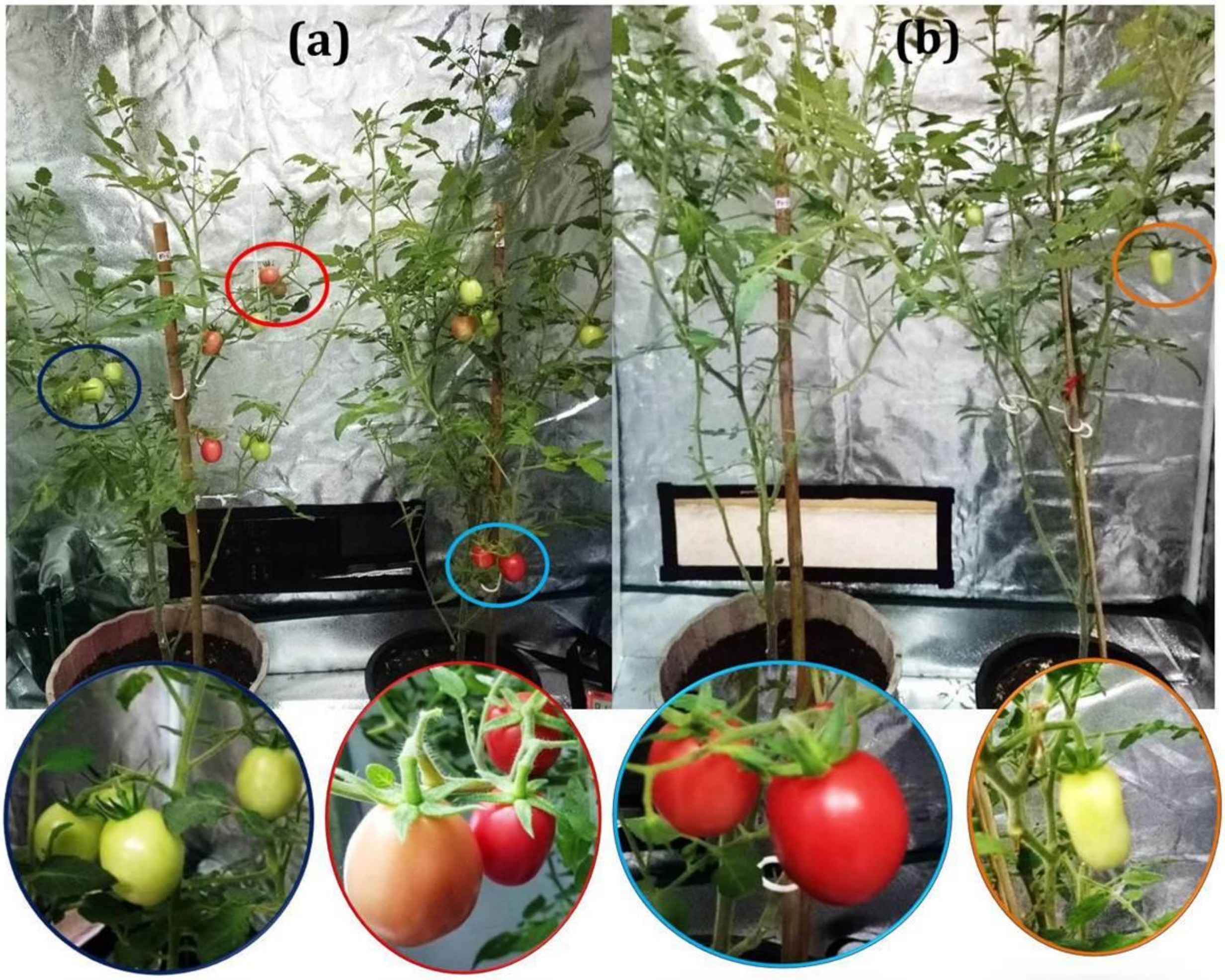

Fig. 4: The experimental setup of the Sida-tomato plants in all groups (a) the first experiment, and (b) the second experiment

2.3. Water treatment

20 ml per pot of Tap water (TW) was supplied to the plants every morning at the seedling stage. On the vegetative growth and fruit stage, the authors increased the TW supply to 50 ml per plant at 14 days after transplantation. Subsequently, 100 ml per pot of tap water were supplied for the next 15 days. Finally, for the last two months, 250 ml per plant of tap water were supplied.

2.4. Observation and measurements

This study focuses on the fruits stage of the tomato. The PPFD spectrum distribution of the LED light sources was measured by the spectroradiometer from Lighting Passport Pro Essence (Asensetek Incorporation, Taiwan). For all experiments, the plant height and stem diameter were measured every 10 days after transplantation (DAT) in the growth tents. Fruits were harvested once when the first fruit turned into light red to red stage at around 80-90DAT (Luitel et al., 2012) in the growth tents. Marketable characteristics for tomato were defined as uniformity in color good shape and morphology, good health state and having the weight of greater than 17.5 g (The value of 17.5 g was measured from 10 samples of Sida-tomato that the authors bought from the market in Nonthaburi, Thailand (data not shown)). The cracked fruits and the ones with weight smaller than 17.5 g were categorized into non-marketable. Observations on fruit characteristics were taken by specific sampling method on five fruits of each group (Luitel et al., 2012). Fruit weight (g) was determined by a digital weight scale 0.01g to 500g (TWK, China). Total soluble sugar content (ºBrix) or TSS was measured by a hand-held refractometer (Yieryi, China) and fruit length (mm), and fruit width (mm) was measured by digital venire caliper 0-200 mm (Mitutoyo Crop., Kanagawa, Japan).

2.5. Statistical analysis

The data from both experiments were subjected to analysis of mean difference by independent t-test at $p \leq 0.05$ using a computer program. The IBM SPSS statistics was used for analysis.

3. Results and discussion

3.1. Effect of the three specific spectra of R:B light ratio on the tomato plant height and stem diameter

The measurement of plant height after transplantation during 90 days (20 March to 20 June 2018) was observed in two periods: (1) Vegetative growth stage (30 DAT, 20 March to 20 April 2018), and (2) Flowering and fruit stage (31 DAT to 90 DAT, 21 April to 20 June 2018). The tomatoes grew and developed very well during the vegetative growth period in all experimental groups (Fig. 5a). The plant height started form 17.5cm/19 cm and increased up to 58.8cm/60 cm (Exp. 1/Exp. 2). In the vegetative growth period, the two experimental groups (Exp. 1 and Exp. 2) were supplied with the PPFD in the same quantity at 200 µmol $m^{-2}s^{-1}$. There was no significant difference between the tomato plant height under Exp. 1 (95.59 cm) and Exp. 2 (106.50 cm) (Table 1) at the same PPFD (300 µmol $m^{-2}s^{-1}$) for the subsequent flowering and fruit stage. This means that the tomato plants height during the vegetative growth stage and the fruit stage under the LED light at three different R:B ratios, and under single R:B light ratio did not have a significant difference ($P \leq 0.05$) after being analyzed by using independent t-test statistics. This is in accordance with the study of Brazaityte et al. (2009). A, whereby it was shown that the tomato transplants height grown under R(638nm+669nm) and B(447nm) LED light with or without the UV(380nm), and yellow/green light were not significantly different($p \leq 0.05$) (Brazaityte et al., 2009). The stem diameter of the Sida-tomato plant was measured at zero DAT. The measured value is 4.94mm/4.53 mm (Exp. 1/Exp. 2). At the vegetative growth stage, the stem diameter of Exp. 1 and Exp. 2 is very close in size, with the stem diameter from Exp. 2 being smaller. The stem diameter from all experimental groups was linearly increasing during the vegetative growth stage (0 DAT to 30 DAT) (Fig. 5b). The stem diameter of Sida-tomato plant gradually increased during the flowering to fruit stage (30 DAT to 90 DAT). The stem diameter of the tomato plant under three different R:B LED lights showed that the diameter in Exp. 1 was the biggest at 10.92 mm, but did not show any significant difference from the stem diameter under sole R:B LED light of 10.23 mm (Fig. 5b and Table 1). Our study exhibited harmonized results with the study of Li. Y, which presented that the effect of R and RB combinations could increase the stem diameter of tomato plant (Li et al., 2017).

3.2. Effect of three specific spectra of R:B light ratios on the fruit weight, fruit length, fruit width, and TSS

Tomato fruit weight obtained from being applied with three specific spectra R:B LED light ratios (Exp. 1) were of good quality in the sense that the fruit weight is 19.38 g (greater than fruit weight of the normal Sida-tomato from the market). The weight of tomatoes treated with three specific R:B LED spectrum was significantly difference ($p \leq 0.05$) from the tomato fruit weight (9.08 g) under treatment by sole R:B LED light ratio (Exp. 2). This is in accordance with the study results of Brazaityte et al. (2009). A, where the yield (weight) of tomato fruits under R (638nm+669nm) and B (447nm) LED light at the R:B ratio(90:10) with and without UV(380nm) produced the highest fruit yield as well as exhibited early tomato yield. Moreover, the yellow light may decrease the total tomato yield (Brazaityte et al., 2009).

This study was confirmed by the study of Jiang. C, where the deep red LED plus white LED inner canopy was applied to promote the fresh tomato fruit weight per plant. In addition to that, the study also showed higher yield than the control treatment (Jiang et al., 2017). The study of Lu. N also confirmed that the growth of the tomato under natural light supplemented with R LED light could increase the fresh and dry yield (Lu et al., 2012).

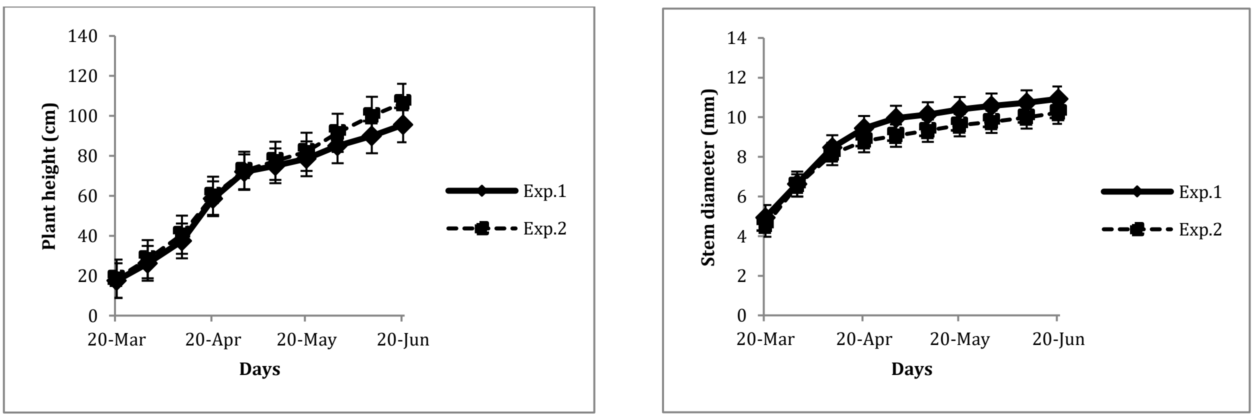

Fig. 5: The tomato plants height (a), and (b) Stem diameter of tomato plants during vegetative growth and fruits stage

Tomato fruit length and width under three specific spectra R:B light ratio (Exp. 1) showed good morphology, having round/square shape (Gastélum-Barrios et al., 2011). The fruit length is 35.22 mm and the fruit width is about 33.09 mm. The tomato fruit length and width under sole R:B LED light ratio

(Exp. 2) was shown to be the smallest at 29.78 mm of length and 23.90 mm of fruit width (Table 1 and Fig. 6). The fruit shape resembles a square and small in size.

Table 1: t-test results on effect of three specific spectra of R:B light ratio on the plants growth, fruit yield and quality of Sida-tomato

Treatment	Plant height (cm)	Stem diameter (mm)	Total fruit/ plant (no.)	Total yield/ plant (g)	Mkt. fruit wt./ plant (g)	Mkt. fruit no./ plant (%)**	Non-Mkt. fruit No./ plant (%)**	Fruit wt./ fruit (g)	Fruit length (nm)	Fruit width (nm)	TSS (°Brix)
Exp.1	95.50[a] ±7.77	10.92[a] ±0.36	11.00[a] ±5.65	166.85[a] ±62.43	88.28[a] ±36.15	41.00	59.00	19.38[a] ±1.45	35.22[a] ±1.25	33.09[a] ±0.88	4.68[a] ±0.23
Exp.2	106.50[a] ±10.60	10.23[a] ±0.18	1.50[a] ±2.12	13.62[a] ±19.26	0.00[a] ±0.00	0.00	100.00	9.08[b] ±4.27	29.78[a] ±7.47	23.90[a] ±4.15	3.97[a] ±0.25

[ab] Followed by the same letter are not significantly different at $p \leq 0.05$ (mean); Mkt. is Marketable;** are not analyst by t-test

The author can conclude that the fruit weight under three specific spectra R:B light ratio was perfect. The obtained values are higher than the normal fruit weight of Sida-tomato by about +5.7%, the fruit weight under sole R:B LED light ratio is lower than the normal fruit weight of up to -92.7%. The Sida-tomatoes that were grown under three specific spectra R:B LED light ratios exhibit the highest fruit weight when compared with the tomato fruit weight under sole R:B LED light ratio. This outcome is in accordance to the study of Paul Deram and others who reported that the tomato fruit production was highest when the 5:1 (R:B) ratio of LED light was applied (Deram et al., 2014).

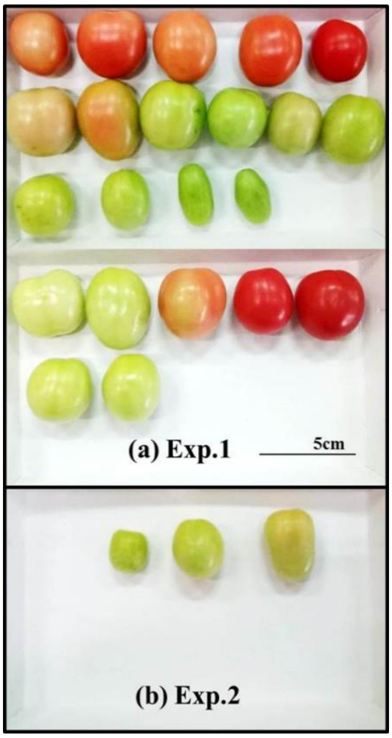

Fig. 6: Tomato fruit yield harvesting on 90 DAT (20June 2018), (a) Twenty-two of the fruits from Exp. 1 (15 from the 1st plant and 7 from the 2nd plant), and (b) Three of fruits from Exp. 2

4. Conclusion

The yield and quality of the Sida-tomato fruit under the application of three specific spectra of R:B LED light ratios harvested at 90 DAT was the highest when compared to the tomato fruits treated with a sole R:B LED ratio. Three specific spectra of R:B LED light ratios could promote the highest stem diameter of tomato plants during the seedling stage and produce the highest total fruit weight, total fruit yield, marketable fruit weight ,marketable fruit yield, good morphology and color of the fruit. Additionally, the highest total sugar soluble of the Sida-tomato was also found in the case where they are treated with three specific spectra of R:B LED ratios. The tomato grown under three specific spectra of R:B LED light ratios decreased the harvesting time. Consequently, this method is interesting and exhibits the possibility of being applied to produce high quality tomato fruit, and yield for the plant factory system. The author would like to apply this method to grow other kinds of fruit that is appropriate for the indoor plantation system such as a cherry tomato, and strawberry.

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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