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Effects of combined Red and Blue light spectra as supplemental light on yield and fruit quality of sweet pepper

Mohammad Adibian[1], Yousef Hamidoghli *[1], Mahmood Ghasemnezhad[1] and Sasan Aliniaeifard[2]

[1]Department of Horticulture, University of Guilan, Rasht, Iran, Postal Code: 4199613776
[2]Photosynthesis Laboratory, Department of Horticulture, College of Agricultural Technology (Aburaihan), University of Tehran, Tehran, Iran, Postal Code: 1417935840

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***Corresponding author:**

Department of Horticulture, University of Guilan, Rasht, Iran, 4199613776.

Email: hamidoghli@guilan.ac.ir

ABSTRACT

Purpose: The use of supplementary light in regions with low natural sunlight is necessary to fulfill the increasing consumer requests for fresh vegetables. This study aimed to investigate the effect of different combinations of red and blue LEDs on yield and quality of greenhouse-grown sweet pepper (*Capsicum annuum* L.) fruits during the growth period. **Research method**: The experiments were conducted in Rasht, Iran as split plots in the form of a completely randomized design in three repetitions (four plants per plot) on two cultivars of sweet pepper (Padra and Shadlin). With the appearance of the first flower buds, plants were exposed to different light treatments including: three combinations of red (R) and blue (B) LEDs (T1:R8B1, T2:R7B2, and T3:R6B3), with a same intensity of 200 $\mu molm^{-2}s^{-1}$ as supplement light to the natural light, together with natural light as control treatment (CT). Sweet pepper fruits were harvested weekly over 27 weeks and fruit yield and quality were assessed. **Findings**: Supplemental light using LEDs significantly increased yield and fruit quality parameters (except titratable acidity and maturity index) compared to the control. Marketable yield was differed among the light treatments and plants exposed to T3 showed the highest marketable yield (14.58 kg/m^2). The effect of supplemental light on total yield was more detectable when the average daily light integral was the lowest (for example, the difference between T3 and the control treatment in January was 1.27 kg/m^2, while this difference was 0.68 kg/m^2 in June). No significant difference was observed between cultivars and T3 was the best treatment in most parameters. **Research limitations:** No limitations were found. **Originality/Value**: In the northern regions of Iran, even in the months that do not seem to have light limitations, the use of supplementary light is recommended to increase the yield of sweet peppers in the greenhouse.

INTRODUCTION

Sweet pepper is a widely cultivated greenhouse crop, which is considered as one of the most consumed vegetables worldwide for fresh consumption or ready-to-eat foods, due to its taste, physicochemical compounds and various antioxidants (Guo et al., 2016; Jokinen et al., 2012; Kim & Son, 2022; Naznin et al., 2019). During the winter months in northern temperate climate, light is a limiting factor for yield and fruit quality of greenhouse vegetables (Lanoue et al., 2022). In the northern regions of Iran, the average daily light integral (DLI) is below 10 $molm^{-2}day^{-1}$duringthe autumn and winter seasons (obtained from the Rasht agricultural meteorological station). At this low DLI, flower abortion occurs in sweet peppers, which leads to a decrease in fruit production (Lanoue et al., 2022). As a countermeasure, artificial supplemental light sources are used to promote photosynthesis and yield and to improve fruit quality of year-round fresh greenhouse crop production, especially in the days with low intensity of natural light (Jokinen et al., 2012).

Traditionally, the commercial greenhouses increase DLI using high-pressure sodium (HPS) lamps as a supplemental lighting source above crop canopy. However, HPS lamps have fixed spectral compositions and may have adverse effects on greenhouse crops due to the conversion of a large portion of the input energy into heat (Klamkowski et al., 2014). Among different types of supplemental lights, light emitting diodes (LEDs) offer many benefits, such as reduced electricity consumption, safety and longevity (Dąbrowski et al., 2015). In addition, the low surface temperature and possibility of manipulation of light spectrum introduced the LEDs as a suitable alternative to HPS lamps (Pattison et al., 2018). The low surface temperature make LEDs feasible to use in close proximity to plant tissue, and the possibility of manipulating the spectral composition of LEDs can lead to biochemical, physiological, and photomorphogenic changes and subsequently improve yield (Guo et al., 2016).

Plants have certain responses to different light wavebands. Red (R) and blue (B) have been highly recommended by the scientific and greenhouse production communities because they are in the chlorophyll absorption region and bring higher photosynthetic and quantum efficiency (Hao et al., 2017; Lin & Jolliffe, 1996). It has been found that blue light plays an important role in pigment accumulation, stomatal opening, photomorphogenesis, leaf expansion and plant growth, and red light controls the function of the reproductive system, chloroplast, as well as petiole and stem growth (Li, et al., 2012). Moreover, the highest photosynthetic photon efficiency (PPE) among LEDs is related to these two wavebands (Hernández & Kubota, 2016). Usually a combination of R and B are used in controlled environment agriculture (CEA) for growth and production of different crops (Esmaeili et al., 2022; Javadi Asayesh et al., 2021). According to the mentioned contents, the suitable light spectra of LEDs are of great importance for the horticulture industry. Although R and B light spectra are proposed as the main spectra absorbed by chlorophyll a and b pigments, however there are scarce of information regarding their effects as the supplemental light for the main fruity greenhouse crops needing supplemental light for keeping economic yielding during seasons with light intensity limitations. In the regions with high precipitation such as Guilan province in North of Iran, at least in half of the year, average of DLI in late autumn and early winter times is lower than 15 $molm^{-2}day^{-1}$ and the amount of light transmitting into the greenhouse is less than 10 $molm^{-2}day^{-1}$. So, the objective of this study was to investigate the effect of different combinations of R and B LED supplemental lighting on the yield and fruit quality of two greenhouse sweet pepper cultivars during two consecutive growing periods in Rasht, Iran, finally, introducing the best light combination for greenhouse production of sweet pepper.

MATERIALS AND METHODS

Location

The experiments were conducted in the research greenhouse of the Faculty of Agricultural Sciences of Guilan University, Rasht, Iran (longitude 37° N, latitude 49° E, and 7 m above sea level (Fig. 1) during 2019-2021. The information about the number of sunny hours and photosynthetically active radiation in the 40-year statistical period (1970-2010) was obtained from the Rasht Agricultural Meteorological Station (Table 1).

Plant materials and growth conditions

This research was carried out as split plots in the form of a completely randomized design in 3 repetitions (fourplants per plot) on two cultivars of greenhouse sweet pepper (*Capsicum annum* L.) including red (Padra) and yellow (Shadlin). Seeds (purchased from Meridiem seeds. Co, Iran) were planted in 45-cell trays (4 × 4 × 8 cm) containing a mixture of 50% perlite and 50% cocopeat at the depth of 0.5 cm. At two-cotyledon stage, healthy, strong, identical and same-sized seedlings were transferred to 1 L plastic pots. With the appearance of the first flower buds, the seedlings were transferred to the main pots with a diameter of 23 cm and a depth of 21.5 cm (7 L). At this stage, the plants were exposed to four light treatments (in total 96 plants). Drip irrigation was done with a modified nutrient solution (Papadopoulos, 1994) based on the plant's water needs on an average of once a day (Fig. 2, Table 2). Stem, flower and fruit pruning were done regularly from the beginning of growth until harvest time.

Fig 1. Location map of the research greenhouse of the Faculty of Agricultural Sciences, Guilan University, Rasht, Iran.

Table 1. Number of sunny hours and photosynthetically active radiation in Guilan (1970-2010). †

Season	Average of total sunny hours (h)	Average of daily sunny hours (h)	Average of daily light integral ($molm^{-2}d^{-1}$)
Spring	489	5.26	20.82
Summer	598	6.43	28.93
Autumn	295	3.28	9.45
Winter	268	2.98	7.52
Yearly	1650	4.52	15.01

† (Rasht Agricultural Meteorological Station)

Table 2. Nutrient solutions used during the growth period of sweet pepper plants.

Stock	Fertilizer	The month after germination				
		First	Second	Third	Fourth	The beginning of the harvest - the end of the period
Stock A	Calcium nitrate	150 g	160 g	170 g	170 g	170 g
	Potassium nitrate	44 g	44 g	44	44 g	44 g
Stock B	Potassium nitrate	34 g	44 g	44	44 g	44 g
	Magnesium Sulphate	40 g	45 g	50	56 g	62 g
	Potassium monophosphate	60 g	60 g	50	50 g	50 g
Stock C	Manganese sulfate	1 g	1 g	1	1 g	1 g
	Zinc sulfate	0.5 g	0.5 g	0.5	0.5 g	0.5 g
	Copper sulfate	0.2 g	0.2 g	0.2	0.2 g	0.2 g
	Sodium molybdate	0.1 g	0.1 g	0.1	0.1 g	0.1 g
Stock D	Borax	2.4 g	2.4 g	2.4 g	2.4 g	2.4 g
Stock E	Sequestrene Fe	10 g	10 g	10 g	10 g	10 g

Fig 2. Sweet pepper plants used in the present study in the fruiting stage.

Table 3. Lighting treatments based on red (R) and blue (B) spectra and the contribution of each light spectrum in the overall light composition. †

Treatment	Description
T1	R:B (8:1)
T2	R:B (7:2)
T3	R:B (6:3)
CT	Control treatment (without supplemental light)

† Peak wavelength λp was 660 nm for red LED and 460nm for blue LED.

Supplemental light application

LED modules (36 W, with an exposure area of 50 × 100 cm) were purchased from Iran Growlight Company, Tehran, Iran. The lamps were installed with a distance of 20 cm above the plants canopy (the lamps were movable and were moved based on the plant's height to maintain the distance). The light intensity of 200 µmol $m^{-2}s^{-1}$, was applied for all light treatments (Hikosaka et al., 2013; Naznin et al., 2019; Nederhoff & Marcelis, 2010). 24 wall washer lamps of one-meter length were used, and 36 LEDs were installed in each lamp. The LEDs were divided into 4 groups of 9. Out of 9 LEDs, 1, 2 and 3 of them were blue and the rest were red in treatments 1, 2 and 3, respectively (Table 3). In order to avoid overlapping of lamps and light diffusion among the treatments, each lamp was installed in the center of each plot. A photoperiod of 14 hours (5 am to 7 pm) was applied to the treatments, and according to the literature (Guo et al., 2016; Maureira et al., 2022) when the intensity of solar radiation was above 400 µmol$m^{-2}s^{-1}$ (10 am - 3 pm on completely sunny days), supplemental lights were turned off. Photosynthetic photon flux density on the plant surface was measured with a photometer (SKP 200, Skye Instruments Ltd).

Data collection

Fruit yield

Fruits at maturity stage (85 days after transferring the seedlings to the main pots) were harvested weekly for 189 days and measurements were taken every week. Fruits weight was measured with an electronic scale and the total yield, marketable yield (fruits weighing more than 100 grams and without blossom-end-rot) and the number of marketable fruits was calculated. The length and diameter of fruits were measured using Vernier calipers.

Fruit quality

Fruits were cut into two halves and flesh thickness was measured at two different points of each half. Soluble solid content was determined from filtered pepper fruit extract using a refractometer (CETI-BELGUM). Titratable acidity (TA) was recorded by titration of 10 mL filtered fruit extract with 0.1N NaOH to pH 8.1 and the quantity (mL) of NaOH was converted into citric acidity (Ghasemnezhad, et al., 2011). Maturity index (MI) was obtained using the following equation (1) (Martínez-Zamora, et al., 2021):

$$\mathrm{MI} = \frac{\mathrm{TSS}}{\mathrm{TA}} \quad (1)$$

Where, TSS is total soluble solids and TA is titratable acidity. The measurement of vitamin C in filtered pepper fruit extract was done by titration against 2,6-dichlorophenol-indophenol solution (Zayed, 2012). The samples were placed in a 65 °C dryer for 72 h, and then the dry matter (DM) was obtained using the equation (2) (Lanoue, et al., 2022):

$$\mathrm{DM} = \frac{\text{Dry weight}}{\text{Fresh weight}} \times 100 \quad (2)$$

Statistical analysis

Comparison of normality tests under skewness and kurtosis coefficients in the range of -2 to 2 was performed using Statistical Product and Service Solutions for Windows, (SPSS, version 16.0) (Ghasemi & Zahediasl, 2012). Analysis of variance was run on yield indices and fruit quality indices using Statistical Analysis Software (SAS, version 9.1) (Littell, 1989) to investigate whether theses indices have a significant relationship with light, pepper cultivars, and also with interactive effects of light × cultivar. Tukey's multiple comparison test ($P<0.01$ and $P<0.05$) was used to check the difference between means.

RESULTS

Fruit yield

The results of variance analysis indicated that total yield, marketable yield, number of fruit, average fruit weight, fruit length and fruit diameter were significantly ($P < 0.01$) influenced by light treatments, but the individual effect of cultivar as well as the interactive effects of light × cultivar were not statistically significant (Table 4). Differences between the means at the 1% level showed that the total yield, marketable yield, number of fruits, average fruit weight, fruit length and fruit diameter of sweet peppers under all levels of supplemental light were significantly higher than their values in control treatment (Table 5).

As shown in Table 5, marketable yield was differed among the light treatments and increased with additional blue light levels, so that T3 (R6B3) had the highest marketable yield (14.58 kg/m^2) and statistically, there was a significant difference between T3 and two other treatments. This is while, study of the differences between the means of total yield, number of fruit, average fruit weight and fruit size ($P < 0.05$) showed that there was no statistical difference among T1, T2, and T3 plants.

Figure 3 compares the average of total yield under four light treatments in different fruit harvested month. With the increase of natural light, an increase in the yield of the control treatment is observed (0.45 kg/m^2 in January vs 2.86 kg/m^2 in June), which makes the difference between the control treatment and the light treatments to be less in months with higher light intensity. For example, the difference between T3 and the control treatment in January was 1.27 kg/m^2, while this difference was 0.68 kg/m^2 in June; however, this difference was still significant.

Table 4. Variance analysis for yield parameters of sweet pepper plants grown under different qualities of supplemental light.

Source	Df	Mean Square (MS)†					
		Total yield	Marketable yield	Number of Fruit	Average fruit weight	Fruit length	Fruit diameter
Light	3	69.71**	70.88**	2145**	0.001**	314**	102**
Light Error	8	0.137	0.04	4	0.001	8.59	11.13
Cultivar	1	0.02 ns	0.01 ns	0.17 ns	0.001ns	20.17 ns	57.1 ns
Light × Cultivar	3	0.02 ns	0.02 ns	1.62 ns	0.001 ns	24.62 ns	8.49 ns
Residual Error		0.27	0.05	8.75	0.001	5.75	3.62
Coefficient of variation	-	4.09	1.77	3.71	3.37	2.79	2.55

† ns, **: Non significant and significant at 1% probability level, respectively.

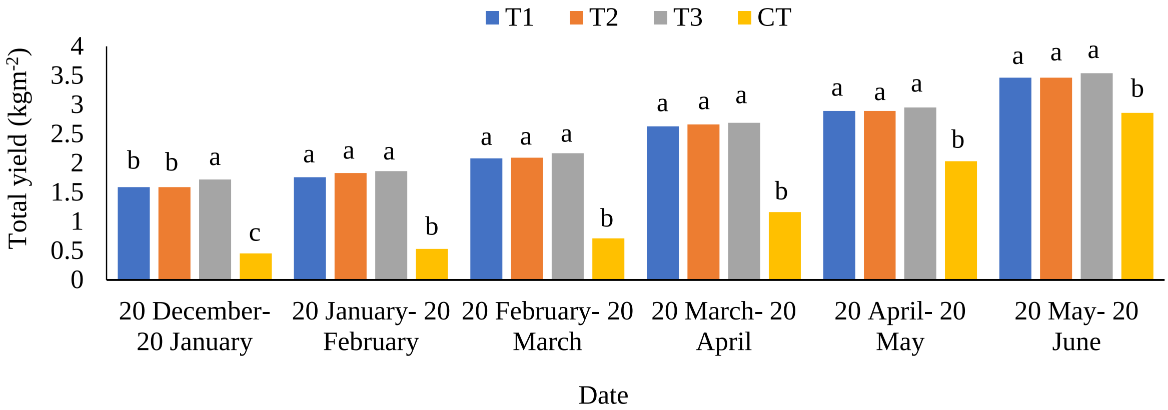

Fig 3. Total yield of sweet pepper under four light treatments during different dates of study.

Table 5. Effect of light treatment on yield parameters of sweet pepper plants.

Light treatment	Yield indices†					
	Total yield (kgm^{-2})	Marketable yield (kgm^{-2})	Number of fruit	Average fruit weight (kgm^{-2})	Fruit length (mm)	Fruit diameter (mm)
T1	14.28^{b}	14.06^{b}	88.17^{a}	0.161^{a}	90.32^{a}	75.83^{ab}
T2	14.35^{ab}	14.18^{b}	89.33^{a}	0.160^{a}	88.00^{a}	84.83^{ab}
T3	14.99^{a}	14.58^{a}	90.33^{a}	0.166^{a}	89.67^{a}	78.83^{a}
CK	7.75^{c}	7.41^{c}	51.50^{b}	0.151^{b}	75.00^{b}	69.00^{b}

† Data are shown as treatment average of three replicates.

Mean values followed by different letters in the same column indicate significant differences by the Tukey's test at $p \leq 0.01$.

Table 6. Variance analysis for fruit quality parameters of sweet pepper fruits under different qualities of supplemental light.

Source	Df	Mean Square (MS) †					
		Flesh thickness	Dry matter	Vitamin C	Total Soluble Solids	Titratable acidity	Maturity index
Light	3	2.15**	0.001**	69.15**	0.66**	0.01^{ns}	0.03*
Light Error	8	0.015	0.001	3.00	0.047	0.01	0.01
Cultivar	1	0.91^{ns}	0.001^{ns}	1.05^{ns}	0.02^{ns}	0.01^{ns}	0.01^{ns}
Light × Cultivar	3	0.02^{ns}	0.001^{ns}	6.94^{ns}	0.01^{ns}	0.2^{ns}	0.01^{ns}
Residual Error		0.06	0.001	8.33	0.06	0.3	0.01
Coefficient of variation	-	3.78	3.03	3.78	3.52	5.12	4.62

† ns, *, **: Non significant and significant at 5% and 1% probability level, respectively.

Table 7. Effect of supplemental light with different spectra of red and blue light on fruit quality parameters of sweet pepper plants.

Light treatment	Yield indices†					
	Flesh thickness (mm)	Dry matter (%)	Vitamin C (mg/100gFW)	Total Soluble Solids (%)	Titratable acidity(%)	Maturity index
T1	6.58^{a}	13.7^{a}	78.83^{a}	7.17^{a}	3.08^{a}	2.32^{a}
T2	6.72^{a}	13.4^{ab}	77.67^{a}	7.15^{a}	3.10^{a}	2.31^{a}
T3	6.83^{a}	13.2^{ab}	78.17^{a}	7.28^{a}	3.12^{a}	2.33^{a}
CK	5.53^{b}	12.2^{b}	71.50^{b}	6.55^{b}	3.07^{a}	2.16^{a}

† Data are shown as treatment average of three replicates; mean values followed by different letters in the same column indicate significant differences by the Tukey's test at $p \leq 0.01$.

Fruit quality

As can be seen in Table 6, light treatment significantly affected the fruit quality parameters except for the titratable acidity and maturity index. However, no significant differences in fruit quality parameters were found between red and yellow fruits. Also, the interactive effects of light × cultivar were not statistically significant. Tukey's multiple comparison test at the 1% level showed that with a higher ratio of light B, flesh thickness and total soluble solids of fruits increased, while vitamin C decreased (78.17 mg in T3 vs. 78.83 mg in T1). However, these differences were not statistically significant (Table 7). Dry matter showed a significant difference among T1 and CK plants, so that T1 (R8B1) had the highest dry matter (13.7%).

DISCUSSION

Fruit yield

Light limitation or uneven light distribution impose restriction on photosynthesis system, which can cause a decrease in plant yield and fruit quality (Yamori et al., 2016). As shown in Table 5, differences between the means of total yield at all levels of supplemental light were significantly greater than control treatment. This is consistent with other reports which showed that LED supplemental lighting improves yield in different crops (Jokinen et al., 2012; Takahashi et al., 2020). It has been found that applying LED lighting on the leaves, elevates carbon dioxide fixation, decrease flower and fruit abortion, improves fruit growth (González-Real et al., 2009), and accelerate fruit maturation, consequently leading to yield improvement (Jokinen et al., 2012).

During low light intensity seasons, cloudy days, or in high latitudes when the average DLI is lower than a threshold level required for induction of flowering or fruit growth, the use of supplemental light is of vital importance to keep yield in many crop species (Fig. 3). Jokinen et al. (2012) showed that mean fruit weight increased due to LED supplemental light as the natural DLI decreased, which led to an increase in total yield (Jokinen et al., 2012). In addition, the results of the present study showed that with the increase of natural light, LED supplemental lighting still has a significant effect on increasing yield. Therefore, using LED supplemental lighting is a promising approach to increase fruit yield in areas that are not necessarily light-limited (at least on the below part of the plant canopy). This finding is in agreement with the report of Joshi et al. (2019).

Malformed fruits, fruits with blossom-end-rot, and small fruits were classified as fruits with low marketable yield. A decrease in blossom-end-rot and as a result an increase in marketable yield was observed in the presence of LED supplemental lighting in the present study (Table 5). This is exactly the opposite of the result reported in the presence of HPS light (Stadler, 2011). The increase in occurrences of blossom-end-rot in the presence of HPS lamp has been considered to be related to the high thermal radiation of HPS compared to LED (Prinzenberg et al., 2021).

There was significant difference among three supplemental light spectra for production of marketable yield. The results showed that a high proportion of B light increases the total yield; thus, the highest marketable yield (14.58 kg/m^2) was observed in T3 plants (R6B3), which is in agreement with the findings of Javadi Asayesh on Guzmania and Vriesea (Javadi Asayesh et al., 2021), and Aalifar on Carnation (Aalifar et al., 2020a; Aalifar et al., 2020b).

As shown in Table 5, differences between the means of number of fruit at all levels of supplemental light were significantly greater than the control treatment. The fruit load of sweet pepper is high and it has been found that at low DLI (less than 10 $molm^{-2}day^{-1}$), due to insufficient photosynthesis, sweet peppers tend to flower drop, which reduces fruit production (Lanoue et al., 2022; Takahashi et al., 2020). Maximum photosynthetic efficiency can be achieved by increasing the incident light level through using supplemental light. It has been found that the spectral energy distribution of R and B lights corresponds to chlorophyll pigment absorption, which causes high photosynthetic activity. Therefore, increase in number of fruit in plants grown under red and blue lights may be as the result of enhanced carbohydrate production due to improvement in photosynthetic capacity, followed by a reduction in fruit drop (Javadi Asayesh et al., 2021). Previous studies have also reported an increase in the number of sweet pepper fruits under LED light treatments (Jokinen et al., 2012; Naznin et al., 2019). Of course, it has been found that red light alone increases starch content by inhibiting the transfer of photosynthates out of the leaves, which may have a negative effect on fruit production (Sæbø et al., 1995). In the present study, increasing the number of fruit under supplementary light led to an increase in total yield, which is in agreement with the results of other studies (Guo et al., 2016; Takahashi et al., 2020).

Fruits with an standard and unique size are more marketable than small - and diversified fruits, which is a criterion for price determination of the product (Lanoue et al., 2022). The results obtained from the fruit length data in the present study showed that the differences between the means of fruit length at all levels of supplementary artificial light were significantly higher than the control treatment. Previous studies also showed that fruit yield parameters such as fruit size and number were highest in plants grown under Rand BLEDs (Gómez & Mitchell, 2016; Pepin et al., 2013). However, in another research that used supplemental intra-canopy LED illumination for sweet pepper, the fruit yield increased in the spring season only by affecting the number of fruit, without affecting the fruit size or weight (Joshi et al., 2019).

Fruit quality

Fresh sweet pepper is rich in biologically active substances, including chlorophyll, carotenoids and vitamin C, which can effectively scavenge active oxygen free radicals in the human body and reduce the risk of Brain and cardiovascular diseases as well as cancer (Blekkenhorst et al., 2018; de Sá Mendes & de Andrade Gonçalves, 2020; Olatunji & Afolayan, 2018). In the present study, all levels of supplementary artificial light significantly increased amount of vitamin C in the fruit compared to the control treatment. Increase in the proportion of blue light in overall spectrum, induced accumulation of vitamin C in fruits, although there was not a statistically significant difference among T1, T2, and T3 plants. Increase of vitamin C content by B light has been reported in tomato and strawberry (Javanmardi & Emami, 2013; Kim et al., 2011). It has been found that there is a significant relationship between the vitamin C content and soluble sugars in leaves of lamb's lettuce, so it seems that blue light plays a role in regulating vitamin C synthesis not only through its effect on blue light receptors, but also through increasing the rate of photosynthesis and the formation of sugars (Wojciechowska et al., 2015). However, Liu et al., who investigated the effects of different LED spectra lightings on the post-harvest nutritional quality of chili peppers, stated that blue light has a negative effect on vitamin C content in several cultivars (Liu et al., 2022a).

Soluble solids and titratable acidity are essential physicochemical factors that can determine the taste of sweet pepper fruits (Ghasemnezhad et al., 2011). In the present study, all LED light treatments significantly increased soluble solids and titratable acidity compared to the control treatment. These results are in consistent with the findings of Kim et al. (2022) who showed that blue and red light increased the content of soluble solids in peppers compared to soluble solid content of fruits obtained from plants grown under natural light (Kim & Son, 2022).

All supplementary light treatments significantly increased the maturity index compared to the control treatment (Tukey's test at $p \leq 0.05$). Maturity index is a reliable index to determine the pepper fruits harvesting time (Navarro et al., 2002). To offer high-quality sweet peppers to the market, the fruits should be harvested at their optimal maturity stage to meet the needs of consumers. At the optimal maturity stage, the fruits must show a variety-specific color, shape, size, acidity and total soluble solids content, but the maturity of the fruit should not be excessive (Ignat et al., 2013).

Higher fruit dry matter content means more nutrients per unit of fresh fruit (Lanoue et al., 2022). Reports have shown that increasing red light can increase the dry matter content of fruit (Liu et al., 2022a; Liu et al., 2022b). In the current study, by increase in the proportion of R light in overall spectrum, the percentage of dry matter increased. This result is in agreement with previous study in pepper (Lan et al., 2022), which showed the increase in red light increased the dry matter content of the fruit compared to its content in the plants grown under natural light, while increase in blue light did not influenced the fruit dry matter content.

CONCLUSION

In conclusion, using combination of red and blue light spectra as supplemental lighting increased total yield of greenhouse-grown red and yellow sweet pepper fruits due to increase in number of fruits and fruit size, compared the fruits produced under natural light conditions. The blue light addition from 10% to 30% to the growing light spectrum improved fruit yield parameters. Therefore, the results showed that T3 (R6B3) was the best treatment. Furthermore, our results showed that LED supplemental lighting by increasing flesh thickness, fruit dry matter, vitamin C, and total soluble solids is a promising approach to improve fruit quality.

Conflict of interest

The author has no conflict of interest to report.

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