

ISSN 1392-3196

Zemdirbyste-Agriculture, vol. 97, No. 2 (2010), p. 99–104

UDK 634.75:581.144.3.035]:631.559

The effect of red and blue light component on the growth and development of frigo strawberries

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Abstract

The experiments were carried out in 2009 in phytotron chambers and commercial greenhouses of the Lithuanian Institute of Horticulture. The frigo plants of 'Elkat' strawberries (*Fragaria x ananassa* Duch.) were investigated. The frigo sprouts were grown in a phytotron chamber for a month under different light-emitting diode (LED) treatment: sole red (640 nm) light, photosynthetic photon flux density (PPFD) beside leaves of strawberries – 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$; combination of red (640 nm) with blue (455 nm) light, maintained PPFD was 174.5 and 25.5 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The photoperiod of 16 hours and 21/16°C day/night temperature in the phytotron chamber were maintained. After LED treatment, strawberry sprouts were transplanted to a bed mulched by white film in the polythene greenhouse. The spectral quality of light influenced the morphogenesis and diverse physiological responses of frigo plants of 'Elkat' strawberry. Development was improved, carbohydrate accumulation and pigment ratio of plants was increased in strawberries grown under red and blue LEDs. Whereas, red LED induced elongation of flowering stem and all plant, and resulted in 1.8 times higher shoot/root ratio. The positive influence of red and blue light treatment on the formation of runners, inflorescence and crown was observed. The fruiting of frigo strawberries ended after 40 days after planting. The treatment of sole red light or combination of red and blue LEDs had no persistent effect on the harvest of frigo strawberries. However, red LED treatment resulted in a smaller size of fruits. It confirms that a mixture of red and blue LED spectral components is necessary for the development of frigo strawberries, likewise for normal plants.

Key words: carbohydrate, photosynthetic pigment, light-emitting diodes, yield.

Introduction

Previously, the most common type of strawberry planting material used in practice was fresh runner plants, but since the introduction of cold-stored plants (frigo plants), this type has become predominant. Compared to fresh runner plants, frigo plants have the advantage of being physiologically older, as flower initiation has already occurred before cold storage (Daugaard, 1999). Such strawberries start to yield 40–60 days after planting. As frigo plants can be stored for a considerable time, they can be planted at any time during the season, which in some countries is used in order to extend the growth season by planting several times during the spring (Laugale et al., 2009). Apart from

other factors, photosynthesis apparatus, morphogenesis and plant architecture of sprouts grown in greenhouses are also influenced by light quality (Brazaitytė et al., 2009).

Light sources generally used for greenhouses are metal halide or sodium (HPS) lamps. The spectral range of these lamps varies from 350 to 750 nm. Lately this lighting has been replaced by light-emitting diodes (LED). Although for commercial greenhouses LED systems are still too expensive in comparison with HPS lamps (Hogewoning et al., 2007), LEDs have some very important properties for horticulture (Tamulaitis et al., 2005). Many studies over the last several decades, prima-

rily in *Arabidopsis thaliana*, have clearly shown that variation in light quantity, quality and photoperiod can be manipulated to affect growth and control developmental transitions (Folta et al., 2005). Light drives the processes of photosynthesis and plant development, and ultimately affects crop yield. The summary of over a century of plant photobiology research shows that plants possess complicated photosensory networks that monitor and respond to a wide spectrum of ambient light energies. As light effects on physiology have been observed from energies arising from the UV-B wavebands into the near infra-red (Johnson et al., 1996). This broad range of environmental information is processed by integrated signaling networks that tailor growth and development to best fit ambient light conditions. Basic plant research has demonstrated that specific light wavebands may affect plant physiology, such as germination, stem growth (Parks et al., 2001), biomass (Kim et al., 2004) and the transition to flowering (Valverde et al., 2004). The supplementation of specific wavebands or skewing of overall spectrum may help modulate the progression of these developmental events.

Previous studies demonstrated that the combination of red and blue light was an effective light source for several crops. It is known that red light is important for shoot/stem elongation, phytochrome responses and changes in plant anatomy (Schuerger et al., 1997). In contrast, blue light is important in chlorophyll biosynthesis, stomatal opening, enzyme synthesis, maturation of chloroplasts and photosynthesis (Tibbitts et al., 1983). It is known that chlorophyll has the second distinct absorption peak in the vicinity of 450 nm (blue light region) other than the first peak in the vicinity of 660 nm (red light region) in its light absorption spectrum. The blue light is also indispensable for the morphologically healthy plant growth. On the other hand, the red light contributes to the plant photosynthesis (Okamoto et al., 1996). Blue and red LEDs have been used for studies in many areas of photobiological research such as photosynthesis, chlorophyll synthesis (Tripathy, Brown, 1995), and morphogenesis (Brown et al., 1995). Many reports have demonstrated the utility of red/far-red/blue LED sources in modulating phytochrome responses during de-etiolation (Yadav et al., 2002), modulation of root growth, root greening (Usami et al., 2004) and senescence (Rousseaux et al., 1997). LED technology has been incorporated into lighting regimes to modulate plant growth and development for decades as acute supplementation of sunlight (Heo et al., 2003) or as the basis of plant growth in commercial chambers (Markelz et al., 2003).

The possibility that combinatorial light regimes may help to optimize growth and control developmental transitions makes the implementation of LED technology particularly attractive to the design of controlled environments targeted to plant production for aesthetic applications, or applications relevant to human nutrition.

The goal of this study was to investigate the effect of red and combination of red and blue light on chlorophyll accumulation, carbohydrate distribution, assimilative indices and yield of frigo strawberries.

Materials and methods

The experiments were carried out in 2009 in phytotron chambers and commercial greenhouses of the Lithuanian Institute of Horticulture. The frigo plants of 'Elkat' strawberries (*Fragaria x ananassa* Duch.) were investigated. The sprouts were stored in the refrigerator under $-2 \pm 1^\circ\text{C}$ temperature till they were planted in 0.5 l vessels with peat substrate (pH \approx 6, PG MIX, NPK 14:16:18, 1.3 kg m⁻³). The sprouts were grown in a phytotron chamber for a month under different LED treatment: sole red (640 nm) light (R), photosynthetic photon flux density (PPFD) beside leaves of strawberries – 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$; combination of red (640 nm) with blue (455 nm) light (R + B), maintained PPFD is 174.5 and 25.5 $\mu\text{mol m}^{-2} \text{s}^{-1}$ respectively. The photoperiod of 16 hours and 21/16°C day/night temperature in the phytotron chamber were maintained. After LED treatment strawberries were developed till XIII organogenesis stage, such sprouts were transplanted to a bed mulched by white film in the polythene greenhouse.

Carbohydrates (fructose, glucose) were measured by a high performance liquid chromatography (HPLC) method. About 1 g of fresh weight of plant tissue (leaves and buds) was ground and eluted with 70°C bi-distilled water. The extraction was carried out for 24 h. The sample was filtered through cellulose and cellulose acetate (pore diameter 0.25 μm) filters. The analyses were performed on Shimadzu HPLC (Japan) chromatograph with refractive index detector (RID 10A), oven temperature was maintained at 80°C. Separation of carbohydrates was performed on Shodex SC-1011 column (300 x 4.6 mm) (Japan), mobile phase – bi-distilled water.

Photosynthetic pigments (chlorophyll a and b) were measured by spectrophotometric method of Wetshtein (Гавриленко, Жыгалова, 2003) in 100% extract of acetone.

Assimilative indices were calculated as follows:

leaf area ratio (LAR) – the ratio of leaf area and total plant dry weight, $\text{cm}^2 \text{g}^{-1}$;

specific leaf area (SLA) – the ratio of leaf area and dry weight of leaves, $\text{m}^2 \text{kg}^{-1}$;

leaf weight ratio (LWR) – the ratio of dry weight of leaves and dry weight of all plant, kg kg^{-1} .

The content of photosynthetic pigments and carbohydrates, the assimilative indices were measured straight after LED treatment. Productivity indices were measured during all harvesting time.

The standard deviation of the mean ($p = 0.05$) of biological ($n = 6$) or analytical ($n = 3$) replications calculated by *MS Excel* programme are presented in the Figures or Tables.

Results and discussion

The shoot/root ratio was higher in strawberries treated with red LEDs (Table 1). This means that the combination of red and blue light resulted in greater root and lower leaf formation. It is known that different light spectra affect the balance between growth and development of the plants. Optimal growth requires morphological or physiological plasticity in the shoot-to-root ratio. In addition to

a change in the biomass ratio of shoot and roots, plants may also have alternative ways to change resource allocation to gain limiting resources, e.g., by changing the morphology and chlorophyll concentration in leaves. Empirical evidence suggests that the shoot-to-root ratio indeed shows plastic response to light and nutrient availability (Aikio, Markkola, 2002).

The addition of 10% blue light had no remarkable effect on strawberries LAR, LWR or whole plant dry weight (Table 1). But it positively affected the SLA. Agreeably to Poorter and Remkes (1990), the variation in LAR and SLA are only significantly correlated with relative grow rate (RGR). Thus, the more a plant invests in leaf area, the higher the total carbon gain and the faster growth will occur. Red and blue light affected the increase in SLA and the slight decrease in LAR, besides the decrease in shoot/root ratio was observed (Table 1). The leaf area ratio (LAR) is the product of a morphological component (SLA, specific leaf area), the ratio of leaf area and leaf mass, and the leaf weight ratio (LWR), indicating the fraction of total plant weight allocated to the leaves (Poorter, Remkes, 1990). In addition, leaf adaptation to spectral quality also involved changes in leaf structure and overall SLA (Kim et al., 2004).

Table 1. The influence of different lighting on 'Elkat' frigo strawberries assimilative indices

Assimilative indices	R	R + B
Shoot/root ratio	0.88 ± 0.041	0.50 ± 0.023
Leaf area ratio $\text{cm}^2 \text{g}^{-1}$	0.14 ± 0.017	0.12 ± 0.019
Specific leaf area $\text{m}^2 \text{kg}^{-1}$	15.40 ± 1.610	18.30 ± 1.440
Leaf weight ratio kg kg^{-1}	0.49 ± 0.010	0.48 ± 0.006
Whole plant dry weight g	34.30 ± 0.160	33.80 ± 0.680
Length of flowering stem cm	11.90 ± 0.900	8.40 ± 0.800

Notes. R – 640 nm, R + B – 640 nm, 455 nm. The standard deviation of the mean ($p = 0.05$) are presented.

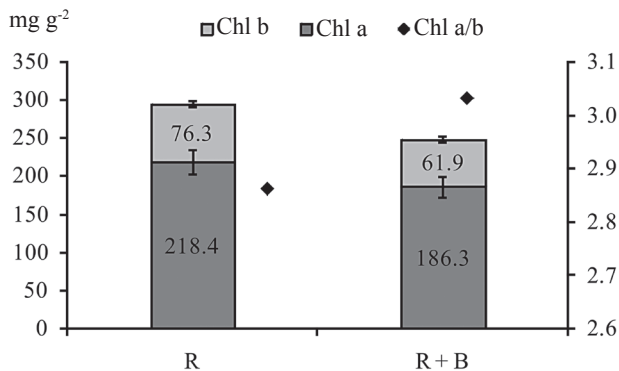
According to our data, the total dry weight was slightly lower of strawberries grown under red + 13% blue light (Table 1). Such decrease in leaf and root dry weight was also noted by Shin (Shin et al., 2008). Brown noticed that (Brown et al., 1995) peppers biomass was reduced when peppers were grown under red LEDs in the absence of blue wavelengths compared to plants grown under supplemental blue fluorescent lamps or metal halide lamps. Furthermore, Yorio with co-workers (2001) states that total dry-weight accumulation was significantly lower for radish and spinach when grown under red LEDs alone than when grown under (CWF) light or red LEDs + 10% BF light. Moreover, total dry weight

was significantly lower under red LEDs + 10% blue light than under CWF light, suggesting that addition of blue light to the red LEDs was still insufficient for achieving maximal growth for these crops (Yorio et al., 2001).

The red light alone influenced the elongation of flowering stem compared to strawberries grown under red and blue light. Frigo plants of strawberries treated with red light alone were to 30 % taller. The addition of blue light component suspended the elongation process, plants were more compact and formed greater specific leaf area (Table 1) (Nhut et al., 2003).

Consistent with our results (Table 1), other authors also state that red light affected flowering stem elongation of strawberries (Hoenecke et al., 1992) and resulted in more intensive synthesis of chlorophylls (Fig. 1) (Tripathy, Brown, 1995). It is known that blue light through photoreceptors interacts with phytochrome system and thus results in the plant response (Rajapakse et al., 1992). The spectral maximum of red and blue LED's coincides with absorption maximums of chlorophyll a and b (Nhut et al., 2003). Our results show the effect of light spectral quality on photosynthetic pigment accumulation and ratio (Fig. 1) and on accumulation of primary photosynthesis products (fructose and glucose) (Fig. 2). In contrast to our data, Shin and co-workers (2008) demonstrated that red LED treat-

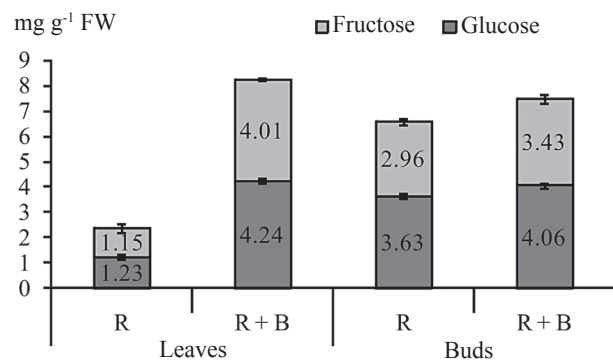
ment led to a significant reduction in chlorophyll contents. However, the ratios of chlorophyll a/b did not vary significantly. According to our data, strawberries treated under red and blue light accumulated less chlorophyll a and b, but the chlorophyll a/b ratio under this treatment was higher (3.03) compared to red light treatment (2.86) (Fig. 1). The significant increase in glucose and fructose content was observed in strawberry leaves grown under red and blue light, whereas in buds only slight increase in hexoses under R + B LEDs treatment was observed (Fig. 2). Since the content of chlorophylls a and b was higher under red light, this treatment affected the low chlorophyll a/b ratio (Fig. 1) and the lowest accumulation of fructose and glucose in strawberry leaves (Fig. 2).



Notes. Explanations under Table 1.

Figure 1. The content and ratio of photosynthetic pigments in strawberry leaves under red and red + blue LEDs treatment.

Agreeably with Brown (Brown et al., 1995), the positive influence of red and blue light treatment on the formation of runners, inflorescence and crown was observed (Table 2). The fruiting of frigo plants of 'Elkat' strawberries ended after 40 days after planting. According to Daugaard (1999) data, harvesting starts 40–60 days after planting. The treatment with red alone or combination of red



Notes. Explanations under Table 1.

Figure 2. The content of carbohydrates in fresh weight (FW) of strawberry leaves and buds under red and red + blue LEDs treatment.

and blue LEDs had no persistent effect on frigo plants of strawberries yield. Red LED treatment affected the size of fruits (they were smaller) (Table 2). Brazaitytė also suggests that the after-effect of different illumination of various LED on cucumber yield was not revealed, but it had effect on the beginning of flowering and harvest (Brazaitytė et al., 2009).

Table 2. The development and yield of 'Elkat' frigo strawberries before (8th of July) and after (24th of July) fruiting

Productivity indices	Fruiting time	R	R + B
Number of runners per plant	Beginning of fruiting	1.0 ± 0.61	1.2 ± 0.30
	Ending of fruiting	2.5 ± 1.22	3.1 ± 0.71
Number of inflorescences per plant	Beginning of fruiting	1.3 ± 0.40	1.4 ± 0.70
	Beginning of fruiting	1.4 ± 0.42	1.6 ± 0.51
Number of berries per plant	During all fruiting	49.7 ± 9.11	50.7 ± 4.12
Mass of berry g	During all fruiting	3.2 ± 0.42	4.9 ± 0.60

Notes. Explanations under Table 1.

Conclusion

Spectral quality (red and a combination of red and blue LEDs) of light influences the morphogenesis and diverse physiological responses of frigo plants of 'Elkat' strawberry. Development was improved, carbohydrate accumulation and pigment ratio of plants was increased in strawberries grown under red and blue LEDs. Red LED induced elongation of flowering stem and whole plant; this resulted in higher shoot/root ratio. It confirms that a mixture of red and blue LED spectral components is necessary for the development of frigo strawberries, likewise for normal plants.

Received 10 03 2010

Accepted 11 05 2010

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ISSN 1392-3196

Žemdirbystė-Agriculture, t. 97, Nr. 2 (2010), p. 99–104

UDK 634.75:581.144.3.035]:631.559

Raudonos ir mėlynos šviesos įtaka braškių daigų, laikytų žemoje temperatūroje (*frigo*), auginimui bei vystymuisi

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Santrauka

Tyrimai atlikti 2009 m. Lietuvos sodininkystės ir daržininkystės instituto fitotrono komplekse ir gamybiniuose šiltnamiuose. Tirtos veislės 'Elkat' aukštos kokybės laikytų žemoje temperatūroje (*frigo*) daigų braškės (*Fragaria x ananassa* Duch.). Jų daigai mėnesį auginti fitotrono kameroje, taikant šviesą skleidžiančių šviestukų (LED) technologiją, apšviesti kietakūnės šviesos spektro deriniais: tik raudonos (640 nm) šviesos, fotonų srauto tankis (PPFD) ties braškių lapais – 200 $\mu\text{mol m}^{-2} \text{s}^{-1}$; raudonos (640 nm) ir mėlynos (455 nm) šviesos, PPFD esant atitinkamai 174,5 bei 25,5 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Fitotrono kameroje fotoperiodas buvo 16 val., o dienos ir nakties temperatūra – +21/16° C. Po skirtingo šviesos poveikio braškių daigai (liepos mėnesį) persodinti į polietileninį šiltnamį, balta plėvele mulčiuotą lysvę. Tyrimų rezultatai parodė, kad šviesos spektro kokybė turėjo įtakos veislės 'Elkat' laikytų žemoje temperatūroje daigų braškių morfogenezei ir nevienodą fiziologinį poveikį. Raudona ir mėlyna šviesa turėjo įtakos augintų braškių vystymuisi, angliavandenių kaupimuisi ir pigmentų kiekiui. Raudona LED šviesa skatino žiedynstiebio bei viso augalo tįsimą ir lėmė 1,8 karto didesnę antžeminės dalies bei šaknų santykį. Nustatyta teigiama raudonos ir mėlynos šviesos įtaka ūsų, žiedynų ir ragelių formavimuisi. Žemoje temperatūroje laikytais daigais padaugintos veislės 'Elkat' braškės baigė derėti praėjus 40 dienų po persodinimo į šiltnamį. Laikytų žemoje temperatūroje daigų braškių bendram derliui šviesos poveikis nebuvo efektyvus, tačiau nustatyta, kad tik raudona šviesa švitinti šių daigų braškių uogakrūmiai formavo smulkesnius vaisius. Tai tik patvirtina teiginį, kad normaliam augalų, taip pat ir laikytų žemoje temperatūroje daigų braškių, vystymuisi yra būtinas LED spektro raudonos ir mėlynos spalvos derinys.

Reikšminiai žodžiai: angliavandeniai, chlorofilai, derlius, lapų plotas, šviesą skleidžiantys šviestukai.