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GROWTH RATE OF SWEET BASIL AND LEMON BALM PLANTS GROWN UNDER FLUORESCENT LAMPS AND LED MODULES

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Abstract. The aim of the experiment was to compare the effect of LED and fluorescent lamps as sources of light on growth and development of sweet basil (*Ocimum basilicum* L.) and lemon balm (*Melissa officinalis* L.). The experiment was conducted in growth chambers under controlled conditions. Plant response to the applied light sources was found to be varied. Basil plants produced greater fresh herbage mass as well as shoot height under Fl lamps. The employed sources of light did not have a significant effect on leaf area or photosynthesis rate in these plants. Light sources did not influence the growth rate of lemon balm plants, but these plants were characterised by a greater net photosynthesis value when grown under FL tubes as compared to LEDs. It can be concluded that the response of plants to the applied light is individual and depends on the species.

Key words: *Ocimum basilicum*, *Melissa officinalis*, LED, FL, light sources

INTRODUCTION

Light is a primary factor influencing growth and development of plants. To a considerable degree, it determines the appearance of plants, their growth rate as well as the duration of reaching individual development stages. Light quality influences the growth and morphogenesis of many plants grown in a closed system at artificial sources of light. Presently, many types of garden crops are cultivated under fluorescent lamps, HPS and LEDs, which are becoming especially popular for vegetable crops [Liu et al. 2011]. LEDs are used as supplemental light for plant growth under conventional sources of light, particularly for the control of plant height, sensitive flowering and blooming period in the feature [Heo et al. 2002, Sttute 2009]. The new generation of LED lamps emitting white light makes it possible to completely replace fluorescent lamps as a primary light source. Light-emitting diodes are an alternative to fluorescent lamps due to

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their low forward current, small size, wavelength specificity, solid-state structures, low degradation and long life [Jao and Fang 2003]. LEDs may thus be suitable for plant cultivation in a controlled environment such as a closed system and have, therefore, received considerable attention in recent years. LEDs also have been considered as a novel light source for growth and development of many horticultural plants [Morrow 2008].

In a closed system, plant environment can be controlled precisely as desired. Annual production capacity of transplants per floor area is about 10 times higher in the closed system than in the greenhouse. It can also be applied for the production of herbal/medicinal and ornamental plants and leafy vegetables, if their height is lower than approx. 30 cm [Kozai et al. 2006].

The aim of this study was to compare growth parameters and intensity of photosynthesis in sweet basil and lemon balm plants grown under white light emitted from fluorescent lamps and light emitting diodes (LEDs).

MATERIALS AND METHODS

The study was carried out in 2011 in growing room of the Marcelin Experimental Station, Poznań University of Life Sciences, Poland. The seeds of sweet basill (*Ocimum basilicum* L.) cultivar 'Wala' and lemon balm (*Melissa officinalis* L.) were germinated on white peat bedding substrate (Klassmann-Deilman, Germany) in pots. A 16-h photoperiod and the day/night temperature of 23/18°C were maintained. The relative air humidity was 65–70%. After germination, plants were still cultivated for 28 (basil) and 35 (balm) days. The following two light sources were used: TL'D 36W/840 fluorescent lamps (**FL**) Philips (Poland) and high-power solid-state lighting module (**LED**) (type SMD, Seoul Semiconductor, South Korea), both with white light and the wavelength range of 320–780 nm. The plants were cultivated in the growing room, in which there were two, separated tables with FL lamps and LEDs. Thus the plants had exactly the same growth conditions. Tables had a size of 1.20 m^2. Above each table hung eight lamps, with a length of 1.20 m. The spectra of the light sources are presented in Fig. 1 and Tab. 1. Photosynthetic photon flux density (PPFD, 400–700 nm) at the plant level was about 160 (FL) and 179 (LED) μmol m^{-2} s^{-1} (±14). PPFD was measured using a quantum sensor (PAR-10, Sanopan, Poland). Spectral distribution of light treatments was measured with a spectroradiometer BLACK-Comet CXR, 280–900 nm (UV-VIS by StellarNet Inc.). Measurements were made 15 cm under the lamps, more or less at the height of the tops of the plants.

The number of plants grown in a single pot was identical and amounted to 40 ±5 plants. They were grown in pots of 280 cm^3 and 49 cm^2 cultivation area. Plants were only watered without nutrients on capillary mats every other day. Plant growth parameters were measured from the 7^{th} (basil) and 14^{th} (sweet lemon balm) day after emergence and then every 7 days throughout the vegetation period; second measurement on the 14^{th} (21^{st} sweet lemon balm) and later respectively third on the 21^{st} (28^{th}) and fourth on the 28^{th} (35^{th}) day of cultivation. Harvesting involved hand-cutting of plants close to the surface of the peat substrate. After harvest, the mass of the fresh matter of shoots

from a given pot was determined. In addition, measurements of plant height, hypocotyl length (only basil, lemon balm hypocotyl is only a few millimeters in length) and leaf area were taken (10 plants from every pot). A scanner (Mustek 1200 UB) and the *Skwer* program (*IksmodaR*, Poland) were used to calculate the surface of leaves.

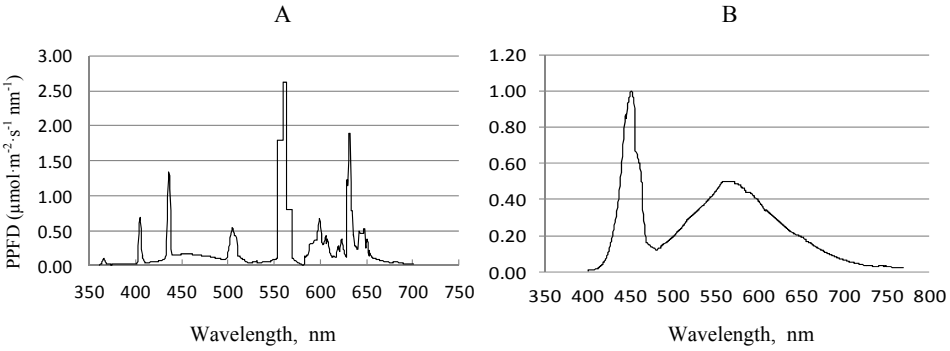

Fig. 1. Spectral distribution of a A – light-emitting diodes (LEDs) and B – fluorescent lamps (FL)

Table 1. Characteristics of light sources

Light color	Wavelength (nm)	Light-emitting diodes		Fluorescent lamps (FL)	
		PFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	%	PFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	%
UV	320–380	0.5	0.3	2.4	1.4
Violet	380–450	15.4	15.5	21.7	12.9
Blue	450–495	30.3	16.3	12.5	7.5
Green	495–570	53.5	28.7	64.9	38.7
Yellow	570–590	18.7	10.1	4.0	2.4
Orange	590–620	21.8	11.8	19.1	11.4
Red	620–700	26.4	14.2	39.8	23.6
Far Red	700–780	5.6	3.1	3.6	2.1
Sum	320–780	172.2	–	168.0	
R:FR		4.6		11.1	

Relative chlorophyll content was measured using the SPAD apparatus, Minolta Company, while net photosynthesis (Pn) and stomatal conductance (g_s) with the assistance of the photosynthesis instrument (LCpro+, ADC BioScientific). Gas exchange and stomatal conductance were measured using a custom-made leaf chamber – 6.25 cm^2. After steady-state rates of A had been recorded (approx. 1 h), leaves were removed from the chamber and leaf area was measured. The photosynthetic rate was calculated on the basis of the following formula: $A = u_s \Delta c$, where: u_s – mass flow of air per m^2 of leaf

area (μmol CO_2 m^{-2} s^{-1}), Δc – difference in CO_2 concentration through chamber dilution corrected (μmol mol^{-1}). A flow rate of about 200 ml min 1 was used. Stomatal conductance to water vapour was calculated using a formula: $g_s = 1/r_s$, where r_s = stomatal resistance to water vapour (m^2 s^{-1} mol^{-1}). Chlorophyll fluorescence measurements were taken using a modulated fluorometer (Fluorometr OS1-FL, Optiscience). The dark adapted parameters used to determine Maximum quantum yield of PS II (photosystem II): Fv/Fm = (Fm – Fo)/Fm (Fo – is the dark adapted initial minimum fluorescence, Fm – is maximal fluorescence measured during the first saturation pulse after dark adaption [Maxwell and Johnson 2000]. Chlorophyll fluorescence was measured one hour after the termination of the lighting period. Pn and g_s was measured before noon in conditions in which plants were grown. The second fully developed leaf was used to measure chlorophyll content, chlorophyll fluorescence and photosynthesis. All measurements were taken in the last week of cultivation. Five plants from each combination were taken for measurements.

The experiments were performed in eight repetitions, where three pots were treated as one repetition. The investigations were conducted in two series (replications, after each other). The significance of the impact of the light source on plant height, hypocotyl length, yields and leaf area as well as physiological indices were determined employing the ANOVA. Differences between means were estimated using the Newman-Keuls test at the level of significance $\alpha = 0.05$. All statistical analyses were carried out applying the *Stat* program.

Dry mass and leaf area data were used to determine the physiological indices of growth as described by Hunt [1982]: relative growth rate (RGR), leaf area index (LAI), net assimilation rate (NAR) and leaf area ratio (LAR).

The index of the relative growth rate (RGR) was calculated on the basis of the following formula: $RGR = (\ln W_2 - \ln W_1)(t_2 - t_1)$, where: W_2 and W_1 are plant dry mass (g), at times t_2 and t_1, respectively.

The leaf area index (LAI) refers to the area of the leaf surface in relation to the pot area. It was calculated on the basis of the following formula: LAI = A/P, where: A – plant assimilation area (dm^2), P – pot area (dm^2).

The net assimilation rate (NAR) is the increment of biomass per unit of time and per unit of any measure of magnitude of the assimilation organs: $NAR = dW/(A \cdot dt)$, where: A – area of assimilation organs (dm^2), dW – dry mass increment (g), dt – time of cultivation (days).

Specific leaf area (SLA) is defined as the ratio of leaf area to the dry mass of leaves. $SLA = L_A/L_W$, where: L_A – leaf area (dm^2), L_W – dry mass of leaves (g).

RESULTS

Results show that light from fluorescent lamps was probably more advantageous than light derived from LEDs for basil plants. These plants growing under Fl lamps were characterised by a greater herbage mass and greater shoot height (tab. 2). In the case of lemon balm, differences in plant growth depending on light sources were not so conspicuous. Plant height and leaf surface of lemon balm plants were slightly greater in

plants grown under LEDs, but differences were not significant. Also herbage mass in the first three weeks of growing was significantly higher in plants under LEDs.

Table 2. Morphological characteristic of sweet basil and lemon balm plants grown under fluorescent lamps (FL) and LEDs

Plant	Growth day	Fresh mass (g)		Hypocotyl (cm)		Height (cm)		Leaf area (dm^2)	
		FL	LED	FL	LED	FL	LED	FL	LED
Sweet basil	7th	3.7 a*	2.7 b	2.7 a	2.1 b	–	–	0.68 a	0.64 a
	14th	8.2 a	7.3 b	4.2 a	4.1 a	5.1 a	4.9 a	3.3 a	2.8 b
	21st	20.3 a	15.5 b	4.5 a	4.9 a	9.7 a	8.7 b	7.3 a	6.5 a
	28th	29.8 a	23.6 b	4.9 b	5.8 a	16.4 a	14.9 b	8.4 a	8.2 a
Lemon balm	14th	0.78 b	1.02 a	–	–	1.3 a	1.5 a	0.65 a	0.71 a
	21st	2.5 b	3.3 a	–	–	3.9 a	3.8 a	1.7 a	1.7 a
	28th	4.8 b	7.1 a	–	–	4.6 a	4.7 a	3.9 a	4.0 a
	35th	8.3 a	8.6 a	–	–	7.6 a	8.0 a	6.0 a	6.3 a

*Different letters within the lines and dates indicate significant differences at $P < 0.05$

Table 3. Growth indices of sweet basil and lemon balm plants grown under fluorescent lamps (FL) and LEDs

Plant	Growth day	LAI ($dm^2\ dm^{-2}$)		SLA ($dm^2\ g^{-1}$)		RGR ($g\ g^{-1}\ d^{-1}$)		NAR ($g\ dm^{-2}\ d^{-1}$)	
		FL	LED	FL	LED	FL	LED	FL	LED
Sweet basil	7th	1.4 a*	1.3 a	2.55 a	2.80 a	–	–	–	–
	14th	6.8 a	5.7 b	3.79 a	3.92 a	0.10 a	0.10 a	0.055 a	0.035b
	21st	15.4 a	13.4 a	6.14 b	7.30 a	0.07 a	0.08 a	0.017 b	0.020 a
	28th	17.2 a	16.8 a	5.46 b	6.42 a	0.09 a	0.05 b	0.010 a	0.014 a
Lemon balm	14th	1.3 a	1.4 a	0.71 b	0.81 a	–	–	–	–
	21st	3.5 a	3.5 a	0.52 b	0.75 a	0.11 a	0.08 b	0.21 a	0.12 b
	28th	8.0 a	8.1 a	0.55 a	0.56 a	0.04 b	0.09 a	0.15 a	0.17 a
	35th	12.2 a	12.9 a	0.71 a	0.74 a	0.05 a	0.03 a	0.07 a	0.04 b

*Different letters within the lines and dates indicate significant differences at $P < 0.05$.

Both light sources had no effect on the area index (LAI) in the examined species (tab. 3). In the early growth of lemon balm (after 14 and 21 days), the specific leaf area (SLA) was greater in the plants under LEDs. In the course of the following days of cultivation, no differences were found in values of SLA between plants grown under

fluorescent lamps vs. those grown under LED modules. Basil plants grown under LEDs were characterised by a higher value of SLA in the 21st and 28th day of cultivation. There were no differences in values of relative growth rate (RGR) between basil plants grown under FL lamps and LEDs for the following two measurements. Only in the 28th day of cultivation, the plants under Fl lamps were characterised by a higher value of RGR. In the 28th day of cultivation of lemon balm plants (second measurement), higher values of RGR were obtained for LEDs, but after 28 days – these values were higher for FL lamps. In the 35th day, there were no differences between the applied light sources. The value of net assimilation rate (NAR) was initially (14 days) higher for basil under FL lamps but after 21st days, it changed in favour of plants under LEDs. After that time, there were no differences. Lemon balm was characterized by a higher value of NAR under FL lamps after 21st and in the 35th day. After 28th days, there were no differences. With respect to physiological indices – no clear impact of the light source could be seen on values of RGR and NAR.

Table 4. Effect of fluorescent lamps (FL) and LEDs on net photosynthetic rate, stomatal conductance and the PSII quantum field in 28th (basil) and 35th (balm) day of cultivation

Plant	Light source	Net photosynthetic rate (μmol CO_2 m^{-2} s^{-1})	Stomatal conductance (mol·m^{-2}·s^{-1})	Maximum quantum yield of PSII (Fv/Fm)
Sweet basil	FL	6.0 a	0.34 a	0.80 a
	LED	6.0 a	0.26 b	0.81 a
Lemon balm	FL	7.3 a	0.52 a	0.80 a
	LED	6.3 b	0.51 a	0.80 a

Different letters within the columns indicate significant differences at $P < 0.05$.

Table 5. Relative chlorophyll content (SPAD) in leaves in last week of cultivation

Plant	Type of lamp	
	FL	LED
Sweet basil	37.4 a	29.9 b
Lemon balm	25.7 a	26.5 a

Different letters within the columns indicate significant differences at $P < 0.05$.

The net photosynthesis value did not vary depending on the light source for basil plants (tab. 4). In lemon balm leaves, the net photosynthesis rate was higher by about 38% under FL light than under LEDs. There were no differences in fluorescence (Fv/Fm) between light sources for both species and only basil plants were characterized by a higher value of chlorophyll content and stomatal conductance under Fl lamps (tab. 5).

DISCUSSION

The reason for the recorded high differences most probably lies in variations between the spectra of the light sources used. LEDs emitting white light were characterised by a greater proportion of blue and green light and a lower proportion of UV in the spectrum and a lower R:FR ratio in comparison with fluorescent lamps.

A greater proportion of blue light in the spectrum of LED modules could have contributed to the inhibition of shoot elongation under LEDs. Some authors reported that blue light determines shorter internodes of plants [Kim et al. 2004a, Johkan et al. 2010]. However, in a study by Głowacka [2008], the highest basil plants were obtained in the treatment where only blue light was applied in comparison with white or mixed (white + blue) light. A greater height of basil plants in present study was recorded for plants grown under FL tubes in the last two weeks of cultivation. Stem elongation, among other things, depends on the red to far red ratio (R:FR) [Alokam et al. 2002]. In response to low R:FR ratio signals, many plants display a rapid and pronounced increase in the elongation growth rate of stems and petioles, often at the expense of leaf and storage organ development [Franklin and Whitelam 2005]. FL lamps were characterised by a higher proportion of red to far red light which could inhibited growth of hypocotyl.

A weaker effect on height in lemon balm plants was observed for the source of light. Similarly to the results obtained in the present study, in earlier experiments, Głowacka [2008] found that the height of lemon balm plants depended on the light colour only in the last growth stage. According to Głowacka [2008], the highest plants were produced under blue light; in this study it was under LEDs.

Greater fresh mass productivity of basil plants growing under FL lamps can, to a considerable extent, be attributed to a significantly higher proportion in these lamps of red light (23.6%) in comparison with LEDs (14.2%). Moreover, Folta and Childers [2008] claim that blue (B) to red (R) light proportions are also important. The abovementioned researchers maintain that the ratio of 1B:3R guarantees appropriate growth and development of strawberry plants. According to those authors, such results indicated the petiole elongation suppression by blue light culminating in a greater mass and length per petiole in conditions in which blue light was lost with increasing red. However the amount of blue light required or optimal for different species is an ongoing question [Massa et al. 2008]

Greater fresh herbage mass of basil plants grown under fluorescent lamps may also be explained by the stimulatory effect of UV radiation which constituted as much as 1.4% of spectral composition. Although in various studies on UV-A radiation, the inhibitory effect on plant growth was determined in different species [Yao et al. 2006, Brazaitytė et al. 2009]. Results similar to those recorded in this study were reported by Brazaitytė et al. [2010]. A positive effect of supplemental UV radiation on the growth rate of plants was found in the later growing stages of tomato transplants.

Lemon balm is a species of slow growth in the initial period of growing. This low growth rate could have also contributed to the lack of marked differences in plant growth depending on the applied light source. In a study by Głowacka [2008], the greatest fresh herbage mass was produced when plants were grown under blue light only, while it was lowest in the case of white light. In this study, during the first 28 days of

cultivation, much greater fresh mass were obtained under LEDs in comparison with fluorescent lamps.

Despite large differences in herbage mass, particularly in the case of basil, no significant differences were observed in leaf area for both species depending on the light source applied. In addition, moderate differences in plant height also show that basil plants grown under FL lamps were more compact and had thicker leaves of greater mass.

No evident dependencies were found between values of growth indices on the applied light sources. A greater effect on values of these indices was observed for their sinusoidal character than for light. Such a parameter as SLA, which depends on the growth environment, can describe morphological adaptation to this environment, while net assimilation rate (NAR) – physiological adaptation [de Groot et al. 2001]. In the initial growth period, a higher NAR value in the case of basil was recorded under FL lamps. In contrast, a higher SLA value was found for plants grown under FL lamps for the last two weeks of growth. It may be maintained that basil plants are physiologically better adapted to grow under FL, but morphological adaptation was not established. On the other hand, lemon balm was characterised by an opposite reaction. In a study by Brazaitytė et al. [2010], SLA for tomato seedlings was highest when plants were growing under sodium lamps in comparison with plants grown under LEDs emitting red and blue light. However, NAR was highest for LEDs emitting red-blue light (RB) with the addition of orange and yellow colour.

A higher value of net photosynthesis in lemon balm was observed for Fl lamps, and it was not correlated with the fresh mass produced by plants or relative chlorophyll content in leaves. Probably, a higher value of net photosynthetic rate was connected with a more advantageous share of red light (R) in fluorescent lamps in comparison with LED modules. It is generally acknowledged that red and blue light (RB) enhances plant growth and development by increasing net photosynthetic rate because the spectral energy distribution of RB is consistent with that of chlorophyll absorption [Kim et al. 2004b, Li et al. 2012]. In a study by Ying et al. [2011], photosynthesis under different light colors was increased, with the RB treatment showing maximal enhancement. The above researchers also suggested that blue light was one of the essential factors for chloroplast development. For basil plants, there were no differences in net photosynthesis. It is known that blue light (B) affects the content of chlorophyll [Mao et al. 2007]. Moreover, Matsuda et al. [2008] observed that supplementation of blue light with red light significantly increased Pn and promoted the growth, blue light also increased stomatal conductance. However, basil plants under FL lamps (7.5% B) were characterized by higher value of stomatal conductance and relative chlorophyll content than plants under LEDs (16.3% B). According to Kim et al. [2004a], green light reversal of blue-light-stimulated stomatal openings occurs in a number of species; this phenomenon is particularly apparent with a higher fraction of green and a lower fraction of red light. Also according to Folta and Maruhnich [2007], green light antagonizes some blue responses such as stomatal opening. Recently, many researchers have concluded that apart from the participation of individual colours in the light spectrum, their mutual proportions and interactions are also important [Folta and Maruhnich 2007, Ying et al. 2011].

The lack of differences between plants grown under FL lamps and LEDs in the PSII quantum yield indicates that there were irregularities in the light-depended photosynthetic reactions in plants grown under both light sources. The value of PSII below 0.8 shows that plants were under a certain degree of stress. Greater Fv/Fm values result in a greater light utilization efficiency and stronger ability of plants to adapt to low-light conditions. Under normal physiological conditions, the Fv/Fm values of a vast majority of C3 plants are within the 0.80–0.84 range [Wu et al. 2012].

CONCLUSIONS

The response of growth parameters to white light quality in basil and lemon plants differed significantly. The obtained results show that the source of light and its spectral distribution should be adjusted individually for every crop species. The light of fluorescent lamps, with its elevated proportions of red light in relation to blue light, exerted a considerably more advantageous impact on the growth of strongly growing basil plants. Our experiments demonstrated that greater share of blue than red light in the spectrum was not advantageous for the growth of basil plants. In the case of slow growing lemon balm plants, light quality did not affect plant growth but it exerted a significant influence on net photosynthesis. Recapitulating, it can be concluded that analysing the effect of different sources of light on plant growth, it is necessary to take into account the influence of individual colours as well as their mutual cooperation (positive or negative) and its impact on plants. Future investigations should go in this direction.

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DYNAMIKA WZROSTU ROŚLIN BAZYLII POSPOLITEJ I MELISY LEKARSKIEJ UPRAWIANEJ POD LAMPAMI FLUORESCENCYJNYMI I DIODAMI

Streszczenie. Celem doświadczenia było porównanie wpływu dwóch źródeł światła białego: lamp fluorescencyjnych i modułów diodowych na wzrost i rozwój roślin bazylii pospolitej (*Ocimum basilicum* L.) i melisy lekarskiej (*Melissa officinalis* L.). Doświadczenie przeprowadzono w kamerach wegetacyjnych, w kontrolowanych warunkach. Stwierdzono zróżnicowaną reakcję roślin na zastosowane źródła światła. Bazylia charakteryzowała się większą świeżą masą ziela oraz wysokością pędów pod lampami fluorescencyjnymi. Zastosowane źródła światła nie miały natomiast istotnego wpływu na powierzchnię liści i fotosyntezę netto tych roślin. Źródła światła nie miały wpływu na dynamikę wzrostu roślin melisy, ale rośliny charakteryzowały się większą wartością fotosyntezy netto, gdy uprawiane były pod lampami fluorescencyjnymi.. Podsumowując, można stwierdzić, że reakcja roślin na zastosowane światło jest indywidualna i zależy od gatunku.

Słowa kluczowe: *Ocimum basilicum, Melissa officinalis*, LED, FL, źródło światło

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