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THE EFFECT OF LIGHT COLOUR AND TYPE OF LAMPS ON ROOTING AND NUTRIENT STATUS IN CUTTINGS OF MICHAELMAS DAISY

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Abstract

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The experiment analyzed the effect of light of different colour variants emitted by two types of lamps on rooting and nutrient status in cuttings of Michaelmas daisy (*Symphyotrichum novi-belgii* var. *novi-belgii*) 'Barbados'. Trays with cuttings were placed in a growth chamber on racks equipped with two types of lamps: fluorescent Philips TLD and LED Tube lamps by Leuchtek. Lamps emitted light colours: white, green, blue, red, blue+red and yellow + red. For all colour variants the intensity of quantum irradiation was 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$. It was found that rooting in cuttings was dependent on lamp type and light colour. Colour of light significantly modified plant nutrient status in case of nitrogen, sodium, iron and manganese, while the type of light source influenced the contents of calcium, sodium and iron in aboveground parts of plants. Conducted investigations documented a significant variation in plant nutrient status under the influence of their exposure to qualitatively different sources of light. Determination of occurring phenomena and their mechanisms, in view of the rapid development in lighting technologies (including LED), requires several studies conducted under strictly controlled conditions in vegetation chambers at artificial lighting of plants. Results of investigations conducted by the authors need to be considered as a contribution to a better understanding of the occurring phenomena.

Key words: fluorescent lamps, LED lamps, macroelements, microelements

Introduction

Factors influencing the process of rhizogenesis include light and temperature. Studies on the effect of light colour on the rooting process concern mainly *in vitro* cultures (Gabryszewska and Rudnicki, 1995; Bach and Świderski, 2000; Witomska and Ładyżyńska, 2001; Miler et al., 2005; Miler and Zalewska, 2006; Cybularz-Urban et al., 2007; Kozak et al., 2010; Kozak, 2011). Their results indicate a varied plant response to this factor, which to a considerable extent was found to be species-specific. In laboratory experiments fluorescent lamps are primarily used to provide lighting for plants. In recent years LED lamps (Light Emitting Diodes) have become increasingly popular and they are considered lighting of the future (Reinders, 2008). Thanks to their special design heat is released through radiators, thanks to which lamps do not heat up and may be placed directly over plants. As it results from research the application of closed plant production systems considerably reduces the area required for cultivation in relation to traditional greenhouse systems. This is facilitated by the production run on many levels on rack shelves in closed facilities with no access of natural light (Kozai and Ohyama, 2006). Such a solution makes it possible to obtain a higher number of plants per unit area and thus reduce heating costs and outlays on the construction of plant cultivation facilities, e.g. greenhouses, since already existing facilities may be converted to accommodate them.

From the point of view of physiology light stimulates iron transport to chloroplasts (Bughio et al., 1990). It may also influence the incidence of magnesium chlorosis on plants (Cakmak and Marschner, 1992). Literature sources mention the effect of phytochromes on the regulation of potassium absorption by plants (Krizek and Berry, 1981). However, Tremblay et al. (1988) indicated a lack of a modifying effect of the light source on iron and magnesium uptake by plants, and its simultaneous effect on calcium and rubidium uptake.

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The aim of the conducted investigations was to determine the effect of colour of light emitted by two types of lamps on rooting and nutrient status of cuttings in Michaelmas daisy 'Bahamas'.

Materials and Methods

Tip cuttings of Michaelmas daisy (*Symphyotrichum novi-belgii* var. *novi-belgii,* syn. *Aster novi-belgii*) 'Barbados' from the Island group, of 6.5 cm in length and having 6 - 10 leaves, were collected from maternal plants grown in soil. Prior to being placed in multi-trays of 30 x 45 cm and in pots of 4 cm diameter cuttings were treated with a rooting hormone Ukorzeniacz A. A TS1 peat substrate was used.

Next trays with cuttings were placed in a growth chamber on racks equipped with two types of lamps: fluorescent Philips TLD and LED Tube lamps by Leuchtek. Lamps emitted the following light colours: white, green, blue, red, red+blue (75:25) and white+blue (50:50). For all colours quantum irradiance was 35 $\mu mol \cdot m^{-2} \cdot s^{-1}$, the day length lasted 12 hours. Air temperature in the growth chamber was maintained at the level of 22°C, while the relative air moisture was within 65-70%. Spectrum characteristics of lamps with the use of a spectroradiometer (USB 4000) are presented by Figures 1 and 2.

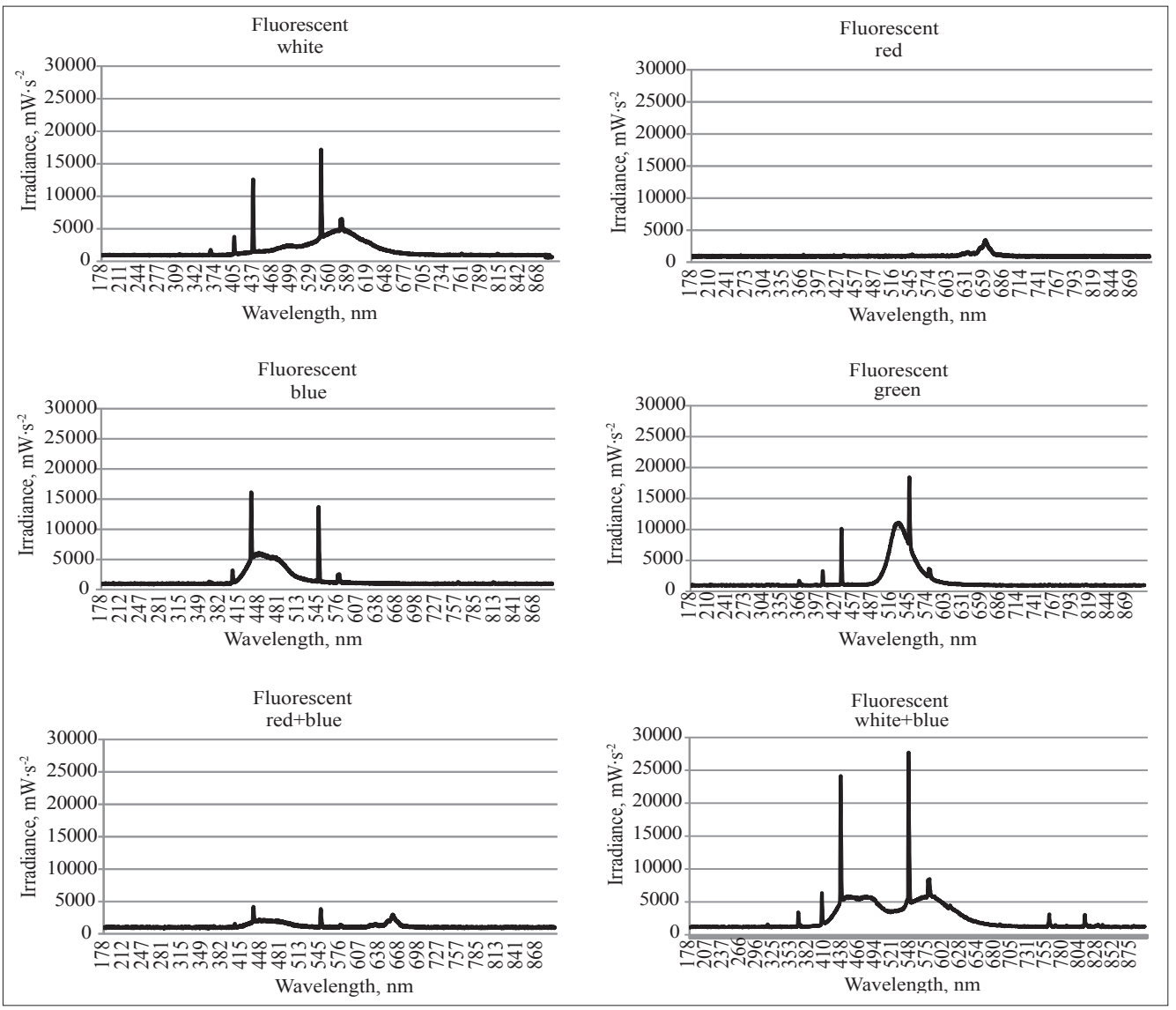

Fig. 1. Spectral characteristic of the fluorescent lamps

Cuttings were regularly sprayed in order to maintain high humidity. The experiment was completed after 4 weeks, when most cuttings formed roots. Then the percentage of rooted cuttings, length as well as fresh and dry weight of cuttings, and root length was determined. Using an N-Tester apparatus by Yara the Chlorophyll index (SPAD) was determined. This measurement is used to determine the intensity of green colour in leaves and consists in the determination of light absorption coefficient connected with the presence of chlorophyll at a wave length of 650 nm and absorption by the leaf tissue at a wave length of 940 nm (Samborski and Rozbicki 2004). One combination of experiment included 40 cuttings (4 replications with 10 cuttings in each one). The experiment was established in two culture cycles. Following biometric measurements cuttings were dried in a drier at a temperature of 45 - 50°C. Dried material was ground and subjected to chemical analyses. For the determination of total nitrogen, phosphorus, potassium, calcium and magnesium the plant material was mineralized in concentrated sulfuric acid, while for iron, manganese, zinc and copper the assays were run in a mixture of nitric and perchloric acids (v/v=3:1) (IUNG 1983). After mineralization of the plant samples, chemical analyses were performed using the following methods: N–total – by the distillation method according to

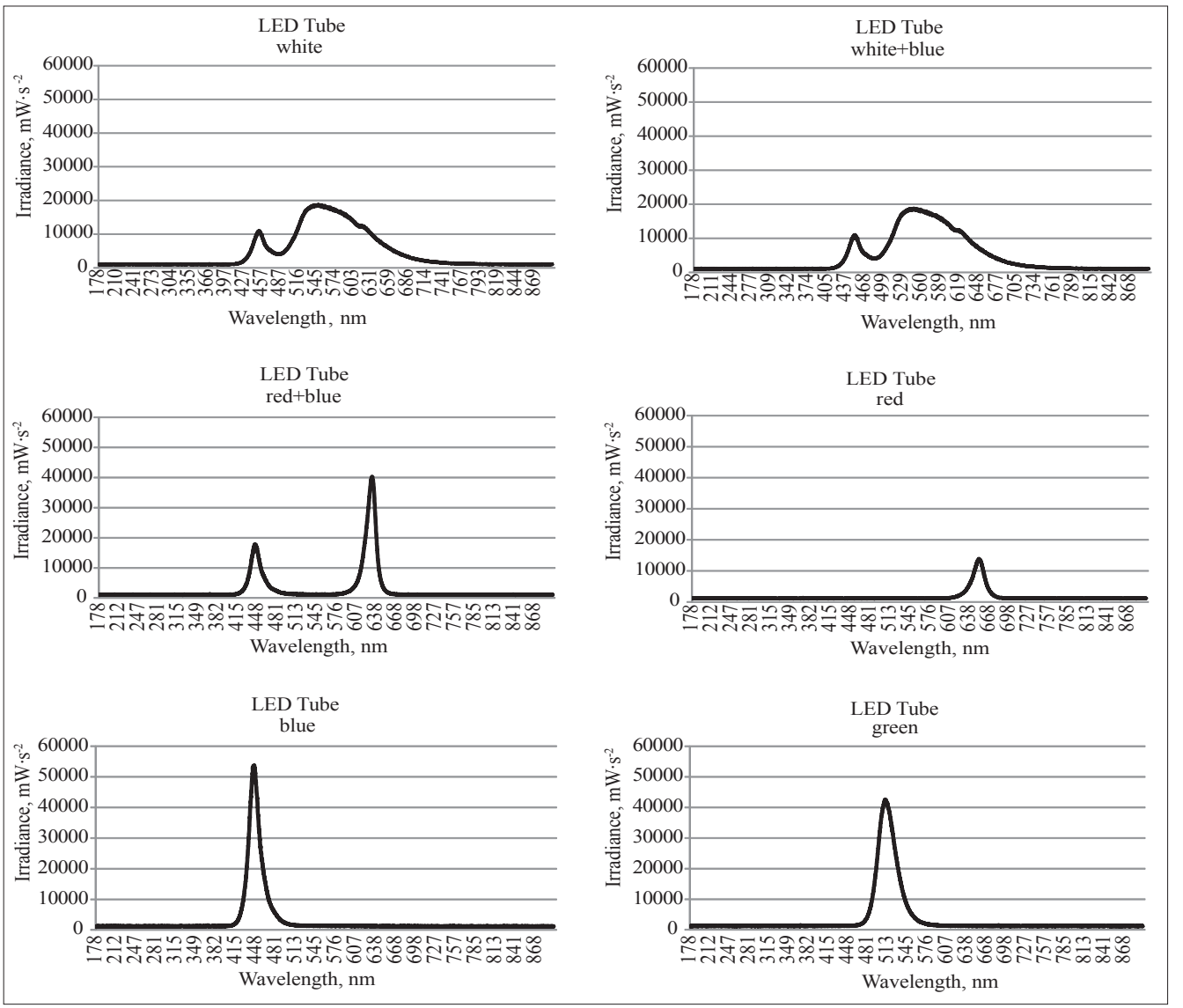

Fig. 2. Spectral characteristic of the LED lamps

Kjeldahl in the Parnas–Wagner apparatus, P – by colorimetry with ammonium molybdate (according to Schillak), K, Ca, Mg, Fe, Mn, Zn and Cu – by atomic absorption spectrometry (AAS; on a Carl Zeiss Jena apparatus). Results of biometric measurements and chemical analyses of plants for their contents of macro- and microelements were analyzed statistically using the Duncan test, with inference at the significance level $p = 0.05$.

Results and Discussion

The effect of light on plant development has been investigated in numerous studies. Thanks to advances in lighting technology it has become possible to obtain light with a preferable spectrum. In recent years more and more attempts have been made to simultaneously apply light sources emitting radiation within different spectrum ranges in lighting of plants. Such attempts were made e.g. in kalanchoe (*Kalanchoë blossfeldiana*), common primrose (*Primula acaulis*), Mexican marigold (*Tagetes erecta*) and scarlet sage (*Salvia splendens*) (Perez et al. 2006; Michalczuk and Goszczyńska, 2002; Jeongwook et al., 2002). In the conducted study it was found that rooting of Michaelmas daisy 'Barbados' was influenced both by light colour and the type of applied lamps. Irrespective of lamp type similar results were obtained under lamps emitting white+blue, white and red coloured light. Considerable discrepancies were observed under lamps emitting green, blue and red+blue light. In these cases the effect of lamp type was clearly manifested. Under LED lamps emitting blue-coloured light 77.5% cuttings rooted, while under fluorescent lamps only 47.5%. As a result of action of LED lamps emitting green light 70% cuttings developed roots, while under fluorescent lamps only 20% (Figure 3).

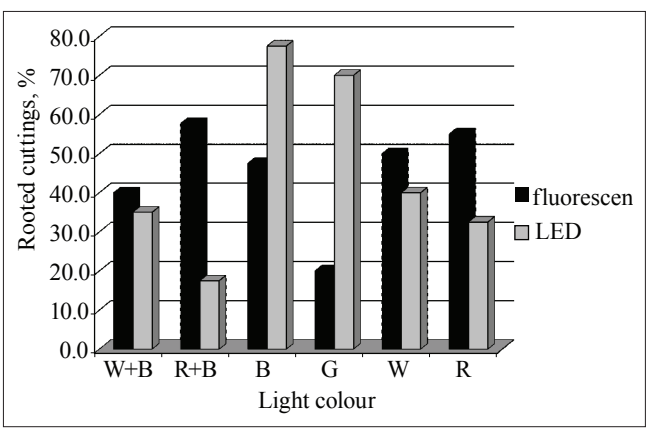

Fig. 3. Percentage of rooted cuttings

An opposite situation was observed in case of the combined action of red+blue coloured light. Fluorescent lamps proved to be more effective, as under their light 60% cuttings developed roots, while under LED lamps as little as 17.5%.

Available literature supplies inconsistent information on the effect of light colour on the rooting process, which to a considerable degree depends on the species. According to Poudel et al. (2008), under LED lamps emitting red light obtained a higher proportion of rooted grapevine cuttings. In turn, in flameray gerbera this colour limited root formation (Gabryszewska and Rudnicki, 1994). As it was reported by Witomska and Ładyżyńska (2002), red and blue coloured light in *in vitro* cultures inhibited the process of rhizogenesis in common petunia, while white light had a beneficial effect on rooting in this species. In case of *in vitro*-propagated pot mum an advantageous effect was found for white and green-coloured light (Miler et al., 2005).

Colour of light may influence shoot elongation. In this study the greatest increment in length of cuttings was observed under red light coming from fluorescent lamps. The cuttings were by almost 30% longer in comparison to cuttings placed under the same coloured light, but emitted by LED lamps (Table 1). Most probably this difference could have been caused by the fact that fluorescent lamps heat up and emitting heat increases the temperature around plants. As reported by Miler and Zalewska (2006) the pot mum microcuttings exposed to blue and red coloured light exhibit the greatest increment in length. Similarly, in princess flower and common petunia red light stimulates shoot growth (Fukuda, 2011; Kozak et al., 2010).

When analyzing data in the conducted experiment concerning the chlorophyll index both the type of lamp and light colour were found to have a significant effect on this trait. In case of the red+blue, blue and red coloured light darker leaves were observed in cuttings placed under fluorescent lamps. In turn, under white+blue light higher values of the SPAD index were recorded for cuttings rooted under LED lamps. According to Miler et al. (2005), the lowest chlorophyll content and thus also the lightest coloured leaves were found in pot mum cuttings grown under blue light, while the darkest - under white light. In grapevine Poudel et al. (2008) recorded higher SPAD index values under blue coloured light.

In this experiment root length also depended on the type of lamp and light colour. The longest roots were formed by cuttings under blue and red light emitted by fluorescent lamps. In case of LED lamps it was under blue, white+blue and white light. Results of the experiments concerning the effect of light colour in *in vitro* cultures on root length indicate high diversity. As it was reported by Witomska and Ładyżyńska (2001), common petunia forms the longest roots under the influence

of white light, while the shortest - in darkness. In contrast, in case of flameray gerbera blue light stimulates root elongation, while red light inhibits it (Gabryszewska and Rudnicki, 1995). Different results were recorded by Kozak (2011) for the *in vitro* rooting of common gardenia. The author reported that blue light significantly inhibited root elongation, while white light stimulated it.

Statistical analyses did not show significant differences either in fresh or dry matter of cuttings. According to Głowacka (2002) in case of tomato seedlings a high fresh and dry matter was obtained under blue light. In contrast, in an experiment conducted by Kozak (2011) the highest fresh weight of shoots in common gardenia was obtained under red light.

In the conducted experiments a significant effect of lamp type was shown on the contents of calcium and sodium in aboveground parts of plants (Table 2). In case of calcium the light emitted by fluorescent lamps, and for sodium – by LED

Table 1
The influence of light colour and lamp type of morfological traits of cuttings

Trait	Light colour	Lamp type	
		Fluorescent	LED
Lenght of cutting, cm	W+B*	7.2 ab**	7.3 ab
	R+ B	6.7 a	7.1 ab
	B	7.6 b	6.9 a
	G	7.0 ab	7.0 ab
	W	7.6 b	7.0 ab
	R	8.8 c	6.9 a
Lenght of root, cm	W+B	6.3 bc	9.0 d
	R+ B	7.3 bc	6.4 bc
	B	9.3 d	9.4 d
	G	2.1 a	6.6 bc
	W	4.5 abc	8.2 d
	R	8.7 d	3.6 ab
Greening index of leaves (SPAD)	W+B	39.8 de	38.3 bcde
	R+ B	40.7 e	37.6 bc
	B	37.7 e	34.4 a
	G	36.4 abc	36.6 abc
	W	35.7 ab	39.0 de
	R	40.3 de	35.3 ab
Fresh weight of cutting, g	W+B	0.81ab	0.9 bc
	R+ B	0.7 ab	0.7 ab
	B	0.8 bc	0.9 bc
	G	0.7 a	0.8 abc
	W	0.7 ab	0.8 abc
	R	0.9 c	0.7 ab
Dry weight of cutting, g	W+B	0.1 a	0.1 b
	R+ B	0.1 a	0.1 ab
	B	0.1 ab	0.1 a
	G	0.1 a	0.1 a
	W	0.1 b	0.1 ab
	R	0.1 a	0.1 a

**Means followed by the same letter are not significantly different at α =0.05
Descriptions for tables 1-3: *W+B- White+blue; R+B - Red+Blue; G- Green; R - Red; B- Blue; W- White

lamps had an advantageous effect on an increase in the contents of these nutrients. No significant effect of lamp type on plant nutrient status was shown in case of nitrogen, phosphorus, potassium or magnesium. The highest content of nitrogen was determined when applying white LED lighting (2.38% N), while it was lowest (1.54% N) in case of red+blue LED light. The lowest mean content of nitrogen was determined for red colour (1.70% N), while the highest (2.09%

Table 2
The influence of light colour and lamp type on the content of macroelements and sodium in plants (% in d.m. of aboveground parts)

Light colour (A)	Lamp type (B)					
	LED	Fluorescent	Mean for A	LED	Fluorescent	Mean for A
	N			P		
W+B*	1.86	1.89	1.88	0.53	0.60	0.57
R+B	1.54	2.21	1.88	0.55	0.67	0.61
G	1.75	1.93	1.84	0.57	0.54	0.56
R	1.58	1.82	1.70	0.56	0.56	0.56
B	2.10	1.89	2.00	0.58	0.57	0.58
W	2.38	1.79	2.09	0.55	0.55	0.55
Mean for B	1.87	1.92		0.56	0.58	
LSD for A		0.22			n.s.	
LSD for B		n.s.			n.s.	
LSD for AxB		0.30			0.06	
	K			Ca		
W+B	3.57	3.63	3.60	1.81	1.85	1.83
R+B	3.47	3.72	3.60	1.70	1.98	1.84
G	3.76	3.57	3.67	1.69	2.11	1.90
R	3.66	3.71	3.69	1.76	1.78	1.77
B	3.56	3.55	3.56	1.73	2.01	1.87
W	3.62	3.35	3.49	1.82	2.05	1.94
Mean for B	3.61	3.59		1.75	1.96	
LSD for A		n.s.			n.s.	
LSD for B		n.s.			0.20	
LSD for AxB		n.s.			0.31	
	Mg			Na		
W+B	0.45	0.36	0.41	0.06	0.04	0.05
R+B	0.36	0.48	0.42	0.06	0.05	0.05
G	0.43	0.41	0.42	0.05	0.04	0.04
R	0.38	0.41	0.40	0.04	0.06	0.05
B	0.39	0.41	0.40	0.05	0.04	0.04
W	0.41	0.33	0.37	0.04	0.04	0.04
Mean for B	0.40	0.40		0.05	0.04	
LSD for A		n.s.			0.06	
LSD for B		n.s.			0.06	
LSD for AxB		0.09			0.08	

Explantations:
n.s. – not significantly

N) for white light. The highest nitrogen content in plants at both types of lamps was accompanied by the formation of the shortest cuttings. In case of white light emitted by LED lamps the highest value of the chlorophyll index (SPAD) was recorded.

Similar dependencies to those for nitrogen were not observed for phosphorus or potassium, whose content – irrespective of lamp type or light colour – did not differ significantly. Significantly more calcium in the aboveground parts of plants was recorded in case of their exposure to light emitted by fluorescent lamps in comparison to LED lamps (an increase by 12%). Colour of light did not have a significant effect on plant nutrition with that nutrient.

No significant variation was shown in the contents of magnesium under the influence of different lighting types applied or the colour of light. Significantly highest content of magnesium (0.48% Mg) was found in case of red+blue coloured light, while it was lowest (0.33% Mg) for white light emitted by fluorescent lamps. In case of the application of fluorescent lamps and interdependence was shown between the contents of this nutrient in plants and the chlorophyll index (SPAD).

A significant effect was shown for light emitted by fluorescent lamps on mean iron content in aboveground parts of plants – such an effect was not found in case of manganese, zinc or copper (Table 3). The highest content of iron among the analysed combinations was determined in case of blue coloured light (163.0 mg $Fe \cdot kg^{-1}$), while it was lowest for green coloured light (119.0 mg $Fe \cdot kg^{-1}$) emitted by fluorescent lamps. Also statistically the highest content of manganese (74.5 mg $Mn \cdot kg^{-1}$) was recorded in case of plant exposure to blue light emitted by LED lamps, while the lowest (54.2 mg

Table. 3
The influence of light colour and lamp type on the content of microelements in plants (mg·kg^{-1} in d.m. of aboveground parts)

Light colour (A)	Lamp type (B)					
	LED	Fluorescent	Mean for A	LED	Fluorescent	Mean for A
	Fe			Mn		
W+B*	125.2	135.0	130.1	57.5	70.5	64.0
R+B	131.7	149.2	140.5	65.5	63.2	64.4
G	141.0	119.0	130.0	67.0	58.2	62.6
R	124.2	132.7	128.5	63.0	65.0	64.0
B	130.7	163.0	146.9	74.5	68.0	71.2
W	130.0	140.2	135.1	54.2	64.7	59.5
Mean for B	130.5	139.9		63.6	64.9	
LSD for A		15.2			7.2	
LSD for B		8.1			n.s.	
LSD for AxB		13.1			8.7	
	Zn			Cu		
W+B	46.5	60.7	53.6	8.00	10.00	9.00
R+B	53.7	55.7	54.7	10.25	9.75	10.00
G	57.5	52.5	55.0	9.25	11.50	10.38
R	53.0	59.5	56.2	8.25	10.25	9.25
B	56.0	61.5	58.7	9.75	9.50	9.63
W	51.7	53.7	52.7	10.50	9.00	9.75
Mean for B	53.1	57.3		9.33	10.00	
LSD for A		n.s.			n.s.	
LSD for B		n.s.			n.s.	
LSD for AxB		9.4			1.75	

Explantations:
n.s. – not significantly

$Mn \cdot kg^{-1}$) – to white light emitted by that type of lamps. A reduction was found for the values of the chlorophyll index (SPAD) with an increase in the contents of this nutrient in plants. In case of zinc the highest content (61.5 mg $Zn \cdot kg^{-1}$) was determined in plants growing under the blue fluorescent light, while it was the lowest (46.5 mg $Zn \cdot kg^{-1}$) at white+blue light (46.5 mg $Zn \cdot kg^{-1}$) emitted by LED lamps. Significantly, the lowest content of copper, similarly as in case of zinc, was determined in plants growing at the white-blue LED light (8.00 mg $Cu \cdot kg^{-1}$), while the highest (11.50 mg $Cu \cdot kg^{-1}$) - at green light coming from fluorescent lamps.

Conducted investigations documented a significant variation in plant nutrient status under the influence of their exposure to qualitatively different sources of light. Determination of occurring phenomena and their mechanisms, in view of the rapid development in lighting technologies (including LED), requires several studies conducted under strictly controlled conditions in vegetation chambers at artificial lighting of plants. Results of investigations conducted by the authors need to be considered as a contribution to a better understanding of the occurring phenomena.

There are no data in available literature on the contents of nutrients in aboveground parts of *Symphyotrichum novi-belgii* var. *novi-belgii* L. In case of China aster (*Callistephus chinensis* (L.), growing in a hydroponic culture with the application of a nutrient solution of the following composition (in $mg \cdot dm^{-3}$): $N\text{-}NO_3$ 169.1, K 214.1, Ca 124.0, Mg 18.5, S 35.2, B 0.24, Fe 1.23, Mn 0.55, Cu 0.03, Mo 0.09, Zn 0.20, EC 1.8 $mS \cdot cm^{-1}$, mean contents of nutrients in leaves were markedly lower than those recorded in this study and fell within the following ranges (in % s.m.): N 0.46 - 0.47; P 0.0067 - 0.0168; K 0.52 - 0.57; Ca 0.11 - 0.13; Mg 0.02 - 0.04 (Nowak 2009, modified). In other studies conducted on the same species (Chaitra, 2006) contents of nitrogen in plants, both leaves and stems, were markedly higher than those recorded in this study and they amounted to 3.03 - 3.76 and 2.72 - 3.28% N in d.m.. Mean contents of phosphorus were similar, amounting to 0.39 - 0.54 and 0.37 - 0.54% P (in leaves and stems, respectively). Recorded potassium contents in plants were over 2-fold lower than those found in this study. In case of *Aster trifolium* grown under saline stress the mean contents of nitrogen (1.25% N), phosphorus (0.39% P), potassium (3.24% K) and magnesium (0.35% Mg) were slightly lower than the results found in this study, while the contents of calcium were almost 2-fold lower (0.96% Ca) (Karlsons et al., 2008). Also mean contents of microelements in leaves were lower than those reported for *Symphyotrichum novi-belgii* var. *novi-belgii* formerly *Aster novi-belgii* L.

Conducted analyses documented the ranges of nutrient contents, both macro- and microelements, in the aboveground parts of Michaelmas daisy, as well as determined the modifying effect of light colour on their contents.

Conclusions

Rooting in cuttings of Michaelmas daisy 'Barbados' was dependent on the type of lamps and light colour. The greatest number of rooted cuttings was recorded under LED lamps emitting blue and green light, while it was the lowest under LED lamps emitting red+blue light and fluorescent lamps emitting green light. The colour of light and the type of lamps did not influence the elongation growth of cuttings except for the red colour. A significant effect of lamp type and light colour was found on an increase in the chlorophyll index (SPAD). No significant effect of light colour or lamp type was found on fresh and dry weight of cuttings. Blue and red coloured light emitted by fluorescent lamps had a significant effect on the length of adventitious roots. In case of LED lamps a significant effect on root length was found for blue, white+blue and white colours of light. Light colour significantly modified nutrition of plants with nitrogen, sodium, iron and manganese, whereas the type of light source influenced the contents of calcium, sodium and iron in aboveground parts of plants. At an identical spectrum range of light, also the type of lamps emitting it may have a significant effect on nutrient status of plants.

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