Journal of Elementology ISSN 1644-2296

Schroeter-Zakrzewska A., Kleiber T., Zakrzewski P. 2017. *The response of chrysanthemum (Chrysanthemum x grandiflorum Ramat./Kitam) cv. Covington to a different range of fluorescent and LED light*. J. Elem., 22(3): 1015-1026. DOI: 10.5601/jelem.2017.22.1.1252

ORIGINAL PAPER

THE RESPONSE OF CHRYSANTHEMUM (*CHRYSANTHEMUM* X *GRANDIFLORUM* RAMAT./KITAM) CV. COVINGTON TO A DIFFERENT RANGE OF FLUORESCENT AND LED LIGHT

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Abstract

A closed system for plant production with artificial light is an innovative method of plant cultivation. By placing plants on shelves, higher space efficiency is achieved and costs of heating are reduced as compared to greenhouse cultivation. The aim of the study was to assess the influence of light colour and type of lamps on the quality and nutrient status of chrysanthemums (*Chrysanthemum* x *grandiflorum* Ramat./Kitam.) cultivated in a growth chamber with no access to natural light. Two-factorial experiments were conducted: (factor A: lamp type: LED and fluorescent, factor B: light colour: Red (denoted as R), Blue+White (B+W), Red+Blue (R+B); Green (G); White (W), Blue (B). For all colours the quantum irradiance was 35 µmol m^{-2} s^{-1} and the day length was 10 hours. The plant growing experiments were conducted in a controlled environment growth room. Measurements and observations were carried out at anthesis when 50% of all flower heads were completely developed. The measurements referred to plant features determining plant quality, i.e. the number of flower buds and flower head, diameter of flower head, height and diameter of plants, index of leaf greenness (SPAD). Plant quality was significantly dependent on light colour and the type of lamps used. Earlier flowering of plants was observed under LED lamps emitting white and blue light. The largest flower heads were produced by plants grown under blue and red + blue colour light. Red light emitted by both types of lamps had an adverse effect on plant flowering. Both the type of lamps and the colour of emitted light significantly modified the plant nutrient status. Interactions between the studied factors were found. The mean content of nitrogen, phosphorus, calcium, magnesium and sulphur was higher in plants grown under LED than FL lamps. A similar trend was also found for the microelement content.

Keywords: colour of light, growth, flowering, nutrient status.

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INTRODUCTION

Chrysanthemum is a quantitative short-day plant (SDP) and one of the most important species cultivated worldwide. In Poland, it is a very popular potted plant of great economic value. In Europe, chrysanthemums are grown in greenhouses or plastic tunnels. A closed system for plant production with artificial light is an innovative method of plant cultivation. This method has several potential benefits, such as a higher quality of transplants, a shorter production period and a lesser consumption of resources when compared with conventional systems (Kozai et al. 1999). There are many environmental factors affecting the growth and development of plants, among which light conditions are one of the most important variables. Most aspects of plant life are influenced by the quality and quantity of light received. Light is not only an energy source for photosynthesis, but also a stimulus that regulates numerous developmental processes, from seed germination to flowering (Christie 2007). Light also provides environmental information for the plant and consequently affects a wide range of photomorphogenic responses, including germination, de-etiolation, elongation, leaf expansion and flowering (Spalding, Folta 2005).

As it was pointed out by Watanabe (2011), LEDs were introduced to factories in the 2000s as a more efficient light source. LEDs are expected to reduce the electricity costs of lighting and cooling thanks to their greater efficiency of converting electric power to light power and the generation of lower heating loads than conventional light sources. At present, the LED technology is still relatively too expensive to replace fluorescent lamps. Fluorescent lamps have different spectral emissions, composed of many wavelengths ranging from 350 to 750 nm. LEDs have several advantages over conventional light sources because of their wavelength specificity and a narrow bandwidth.

Plant development is strongly influenced by the light quality, which refers to the colour or wavelength reaching plants' surface (Johkan et al. 2010). Red and blue lights have the greatest impact on plant growth, because they are the major energy sources for photosynthesis and CO_2 assimilation in plants (Kasajima et al. 2008). Combined red and blue lights were proven to be an effective lighting source in plant production in controlled environments (Shin et al. 2008). Green and yellow wavelengths are reflected or transmitted and thus are not as important in the photosynthetic process (Yeah, Chung 2009).

The purpose of the following study was to determine the influence of a light spectrum and type of lamps on the quality and nutrient status of chrysanthemums cultivated in a growth chamber with no access to natural light.

MATERIAL AND METHODS

The plant growing experiments were conducted in 2012-2013, in a controlled environment growth chamber located at the Experimental Station of the Departments of the Faculty of Horticulture and Landscape Architecture, the Poznań University of Life Sciences (Poland). The aim of the study was to assess the influence of varied light sources on growth, development and nutrient status of medium-flowered pot chrysanthemum (*Chrysanthemum* x *grandiflorum* Ramat./Kitam.) var. Covington.

Pots with rooted cuttings were placed in a growth chamber (on a three-layer shelf system) on 120 x 50 cm shelves lined with felt. The shelves were equipped with Philips TLD fluorescent lamps (FL) and Leuchtek LED Tube lamps emitting light of different colour, ranging from white, blue, and green to combinations of two colours: blue + white (50:50), and red + blue (75:25). Each year of the study, a 2-factorial experiment was conducted [(factor A: lamp type: LED and fluorescent, factor B: light colour: Red (denoted as R), Blue+White (B+W), Red+Blue (R+B); Green (G); White (W), Blue (B)]. The experiments were run in 12 combinations (2 lamp types x 6 light colours) on 360 plants in 6 replications in each year of the study. One pot with 5 plants was a single replication. Three days after planting, the plants were pinched off above the fifth leaf, counting from the base of the shoot.

For all light spectra, the quantum irradiance was 35 µmol m^{-2} s^{-1} and the day length was 10 hours. The a ir temperature in the growth chamber was maintained at 20°C, while the relative humidity was within 65-70%.

Plants were grown in containers (1 dm^3) filled with peat substrate of the following chemical composition (in mg·dm^{-3}): N-NO_3 8, P 57, K 35, Ca 2581, Mg 139, Fe 43.5, Mn 5.78, Zn 3.7, Cu 0.38, Cl 72, NaCl 1.33, at pH 6.3. In all the studied combinations, plants were fertigated once a week with nutrient solution containing (in mg dm^{-3}): N-NO_3 224, P 40, K 370, Ca 44, Mg 58, Fe 0.89, Mn 1.31, Zn 0.31, Cu 0.18, Na 24.7; EC 3.34 mS cm^{-1}, pH 7.34.

Measurements and observations were carried out at anthesis when 50% of all flower heads were completely developed. The measurements referred to plant features determining morphological traits, i.e. the number of flower buds and flower heads, diameter of flower heads, height and diameter of plants. The index of leaf greenness (SPAD) was also recorded using a Yara N-Tester apparatus. This measurement is used to determine the intensity of the leaf green colour and is calculated as a quotient of light absorption connected with chlorophyll presence at the wavelength of 650 nm and the absorption by leaf tissue at the wavelength of 940 nm. Healthy, fully developed leaves were collected from all the plants on the last day of every cycle, after which they were dried and ground. The plant material was digested in concentrated sulphuric acid in order to assay the total forms of N, P, K, Ca and Mg, and in in a mixture of nitric and perchloric acids (3:1, v/v) for analyses of total Fe, Mn, Zn and Cu. After mineralisation, the following determinations were performed: N-total using the distillation method according to

Kjeldahl in a Parnas Wagner apparatus; P – colorimetrically with ammonia molybdate; K, Ca, Mg, Na, Fe, Mn, Zn, Cu using flame atomic absorption spectroscopy (FAAS, on a Carl Zeiss Jena apparatus). The experiment was run in two culture cycles. Results of measurements are given as meana from two years of research. The results were analysed by ANOVA and the Duncan test ($p = 0.05$).

RESULTS AND DISCUSSION

The results showed a significant effect of the light colour and type of lamps used on the morphological traits of chrysanthemums grown under artificial light (Table 1). When analysing the plant height, irrespective of a light colour, a significant effect of the type of lamps on plant growth was observed. Plants grown under LED lamps were characterised by lesser growth in comparison to those growing on shelves equipped with FL lamps. This probably results from the fact that LED lamps do not emit heat, as opposed to FL lamps. Depending on a light colour, the lowest height was observed in plants exposed to green, white and blue light. In contrast, the tallest plants were produced under the influence of a combination of white + blue light and red + blue light. Marked differences in plant growth were observed for the red light colour. Plants growing under LED lamps were on average by 8.5 cm lower in comparison to those placed under FL lamps. The inhibitory effect of red light on the height of scarlet sage was reported by Heo et al. (2002). In turn, Fan et al. (2013) showed that the height of tomato plants exposed to red + blue light (50:50) was significantly dependent on light intensity – the lower the light intensity, the higher of plants.

Similarly to the plant height, their diameter was greatly influenced by the light colour as well as the type of lamps used. The greatest diameter was recorded in plants grown under FL lamps. When analysing a light colour, markedly greater diameters were recorded for plants grown under the combination of red + blue colour light.

Plant flowering also depended significantly on a light colour. Distinctly inhibited flowering was observed under the red-coloured light emitted by both lamp types. Under the influence of these colour of light, plants developed 74% fewer flower heads in relation to the other plants. The largest number of flower head buds occurred on plants grown under blue light, on average by 20 buds more in comparison to plants grown under the red-colour light. As it was reported by Jeong et al. (2012), supplementary lighting of chrysanthemums with blue light induces flowering to a greater extent than a short day does. Fakuda et al. 2016 demonstrated that longer exposure to blue LED light induced earlier flowering of petunia. In turn, Qingwu, Runkle (2015) reported that low-intensity blue light has no effect on plant flowering. Watanabe (2011) stated that red light and far red light in the phytochrome

Table 1
The influence of the light spectra and lamp types on the morphology chrysanthemum plants (mean from two years of research)

Lamp type	Light colour						Mean
	R	B+W	R+B	G	W	B	
Height of plants (cm)							
FL	17.8*e*	21.3*f*	24.6*g*	10.3*abcd*	11.5*d*	11.3*d*	16.1B
LED	9.3*a*	11.6*d*	11.0*bcd*	9.6*ab*	10.0*abc*	10.6*abc*	10.3*A*
Mean	13.5*B*	16.4*C*	17.8*C*	9.9*A*	10.7*A*	10.9*A*	
Diameter of plants (cm)							
FL	22.3*e*	30.5*f*	32.8*g*	18.1*ab*	20.6*cde*	19.6*bcd*	23.9*B*
LED	16.3*a*	20.5*cde*	21.3*de*	18.6*bc*	20.3*cde*	20.3*cde*	19.5*A*
Mean	19.3*A*	25.5*B*	27.0*C*	18.3*A*	20.0*AB*	19.9*A*	
Numbers of flower buds							
FL	4.5*a*	15.8*cd*	21.1*ef*	11.5*b*	16.6*d*	23.3*fg*	15.4*A*
LED	6.1*a*	18.0*de*	21.6*fg*	12.5*bc*	25.3*g*	24.6*fg*	18.0*B*
Mean	5.3*A*	16.9*C*	21.3*D*	12.0*B*	20.9*D*	23.9*E*	
Numbers of flower heads							
FL	3.0*a*	12.6*cd*	12.6*cd*	9.0*b*	10.5*bc*	11.6*bcd*	9.8*A*
LED	3.6*a*	13.3*cd*	12.7*cd*	8.3*b*	14.5*d*	13.0*cd*	10.9*A*
Mean	3.3*A*	12.9*C*	12.6*C*	8.6*B*	12.5*C*	12.3*C*	
Diameter of flower heads (cm)							
FL	4.0*ab*	4.2*b*	3.9*a*	4.6*c*	5.0*d*	4.8*c*	4.4*A*
LED	4.4*b*	4.5*c*	3.7*a*	4.3*b*	4.1*b*	5.0*d*	4.3*A*
Mean	4.2*B*	4.3*B*	3.8*A*	4.4*B*	4.5*B*	4.9*C*	
Index of greening leaves (SPAD)							
FL	36.9*a*	48.4*c*	51.0*cd*	52.1*de*	53.2*de*	52.6*de*	49.0*A*
LED	44.5*b*	55.7*e*	55.7*e*	55.1*e*	54.0*de*	54.3*de*	53.2*B*
Mean	40.7*A*	52.0*B*	53.3*B*	53.6*B*	53.6*B*	53.4*B*	

Description for Tables 1-3: FL – fluorescent light, LED - Light Emitting Diode, R – Red, B+W – Blue+White, R+B – Red+Blue, G – Green, W – White, B – Blue. Within rows and columns (separately for each factors) means marked with different capital letters differ significantly; within rows and columns, means marked with different small letters differ significantly.

system are related to flowering, which is caused by changes in the period of daytime in such plants as chrysanthemums.

As it was shown in statistical analysis, a light colour also influenced the size of flower heads. Irrespective of a lamp type, the greatest diameter was recorded in plants grown under blue light, but it was smallest for the red + blue light combination. A positive effect of blue-colour light on the size of chrysanthemum flower heads was reported by Jerzy et al. (2011).

The quality of ornamental plants is also determined by leaf colour. It was shown in the experiments that the type of lamps used had a significant role in leaf colouring, particularly in the case of red, blue + white and red + blue light. Plants grown under the light in these colours emitted by LED lamps formed darker leaves than plants grown under FL lamps. Irrespective of a lamp type, the lowest SPAD values were recorded for plants grown under red light. According to Schroeter-Zakrzewska, Kleiber (2014), asters rooted under controlled conditions with red light emitted by FL lamps also produced lighter-coloured leaves.

Plants placed on shelves equipped with lamps emitting green, white and blue light did not differ significantly in terms of this trait. In turn, Miler et al. (2005) reported that chrysanthemums grown under blue-coloured light produced light-coloured leaves, while markedly darker leaves were formed on plants placed under white-coloured light.

Both the type of lamps and light colour significantly modified the chemical composition of chrysanthemum leaves (Tables 2, 3). The mean contents of nitrogen, phosphorus, calcium, magnesium and sulphur were higher in plants under LED than under FL lamps. The lowest content of macroelements was found in plants receiving R+B (red+blue) light emitted by FL lamps. The highest nitrogen content was determined in the LED combination emitting green light, but that of calcium was the highest in the case of the same colour emitted by FL. The highest concentrations of phosphorus, potassium, magnesium and sulphure were recorded in the variant of LED lamps emitting red-colour light.

Light serves as an energy source for plant growth through photosynthesis (Watanabe 2011). It is also closely related to plant growth, especially leaf extension, flower formation and morphogenesis. The range of light known as PAR (*photosyntethically active radiation*) is between 400 nm and 700 nm. The intensity of photosynthesis depends not only on the colour of light, but also on the radiation intensity. The strongest absorption of light is observed at about 480 and 680 nm (blue-violet and red). Plant response to light emitted by different sources is species-dependent. Along with the deterioration of light quality during the plant growing period, changes were observed in the content of nitrogen, phosphorus, potassium, calcium and magnesium in leaves. This effect was most evident in the case of nitrogen and potassium and weakest in the case of magnesium (Breś, Jerzy 2004).

Schroeter-Zakrzewska, Kleiber (2014) found no differences in the macro- and microelement content (except for calcium and iron) in michaelmas daisy leaves between LED and FL type lighting. In contrast to this study, Schroeter-Zakrzewska, Kleiber (2014) reported the lowest mean content of nitrogen in leaves lighted by green light and the highest one in the case of white light. Comparing the results of analyses on leaves with the literature data, it can be concluded that a generally similar content of this nutrient (3.25-5.41% N) was found by Breś et al. (2002), whereas Breś, Jerzy (2004)

Table 2

The influence of a light colour and lamp type on the content of macroelements in chrysanthemum leaves (g kg^{-1} d.m.) mean from two years of research

Lamp type	Light colour						Mean
	R	B+W	R+B	G	W	B	
N							
FL	3.45*ab*	3.65*bc*	3.23*a*	3.31*a*	3.89*cd*	3.79*c*	3.55*A*
LED	4.11*de*	3.76*c*	4.18*e*	4.35*e*	3.86*cd*	3.85*c*	4.02*B*
Mean	3.78*A*	3.70*A*	3.70*A*	3.83*A*	3.87*A*	3.82*A*	
P							
FL	0.94*c*	0.82*b*	0.63*a*	1.11*fg*	1.13*fg*	0.97*cd*	0.93*A*
LED	1.25*h*	1.16*g*	0.96*cd*	1.02*de*	1.06*ef*	0.85*b*	1.05*B*
Mean	1.09*D*	0.99*C*	0.79 A	1.06*D*	1.09*D*	0.91*B*	
K							
FL	5.01*de*	4.65*bc*	4.20*a*	4.73*c*	4.95*d*	4.48*b*	4.67*A*
LED	5.16*e*	5.12*de*	4.66*bc*	4.57*bc*	4.66*bc*	4.50*b*	4.78*A*
Mean	5.09*D*	4.88*C*	4.43*A*	4.65*B*	4.80*C*	4.49*A*	
Ca							
FL	3.28*d*	3.07*c*	2.67*a*	4.35*f*	2.84*b*	3.09*c*	3.21*A*
LED	3.39*d*	4.32*f*	3.14*c*	3.81*e*	3.06*c*	3.31*d*	3.50*B*
Mean	3.33*C*	3.69*D*	2.90*A*	4.08*E*	2.95*A*	3.20*B*	
Mg							
FL	0.65*bc*	0.65*b*	0.45*a*	0.74*d*	0.72*cd*	0.64*b*	0.64*A*
LED	0.96*e*	0.91*e*	0.64*b*	0.75*d*	0.69*bcd*	0.73*d*	0.78*B*
Mean	0.80*E*	0.78*DE*	0.54*A*	0.74*CD*	0.70*BC*	0.68*B*	
S							
FL	0.44*c*	0.38*b*	0.28*a*	0.57*f*	0.51*de*	0.46*cd*	0.43*A*
LED	0.70*g*	0.55*ef*	0.50*de*	0.51*de*	0.52*de*	0.54*ef*	0.55*B*
Mean	0.57*E*	0.46*B*	0.39*A*	0.54*DE*	0.51*CD*	0.50*C*	

determined a wider range of the nitrogen content in chrysanthemum leaves. Borowski et al. (2014) reported significantly lower contents of nitrogen and nitrates in leaves of plants grown under FL light, which was confirmed in our studies, where the concentration of nitrogen was lower in plants grown under FL light than under LED. The nitrogen content in leaves showed similar tendencies as the chlorophyll content. Klamkowski et al. (2012) stated that LED lighting resulted in higher chlorophyll content in leaves, a relationship which in our study was also found in the case of R, B+W and R+B colours of light. Generally, the content of phosphorus in leaves was similar to the one reported by Breś, Jerzy (2004) and by Breś et al. (2002) (0.35-1.00% P).

Table 3

The influence of a light colour and lamp type on the content of microelements in chrysanthemum leaves (mg kg^{-1} d.m.) mean from two years of research

Lamp type	Light colour						Mean
	R	B+W	R+B	G	W	B	
Fe							
FL	68.70*a*	82.50*b*	66.85*a*	80.40*b*	89.90*c*	95.85*d*	80.70*A*
LED	101.25*e*	101.35*e*	90.60*c*	87.50*c*	81.75*b*	89.90*c*	92.06*B*
Mean	84.98*B*	91.93*C*	78.73*A*	83.95*B*	85.83*B*	92.88*C*	
Mn							
FL	42.40*a*	46.45*a*	50.95*b*	65.50*c*	76.40*e*	69.20*cd*	58.48*A*
LED	71.65*d*	82.90*f*	86.15*fg*	76.10*e*	90.25*gh*	93.80*h*	83.48*B*
Mean	57.03*A*	64.68*B*	68.55*C*	70.80*C*	83.33*D*	81.50*D*	
Zn							
FL	41.20*cd*	38.65*b*	35.25*a*	38.85*b*	41.10*cd*	38.90*b*	38.99*A*
LED	40.45*bcd*	47.90*f*	40.45*bcd*	39.15*bc*	44.85*e*	42.00*d*	42.47*B*
Mean	40.83*B*	43.28*C*	37.85*A*	39.00*A*	42.98*C*	40.45*B*	
Cu							
FL	8.87*a*	13.37*e*	8.81*a*	9.03*a*	11.36*c*	10.50*b*	10.32*A*
LED	9.99*b*	12.15*cd*	12.44*d*	10.30*b*	10.38*b*	10.43*b*	10.95*B*
Mean	9.43*A*	12.76*C*	10.62*B*	9.66*A*	10.87*B*	10.46*B*	

In the current studies, the light colours caused significant changes (sometimes almost 2-fold) in the content of this nutrient. Unlike in this study, Schroeter-Zakrzewska, Kleiber (2014) found no differences in the phosphorus and potassium content in leaves between LED and FL lamps. Similarly to in the case of nitrogen, Breś, Jerzy (2004) determined a wider range of the potassium content in leaves. Also Breś et al. (2002) reported a wider range of this nutrient content in chrysanthemum leaves (4.34-7.50% K). In the opinion of Schroeter-Zakrzewska, Kleiber (2014), a higher mean content of calcium in leaves characterises plants grown under FL rather than LED lamps, whereas an opposite trend was found in this study. However, Tremblay et al. (1988) showed the lack of a differentiated effect of the light source on iron and manganese uptake by plants, and its simultaneous effect on calcium uptake. The calcium content in leaves recorded in our studies was higher than found by Breś, Jerzy (2005), although it ranged within the content (1.70-3.50% Ca) given by Breś et al. (2002). A similar content of magnesium (0.50-1.20%) in chrysanthemum leaves was determined by Breś et al. (2002). Breś, Jerzy (2004) stated that the differences between the minimum content of this nutrient in leaves in the summer months and their maximum levels found in the winter months were considerable, at times even exceeding 50%. Also, a large variability in the effect of different light quality was observed in our experiments. There is an interaction between type of lamps and emitted light colour on the magnesium status of leaves (Schroeter-Zakrzewska, Kleiber 2014). Those authors found the highest content of that nutrient in the case of R+B light emitted by FL lamps, while the lowest in the case of white light emitted by the same lamps type.

A trend similar to that for macroelements appeared in the content of microelements, as the highest mean content of iron, manganese, zinc and copper was determined for the LED variant. The lowest content of iron, zinc and copper was found in leaves of plants lighted by FL emitting R+B light, while the manganese content was the lowest in leaves of plants lighted by FL emitting red colour light. The highest content of iron was recorded in leaves of plants grown under B+W light emitted by LED, while manganese was the highest in leaves exposed to the blue colour light also emitted by LED. The highest zinc and copper content occurred in leaves of plants grown under LED (B+W and R+B, respectively). Breś, Jerzy (2005) stated that the time of culture associated with real insolation had a significant influence on micronutrient content. The content of iron in chrysanthemum leaves in our experiments was generally lower than its leave content determined by the cited authors. A wider concentration of that microelement (25-80 mg kg^{-1} d.m.) was described by Kreij et al. 1990 as an optimal one. Also, in contrast to our study, Schroeter-Zakrzewska, Kleiber (2014) reported the highest content of iron in michaelmas daisy grown under blue coloured light, and the lowest one under green coloured light emitted by FL lamps. Light stimulates iron transport to chloroplasts (Bughio et al. 1990). In the described studies the increasing trend of this microelement content was found in the case of LED (except for white and blue colour light) when compared with FL lamps. Similarly as in this study, Schroeter-Zakrzewska, Kleiber (2014) determined statistically the highest content of manganese in plants exposed to blue light emitted by LED lamps. These authors also found different trends of the zinc and copper status in leaves. Generally. the determined content of copper in leaves was similar to levels reported by Breś, Jerzy (2005, 2008). Also, a similar concentration of copper (5-14 mg kg^{-1} d.m.) in chrysanthemum leaves was found by Adams et al. (1975). During the light deficit, leaves of chrysanthemum contained the highest concentrations of copper and boron, while an opposite relationship was observed for the content of iron (Breś, Jerzy 2005).

Shimizu et al. (2005) reported that blue light could be used to inhibit extension growth of chrysanthemum. In our study, such an effect was found only in plants illuminated with FL, as there were no significant changes in plants grown under LED. Many authors showed that blue light plays an important role in chlorophyll biosynthesis (Kamiya et al. 1981, Tibbits et al. 1983, Schuerger et al. 1997, Shin et al. 2008). Such an effect was not confirmed clearly in our studies.

CONCLUSIONS

1. Plant quality was significantly influenced by the light spectra and the type of lamps used. Irrespective of a light spectrum, taller plants were produced under FL lamps.

2. Plants grown under LED lamps were characterised by a more compact growth, especially in treatments with R; B+W and R+B light spectra. However more compact plants had darker leaves (SPAD Index).

3. Earlier flowering of plants was observed under LED lamps emitting white and blue light.

4. The largest inflorescence heads appeared in plants grown under blue and red + blue colour light. Red light emitted by both types of lamp had an adverse effect on plant flowering.

5. Both the light colour and lamp type significantly influenced the chemical composition of leaves:

- the highest mean contents of nitrogen, potassium, calcium, magnesium, sulphure and also metallic microelements (iron, manganese, zinc, copper) were found in leaves from plants grown with LED light comparing with FL;
- the lowest mean contents of phosphorus, potassium, calcium, magnesium and sulphure in leaves were recorded in the case of R+B light colour, while the highest appeared under the R colour for: phosphorus (as well as W colour), potassium, magnesium and sulphur.

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