Research Article

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Effect of light spectrum on growth, development, and mineral contents of okra (*Abelmoschus esculentus* L.)

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Abstract: Influence of the light spectrum on growth, development, and nutrients contents of okra was studied by growing okra (*Abelmoschus esculentus* L.) under three different LED-based irradiations defined by their peak wavelength at 455.45 ± 1.80 nm (B_{455}), 522.27 ± 1.46 nm (G_{522}), and 635.03 ± 1.33 nm (R_{635}), respectively in the blue, green, and red regions of the visible spectrum. The photosynthetic photon flux density (PPFD) of 200 µmol m^{-2} s^{-1} was provided by the LEDs for 18 h daily. Leaves macronutrients and micronutrients concentration and plant biometric parameters were measured 60 days after sowing; the evolution of biometric parameters was also monitored during the growing period. Results related to biometric parameters have shown that highest leaf area, plant height, and fresh and dry weight were achieved under B_{455} light; both R_{635} and G_{522} lights produce the highest quantity of leaves; and largest stem diameters were observed under B_{455} and G_{522} lights. Regarding mineral contents, highest calcium, phosphorus, and manganese concentrations were obtained under R_{635} light; highest sodium content was observed under G_{522} light; and the highest nitrogen content was obtained under both B_{455} and G_{522} lights. However, there were no significant differences observed for potassium, magnesium, and zinc concentrations among the three light treatments. These results revealed that selective spectrum in artificial lighting design can be strategically used to optimize the plant growth, development, and mineral contents uptake under controlled environments.

Keywords: horticulture lighting, LED, okra growth, light spectrum, mineral content

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1 Introduction

During past few years, lighting applications in horticulture have been increasingly used to improve the plant growth, development, quality, and crop production (Lu and Mitchell 2016; Bantis et al. 2018). To optimize the light environment, many research experiments have been conducted to understand plant responses for various light conditions (Ouzounis et al. 2015; Chen et al. 2016). However, plants response to light has been found species dependent, leading to more research experiments to be undertaken. Among species, lettuce has been broadly studied (Bantis et al. 2018), but some nutritionally important vegetables like okra has been appeared in a few or no publication.

Meanwhile, to achieve lighting application requirements in plant biology, various lamps technologies have

been used to produce artificial light, such as high-pressure sodium, metal halide, fluorescents, incandescent, and light emitting diodes (LED) (Nelson and Bugbee 2013; Wallace and Both 2016). But in the last decades, the use of LED lamps in horticulture applications has increased (Mitchell et al. 2015) due to the rapid development in this technology and its numerous benefits including durability, adjustable size, relatively cool, and long operating lifetime. Furthermore, all other conventional artificial light sources have important emission in the visible spectrum regions that plants do not need. Since light produced by all light sources is at the expense of electrical energy, it becomes impractical and expensive to provide wavelengths of light, which are being not used by plants (Gupta and Agarwal 2017). LED in comparison to other light source, has a narrowband unique advantage, and can be used to control the spectral composition matching the absorption peak of plant photoreceptors; and more, LED may offer the ability to study responses of plants to monochromatic spectra (Bantis et al. 2018).

Light can greatly affect the composition of mineral elements of plants (Amoozgar et al. 2017). Since plants have been grown in many environments and under many conditions, the factors that affect their mineral composition need to be taken into account and better understood. But few studies have focused on these effects of light. Besides, change in light spectral qualities led to different morphogenetic and photosynthetic responses depending on the plant species (Schuerger et al. 1997). Knowing these photoresponses could help researchers to set a proper design to optimize growth, development, and quality of plants (Samuolienė et al. 2011). However, the effects of light spectrum in plant growth and development of many species like okra are still not explored in detail.

Okra is a vegetable widely cultivated in tropical, subtropical, and warm tropical regions and is one of the world's oldest cultivated vegetable crop plants (Lamont 1999). Okra plants are nutritionally rich, and both their leaves and fruits are consumed as vegetables in diet (Lamont 1999); besides, okra have numerous therapeutical benefits: antidiabetic, antihyperlipidemic, antioxidant activity, and prevention of diseases linked to cellular damage, treating dysentery, and diarrhea (Roy et al. 2014). Okra extract also appeared to be the principal ingredient in many important commercial food and medical products and, in recent trends, could play a leading role as a nanoscale carrier to make better drug delivery systems (Roy et al. 2014). Therefore, it is of great importance to ensure a year-round production and to improve the quality of okra crop despite the adverse effect of climate change; knowing the effects of different light spectra on growth and mineral uptake will help to design artificial lighting system to grow okra in a controlled environment.

The aim of several previous studies is to improve the growth and development of several crops using LEDs or supplementary lighting with LEDs and to understand the effect of wavelength on morphological, anatomical, physiological, photosynthetic, metabolic, and developmental plants parameters (Ouzounis et al. 2015; Bantis et al. 2018). But more research experiments are still needed to bring helpful knowledge to validate the proper wavelength for important plant species (Bantis et al. 2018). Furthermore, only a few literature have studied the effects of light on mineral uptake by plants (Tremblay et al. 1987; Shin et al. 2013; Amoozgar et al. 2017); but in these studies, only lettuce was considered; thus, other vegetables, nutritionally important, need to be investigated since plant response to light is species and cultivar dependent (Olle and Viršile 2013). Therefore, it is still unknown if artificial lighting and LEDs may affect the growth, the morphology, and the nutrient element uptake in okra. The optimal wavelength to grow high-quality okra with high nutrition value is unknown. Within this context, the objective of this study is to evaluate the effects of different light spectra, on one hand, on the growth and development of okra and, on the other hand, on the macronutrients elements (N, P, K, Ca, and Mg) and micronutrients elements (Fe, Mn, Zn, and Na) of okra leaves.

2 Material and methods

2.1 Experimental design

Experiment was conducted indoor in a closed room located on the north site of the National Polytechnique Institute Felix Houphouët-Boigny of Yamoussoukro. Three boxes of dimension $2 \times 2 \times 2$ m were used to host three pots per box, and each pot was containing one single plant. Within each box, the same light treatment was used to irradiate each pot, resulting in three replications for each light treatment (Figure 1); thus, a total of three different light treatments and nine pots were used in this experiment. Furthermore, black covered plastic were used to isolate the boxes from ambient light.

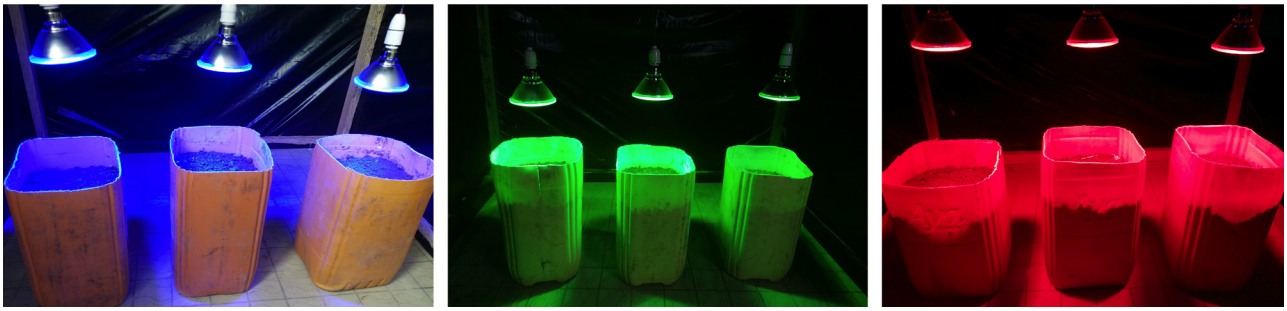

Figure 1: Pots and light treatment inside each box.

2.2 Plant material and soil properties

Okra variety GB1230 was used, which has been originated from ORSTOM-France (Office de la Recherche Scientifique et Technique d'Outre-Mer), and provided by the national center of agricultural research of Côte d'Ivoire (CNRA).

Before sowing, three composite samples of surface soil (0–15 cm) used in the pots were taken for analysis. During 15 days, the samples were dried in an open-air laboratory; clods were crushed by hand and the gravel was removed. Analyzes were carried out on soil fractions less than 2 mm after filtering with a 2 mm calibrated sieve and the lightly crushed soil samples. A pH meter was used to determine pH in a water–soil (ratio 2/5) solution. The methods of Kjeldahl (1883), Walkley and Black (1934), and Thomas (1982) were used for the determination of total nitrogen, organic carbon, and organic ammonium, respectively. The ammonium acetate method was used to extract cation exchange capacity (CEC) and the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}) (Thomas 1982). The Olsen method–modified Dabin was used to estimate the assimilable phosphorus, and total phosphorus was extracted by perchloric acid. Finally, means with standard deviation of soil properties resulting from the soil analysis are as follows: soil pH, 7.0 ± 0.06; carbon, 2.9 ± 0.15%; nitrogen, 0.3 ± 0.3%; assimilable phosphorus, 69.9 ± 2.57 ppm; CEC, 17 ± 2 cmol kg^{-1}; Ca^{2+}, 2.1 ± 0.14 cmol kg^{-1}; Mg^{2+}, 1.0 ± 0.09 cmol kg^{-1}; K^{+}, 2.5 ± 0.14 cmol kg^{-1}; Na^{+}, 0.2 ± 0.06 cmol kg^{-1}.

2.3 Light treatments

Light treatment is defined by only one factor, i.e., the light spectrum at three different levels. Each level represents a specific light spectrum and is achieved using the LED spot. This results in a total of three light treatments obtained with three different types of LED spots, each type of LED irradiated in a specific wavelength. A spectrometer Ocean Optics USB4000 was used to measure spectra of each LED spot, and the resulting peak wavelength (PW) and full width at half maximum (FWHM) were determined. These three light treatments given here by their peak wavelength (PW) and their full width at half maximum (FWHM) are as follows: B_{455} (PW = 455.45 ± 1.80, FWHM = 33.35 ± 2.36, n = 3), G_{522} (PW = 522.27 ± 1.46, FWHM = 39.10 ± 0.55, n = 3) and R_{635} (PW = 635.03 ± 1.33, FWHM = 22.11 ± 0.47, n = 3); and they have their spectrum, respectively, in the blue, green, and red region of the visible spectra.

For all light treatments, the height of the LED spot was adjusted to obtain a PPFD of 200 µmol m^{-2} s^{-1} at the top of each plant; light PPFD was measured with a quantum-meter LightScout 3415FXSE. All plants were exposed to LED irradiation during 18 h per day giving a photoperiod of 18 h set by a programmable electrical socket, thus resulting in a daily light integral (DLI) of 12.96 mol m^{-2} day^{-1} to grow these plants.

2.4 Humidity and temperature collection

Environment factors such as temperature and humidity (Figure 2) were also recorded during experiment by using a professional weather station AcuRite model 01036. This station was connected through a USB cable to a computer with AcuRite PC software running on it; the software was set up to automatically transfer indoor humidity and indoor temperature every 12 min to a CSV file saved locally on the computer throughout all experiment duration. At the end of experiment, CSV files were processed using MATLAB software. Indoor temperature had a variation between 26.11 and 31.67°C with the average indoor temperature at 27.96 ± 0.59°C. Indoor relative humidity had a fluctuation between 64 and 85% with an average of 75.41 ± 4.22%.

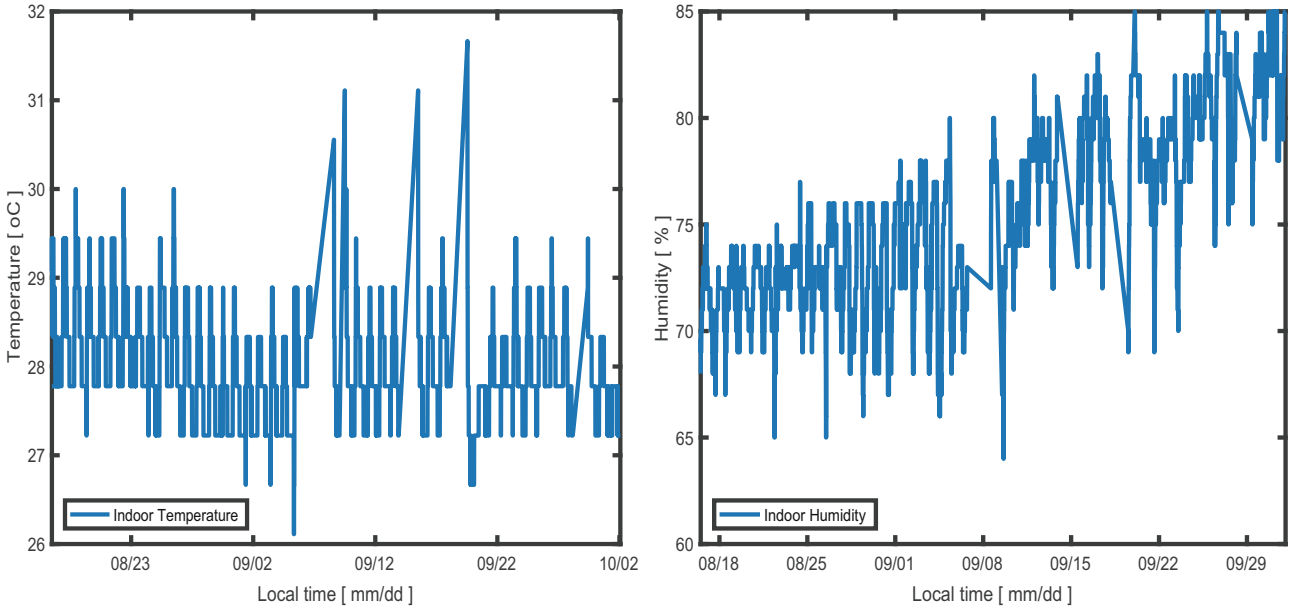

Figure 2: Indoor temperature and humidity during okra, *Abelmoschus esculentus* growth period.

2.5 Growth and biometrics parameters

Okra plants were grown for 60 days under different light treatments B_{455}, G_{522}, and R_{635}. During this period, biometric parameters were recorded almost each 2 days. Number of leaves of each okra plant were counted manually and recorded. A graduated rule was used to measure the length and width of each leaf per plant, and the resulting leaf area (LA) was calculated according to Hoyt and Brandfield (1962): LA = Leaf Length × Leaf Width × 0.75. The height of the aerial part of each plant, from the soil to the top end, was measured using a tape measure and then recorded as the plant height. The stem diameter was also collected with a caliper. After these 60 days, all plants were destructively removed for fresh and dry weight measurements using a balance E_{50} S/3 from Gibertini with a 0.01 to 0.1 mg resolution. Dry weights were measured after drying plants samples in an oven for 72 h.

2.6 Mineral elements analysis

Okra leaves were collected and destructively sampled to obtain their macronutrient and micronutrient concentrations. A total of 0.4 g sample taken from dried and ground leaves samples were mineralized and dissolved in nitric and chlorhydric acid (AOAC 1990). Nitrogen content was determined using the Kjeldahl reference method (Kjeldahl 1883), and the phosphorus concentration was measured by UV/Vis Spectrometer Jasco V-530 Inc. Concentrations of iron, manganese, zinc, sodium, calcium, and magnesium were determined by flame atomic absorption spectrometry air-acetylene using spectrophotometer VARIAN type AA20, Australia (Pinta 1973).

2.7 Data analysis

All measurements were analyzed for statistical significance by one-way analysis of variance (ANOVA) to determine significant differences between the means of the treatments. Since the main aim is to determine which treatment gives significantly higher or lower values compared to others, we used the *post hoc* Tukey's HSD test to perform multiple comparisons among light treatments means.

3 Results

3.1 Biometric parameters

Results related to biometrics parameters are presented in Table 1. A picture of okra plants grown under different

Table 1: Mean (±SE) of biometric parameters measured on okra plant irradiated under different light spectrum treatment. For each parameter, different letters indicate significant differences among treatments at $p < 0.05$ by Tukey's test

Light spectrum		Biometric parameters					
		LA (cm^2)	Plant height (mm)	Leaf number	Stem diameter (mm)	FW (g)	DW (g)
B_{455}		166.2809 ± 21.1906^{b}	966.6667 ± 23.3333^{b}	11.0000 ± 0.0000^{a}	9.1667 ± 0.1667^{b}	98.4438 ± 3.7797^{b}	9.3712 ± 0.0715^{b}
G_{522}		100.4970 ± 10.0673^{a}	600.0000 ± 30.0000^{a}	13.3333 ± 0.3333^{b}	9.3333 ± 0.3333^{b}	38.4346 ± 0.4498^{a}	3.3780 ± 0.0242^{a}
R_{635}		93.0109 ± 9.4441^{a}	506.6667 ± 14.5297^{a}	13.3333 ± 0.3333^{b}	8.0000 ± 0.0000^{a}	35.3267 ± 5.0494^{a}	3.7967 ± 0.4201^{a}
ANOVA	df	(2;110)	(2;6)	(2;6)	(2;6)	(2;6)	(2;6)
	F	8.132	107.1	24.5	11.4	94.97	184.3
	P	0.0005	0.00002	0.0013	0.0090	0.00002	0.000004

light treatments (B_{455}, G_{522} and R_{635}) is shown in Figure 3. LA was significantly different among light treatments. Highest LA is obtained with B_{455} in comparison with G_{522} and R_{635}, but there are no significant differences between G_{522} and R_{635}.

In comparing the plant height, significant differences among light treatments were found. The plant height is higher under B_{455} compared to G_{522} and to R_{635}. Multiple comparison tests showed no significant differences between plants under G_{522} and R_{635}.

Leaf numbers showed significant differences among treatments. Plant grown under B_{455} showed less leaf number than plant grown under G_{522} light and plant under R_{635} light. Highest leaf number is achieved by both G_{522} and R_{635}, which are not significantly different.

Significant differences existed between light treatments for stem diameter. Stem diameter was the highest under B_{455} and G_{522} lights compared to R_{635} light. However, no significant differences were observed between B_{455} and G_{522} lights.

FW and DW of plants differ significantly among treatments. FW and DW of plants were the greatest when grown under B_{455}. Tukey's multiple comparison test showed similarities for FW and DW of plants grown under G_{522} and R_{635}.

In summary, leaf area, plant height, leaf number, FW, and DW under R_{635} and G_{522} lights are not significantly different. B_{455} induces larger leaf area, longer plant height, and higher FW and DW than R_{635} and G_{522}. R_{635} and G_{522} produce similar quantities of leaves, and B_{455} produces the lowest number of leaves compared to other treatments. Furthermore, the stem diameters of samples under B_{455} and G_{522} treatment are not significantly different and are greater than stem diameters of samples treated with R_{635}.

In addition, Figure 4 shows the evolutions of leaf area, leaf number, plant height, and stem diameters over 54 days of the growing period. Around the first 30 days, the leaf area and plant height were approximately similar between all light treatments. It is only after 38 days after sowing that B_{455} started to differentiate from other light treatments in stimulating a better response in plants for leaf area and plant height. B_{455} giving the lowest leaf number and R_{635} giving the lowest stem diameters seem consistent throughout the growing period since 20 days after sowing.

3.2 Mineral content

The results related to the mineral content of our experiment are presented in Table 2. There was a significant

Figure 3: Okra (*Abelmoschus esculentus* L.) plants 54 days after sowing. From left to right, respectively, okra plants treated under blue, green, and red light.

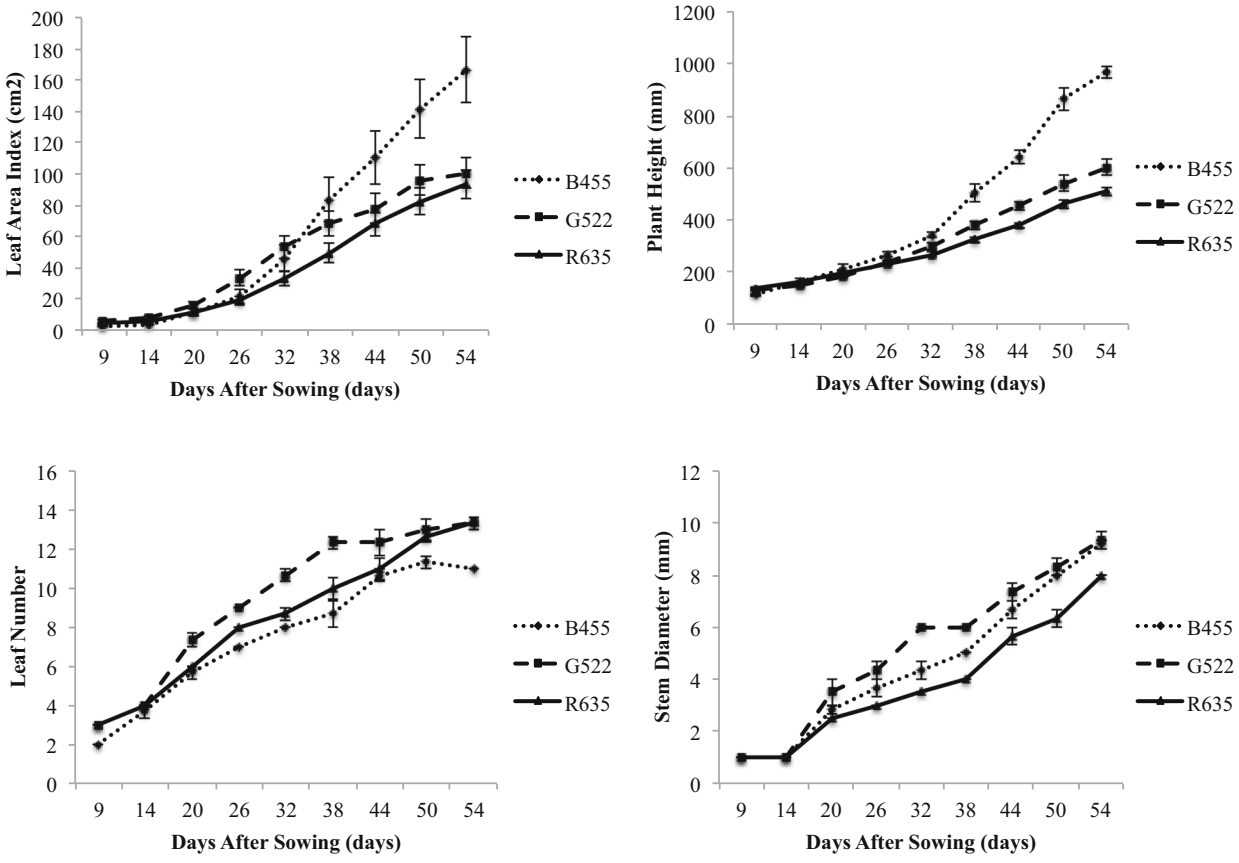

Figure 4: Evolution of leaf area, leaf number, plant height, and stem diameter during 54-day growing period of okra (*Abelmoschus esculentus* L.) plants. The bars represent standard errors.

difference in the nitrogen content of okra leaves among the three light treatments. Leaves of plants treated under B_{455} had greater nitrogen content than those under G_{522} light, and leaves of plants treated with B_{455} and R_{635} lights had similar level of nitrogen content. The phosphorus content of plants under the three light treatments was significantly different. Plants treated under R_{635} have the greatest phosphorus content followed by G_{522}, and the lowest content is under B_{455}. In the same tendency, we observed that the manganese content in leaves are significantly different among the three light treatments; leaves treated under R_{635} light had greater manganese content than those treated under B_{455} and G_{522} lights; the manganese content in leaves treated with G_{522} is

Table 2: Mean (±SE) of nutrients contents measured on okra leaves irradiated under different light spectrum treatment. For each parameter, different letters indicate significant differences among treatments at $p < 0.05$ by Tukey's test

Light spectrum		Nutrients contents								
		N (g 100 g^{-1})	P (g 100 g^{-1})	K (g 100 g^{-1})	Ca (g 100 g^{-1})	Mg (g 100 g^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Na (mg kg^{-1})	Zn (mg kg^{-1})
B_{455}		6.07 ± 0.77^{b}	0.40 ± 0.01^{a}	2.44 ± 0.22^{a}	3.45 ± 0.31^{a}	0.47 ± 0.05^{a}	4.13 ± 2.08^{b}	4.86 ± 0.07^{a}	2.13 ± 0.04^{a}	6.29 ± 0.09^{a}
G_{522}		3.97 ± 0.22^{b}	0.44 ± 0.01^{b}	3.15 ± 0.79^{a}	3.88 ± 0.24^{a}	0.49 ± 0.02^{a}	29.73 ± 13.78^{a}	5.44 ± 0.14^{a}	4.25 ± 0.94^{b}	6.17 ± 0.03^{a}
R_{635}		4.49 ± 0.09^{ab}	0.49 ± 0.01^{c}	3.28 ± 0.35^{a}	5.01 ± 0.36^{b}	0.52 ± 0.02^{a}	2.9 ± 1.42^{ab}	6.37 ± 0.22^{c}	3.20 ± 0.05^{a}	6.16 ± 0.06^{a}
ANOVA	$F(2;6)$	5.6019	27.3500	0.7679	6.8191	0.5689	3.5099	24.4584	3.8380	1.2140
	P	0.0424	0.0009	0.5047	0.0285	0.5940	0.0979	0.0013	0.0844	0.3608

higher than that in leaves treated with B_{455}. Potassium, magnesium, and zinc contents of okra leaves treated under B_{455}, R_{635}, and G_{522} lights were not significantly different. Calcium contents in leaves were different among the three light treatments. Plants grown under R_{635} light have higher calcium content compared to B_{455} and G_{522}, but there is no difference in the calcium content of leaves treated under B_{455} and G_{522} lights. Furthermore, results show differences in the sodium content of okra leaves between the three light treatments: leaves under G_{522} light show greater sodium contents than leaves under B_{455} but are not significantly different of leaves under R_{635} light; in addition, sodium contents of leaves under R_{635} and B_{455} were similar.

4 Discussion

Okra preferably grows in fertile soil rich in organic matter. However, okra can be cultivated on a wide range of soil types, although rich, fertile soils are optimal (Lamont 1999; Fondio et al. 2007; Roy et al. 2014). The soil we used for our crop has a high CEC (17 cmol kg^{-1}); the proportion of organic matter in the soil is 4.92% (is equal to %C × 1.72) with a high nitrogen content (0.3%); and the C/N ratio is approximately equal to 9.66. These properties mean that this soil is fertile and rich in the organic matter that can be mineralized easily (Boyer 1982). In addition, a correct pH guarantees an optimal absorption of nutrients. According to Lamont (1999), the optimum pH range for okra is 6.0–7.0. However, okra tolerates a wide range of soils with a pH ranging from 5.5 to 8.0 (Roy et al. 2014); the soil that we used, with a pH of 7.0, is in phase with these recommendations.

Light influences metabolite production in plant and can be used as an effective instrument for targeting metabolic modification in plants, including reduction or increase of nutrient accumulation (Liu et al. 2004). A change in the light environment to a specific wavelength induces a physiological change in the plant irradiated (Ouzounis et al. 2015). Thus, the light spectrum has an effect on plant physiology and metabolism. It was confirmed from our study that the highest manganese, phosphorus, and calcium contents in leaves were obtained under red light (R_{635}). Highest nitrogen content in leaves was obtained under blue light (B_{455}), which is not significantly different from that obtained under red light. The highest sodium content was observed under green light (G_{522}) in comparison to blue light and red light. However, potassium, magnesium, and zinc contents were similar in all light treatments.

Both mineral deficiencies and toxicity or overabundance can reduce the plant growth (Levetin and McMahon 2008). This may be overcome by results from this study, revealing that selective light spectrum could play a role in the adjusted mineral contents.

Nitrogen (N) plays an essential role in the growth and development of plants. Many authors have established a link between nitrogen supply and photosynthesis. Nitrogen supply and allocation in plant leaves have a significant effect on the photosynthesis process by controlling the biosynthesis of photosystem I (PSI), photosystem II (PSII) and light-harvesting complexes (LHCs), cytochrome *b6f* complex, adenosine triphosphate synthase (ATP), and photosynthetic enzymes. Most plants will experience a decrease in the photosynthetic rate in case of a serious N deficiency (Mu and Chen 2020). Thus, a high photosynthetic rate may increase the nitrogen uptake in plants. Chlorophyll a (chl a), one of the main photosynthetic pigments, has its peak absorption in the blue and the red regions, with the blue being the most important; chl a absorption is very weak in the green region. This could lead to a high photosynthetic activity for plants under blue light and may explain why blue light induces the highest nitrogen uptake. The fact that plants irradiated with blue have the largest leaf area, highest plant height, and the most important FW and DW confirms the high photosynthetic activity under blue light.

Furthermore, experiments of the previous research have reported that the light spectrum has an effect on the oxidative metabolism of leaves; blue light inhibits senescence by keeping up a high level of catalase activity while, in contrary, there is a development of senescence symptoms under red light (Causin et al. 2006). However, it is well known that cell senescence induces a high accumulation of calcium; this may explain the lowest accumulation of calcium under blue light and the highest under red light. Due to the antagonism between calcium and iron during their ion interactions, the high accumulation of calcium under red light will reduce iron absorption, and this could explain why plants grown under red light have a low concentration of iron.

Our results have shown consistency with the previous studies on cucumber grown under different treatments of red and blue lights and also showed no differences in nitrogen concentration between blue light and red light irradiation; the same study also report that an increase in blue light tends to increase the nitrogen content in leaves (Hogewoning et al. 2010). No difference for nitrogen content in leaves of lettuce grown under red light compared to blue light was also observed in another study, and manganese and phosphorus concentrations were significantly higher under red light (Amoozgar et al. 2017). In the same direction, further studies on lettuce demonstrate that higher concentration of nitrogen was obtained under blue light or combined blue + red LEDs in comparison to other light environments (Shin et al. 2013), and red light highly affects the manganese concentration in lettuce leaves (Tremblay et al. 1987).

Zinc concentration of lettuce leaves grown under red light in comparison to blue light was reported also similar in previous studies (Amoozgar et al. 2017).

Furthermore, the light spectrum has a higher effect on the plant growth, plant morphology, and developmental traits (Ouzounis et al. 2015; Gupta and Agarwal 2017; Bantis et al. 2018). Indeed, the present study shows that okra plants grown under blue light have greater LA, height, and FW and DW than plants grown under red and green lights, which are similar. In fact, plant photoreceptors, cryptochromes, and phototropins absorb highly in the blue region of the visible light spectrum; cryptochromes are responsible for morphological responses such as stem elongation and leaf expansion; phototropins take part in the process of the controlling pigment content, in the optimization of harvesting light, and in the prevention of photoinhibition (Gupta and Agarwal 2017). Besides, the high content of nitrogen found in plants grown under blue light may also justify this positive morphological response; nitrogen is of vital importance for effective plant growth and development as it plays a significant role in the physiological and biochemical functions of plants (Leghari et al. 2016). Nitrogen supply will cause cell multiplication and, therefore, vegetative growth due to the formation of an auxin (indole acetic acid); it will also cause the multiplication of chloroplasts responsible for photosynthesis and the synthesis of carbohydrates that are subsequently transformed into amino acids and proteins. In the same direction, results highlighting the importance of blue light were previously reported. A study on cucumber, tomato, and chili transplants shows that the blue light causes an increase in the leaf area of these plants (Samuolienė et al. 2011). Another study on the effects of monochromatic light on cabbage shows that the blue light causes higher stem length than the red light on *kunshin* cultivar and show similarity for green and red light; leaf area of *red cookie* cultivar irradiated with blue light is greater than green, and furthermore, green and red lights have similar LA (Mizuno et al. 2009). Higher stem length leads to higher plant height as observed in our results for blue light. In red leaf lettuce, the leaf area, fresh weight, and dry matter weight of plants were higher under blue light than those grown under red light (Johkan et al. 2010). In addition, the

study on lettuce shows that the supplemented blue light induces larger leaves than the supplemented red or green light (Chen et al. 2016). Blue light tends to produce higher plant biomass in cucumber leaves (Hogewoning et al. 2010).

In this study, we also demonstrate that the stem diameter of plants under blue and green lights are greater those under red light, and blue light and green light show similar stem diameter. In the same direction, the study on rapeseed plantlets showed that the blue light, in comparison with red light, has greater stem diameter and more important stomata opening (Li et al. 2013).

We also reported in this study that the leaf number of plants grown under red and green lights was similar, but they are both greater than blue light. This result is supported by the research done on lettuce, which report higher leaf number for plants supplemented with red light compared to blue light (Chen et al. 2016).

5 Conclusion

Our investigations revealed that B_{455} light has a better effect than both R_{635} and G_{522} at promoting plant height, leaf area, and fresh and dry weight of okra. High number of leaves can be achieved using R_{635} or G_{522} and high stem diameter can be obtained with B_{455} or G_{522}. On the other hand, R_{635} was suitable than B_{455} or G_{522} in promoting higher concentration of phosphorus, manganese, and calcium. B_{455} was the most efficient for nitrogen accumulation, and G_{522} was the most efficient for higher sodium content.

These results are a step toward understanding the wide effect of monochromatic spectra on plant growth and their mineral nutrition. Moreover, results may be exploited for tailoring suitable light source with LEDs to optimize the plant growth and more specifically okra. Moreover, this study outcome may help overcome an eventual mineral deficiency or toxicity in plants. However, more studies are needed to validate the effects of monochromatic light spectrum on other vegetables. Besides, new horticultural lighting system having specific functionalities of plant mineral adjustment and growth and development adjustment should be developed and proposed to growers.

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