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RESEARCH ARTICLE

Physiological quality of cucurbits in spectral qualities

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ABSTRACT

The objective of this work was to evaluate the influence of spectral qualities on the germination and vigor of cucurbit seeds. This experiment was a completely randomized design, in a factorial scheme 3 x 6, with three species of cucurbitaceae: cucumber, melon and watermelon. The experiment was carried out at the Federal University of Santa Maria, Campus Frederico Westphalen/RS in 2017. Six spectral qualities were used: blue LED, white LED, red LED, blue + red LED, fluorescent and dark (no light). Variables related to germination and vigor were analyzed. The cucurbitaceae presented differentiated responses when submitted to the different spectral qualities. For cucumber seeds, the luminous spectra increased root length, compared to the dark treatment. The melon seeds had low physiological quality; for these, the dark promoted a higher percentage of germinated and normal seeds. For watermelon seeds, the white LED conditions led to a higher percentage of normal seedlings, high rate of germination (IVG) and lower percentage of dead seeds. Red LED conditioned high IVG in watermelon. In general, fluorescent light favors carotenoid content and the dark condition favors shoot length in cucurbit seeds.

Keywords: Cucumis sativus; Cucumis melo; Citrullus lanatus; germination, force

INTRODUCTION

The cucurbitaceae family includes species of great economic, social and nutritional importance, with more than 118 genera and 825 species (Leal, 2013); among them are the cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*) and melon (*Cucumis melo*), which together with pumpkins represent a significant percentage of the production of olive groves in the world (Chang, 2017). They are also an important source of food and fiber for humans, via their fruits and edible seeds (Leal, 2013).

The implantation of cucurbit crops is performed through seeds and, because of the great specialization and high technological level involved in their production, these have a high commercial value. In this sense, studies involving methods to increase the development potential of the seedlings should be intensified, since the success of cultivation is directly related to the emergence and initial performance of the seedlings.

According to Parreira et al. (2011), seed germination is linked to internal factors, which are intrinsic to the seed, and external factors, like temperature, light, water and oxygen. A low percentage of germination may be due to problems such as dormancy, a low physiological quality of the seeds and environmental factors, such as light and temperature (Menezes et al., 2004). Thus, light constitutes an important factor for germination, depending on the light quality, intensity and time of exposure (Menezes et al., 2004).

Plants use receptor molecules, called photoreceptors, to detect light, which are hormone receptors that respond to light and initiate reactions. Photoreceptors absorb a photon of a certain wavelength, and use that photon as a signal to initiate a response (Taiz et al., 2017). Phytochrome is a photoreceptor that is important in vegetative development regulated by light, absorbing light mainly in the red and distant red (600–750 nm), blue light (350–500 nm) and UV-A (320–400 nm) wavelengths (Taiz et al., 2017). By absorbing light within a given wavelength, phytochrome allows for morphogenesis (Menezes et al., 2004).

Cryptochrome is a photoreceptor for blue light that intervenes in several responses, such as the omission of hypocotyl elongation, repression of petiole elongation,

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development of cotyledon expansion, and regulation of the circadian clock, among others (Taiz et al., 2017). Phototropine is another photoreceptor that acts on phototrophic responses and regulates some light responses that work together to improve photosynthetic efficiency and enable plant growth, especially in low light conditions (Taiz et al., 2017).

Aromatic plants germinated in red + blue LEDs in a proportion of 3: 1 increased their percentage of germination and early development when compared to fluorescent lamps (Sanoubar et al. 2018). In this aspect, we ask ourselves if the seeds of cucurbitaceas present this same behavior.

Studies on the responses of species to different light conditions are fundamental to assist in several stages of the implantation process in agricultural areas. This knowledge can improve production and seedling propagation techniques, contributing to management strategies, and increasing the chances of cucurbit plantation success. Thus, the present work aimed to evaluate the influence of different spectral qualities of light on the germination and vigor of cucurbit seeds.

MATERIALS AND METHODS

The experiment was a completely randomized design, in a 3 x 6 factorial scheme, totaling 18 treatments, with four replications of 100 seeds. The three evaluated cucurbit species were cucumber (*Cucumis sativus*), melon (*Cucumis melo*) and watermelon (*Citrullus lanatus*). The six spectral qualities were the TEC-LAMP® blue LEDs (450 nm); white LEDs; red LEDs (660 nm); blue (450 nm) + red (660 nm) LEDs in a ratio of 40 and 60%, respectively; fluorescence of the special daylight type (Osram®, Brazil) and dark (without light).

The seeds were placed in polypropylene trays, covered with clear plastic, and the dark treatment was provided with aluminum foil. The experimental conditions of the test follow the Rules for Seed Analysis (Brazil, 2009). The trays were kept in a growth room, at a temperature of 25 ± 2 °C and a light intensity of 36 μmol m^{-2} s^{-1} for eight days for cucumber and melon cultivation and 14 days for watermelon. For the germination test, 400 seeds per treatment were used, divided into four replicates of 100 seeds.

Calculations included the germination speed index (IVG), and the percentage of normal, abnormal and dead seedlings. The first count (PC) was performed in conjunction with the germination test, counting the normal seedlings, and performed on the fourth day after the installation of the test for cucumber and melon, and on the fifth day for watermelon (Brazil, 2009).

The germination speed index (IVG) was obtained by summing the number of seeds that germinated daily, divided by the number of days of sowing to germination, according to Maguire (1962).

The aerial part length (CPA) and root length (CR) were obtained by measuring the length of 10 seedlings of each replicate, using seedlings from the germination test, with a digital caliper. Fresh shoot (MFPA) and root (MFR) mass were obtained by weighing 10 seedlings of each replicate, using the seedlings measured for CPA and CPR. These seedlings were packed in paper bags and transported to the greenhouse, where they were maintained at a temperature of 60 °C until reaching a constant weight, and weighed with a precision scale.

The photosynthetic pigments (chlorophyll a, b and carotenoids) were evaluated by the removal of disks from seedlings with a 3.0 mm diameter cast iron cylinder and placed in a DMSO + $CaCO_3$ solution for 48 hours in the dark. Subsequently, their wavelengths were read at 480, 645 and 665 nm in a spectrophotometer. Five replicates were performed per treatment, with three disks each.

The data were submitted to an analysis of variance using the statistical program Genes (Cruz, 2013); when significant, they were compared using a Tukey's test at a 5% probability of error.

RESULTS AND DISCUSSION

The analysis of variance showed a significant interaction between cultures and spectral qualities for the index of germination speed, first count, percentage of normal seedlings, root length and percentage of dead seeds. The percentage of abnormal seedlings, shoot length, fresh shoot mass, chlorophyll a, chlorophyll b and carotenoids were significant in isolation for the spectral qualities and cultures.

For the melon and watermelon cultures, white LED promoted the highest rate of germination. The lowest germination speed was observed with the blue + red LED for the melon culture, and with the blue LED for watermelon (Table 1).

The germination speed of cucumber seeds was not influenced by the tested spectral qualities, showing indifference towards the presence of light. These results agree with those of other authors, such as Ferraz-Grande and Takaki (2006) for *Caesalpinia peltophoroides* and Passos et al. (2008) for *Cedrela odorata*. In the same way, Parreira et al. (2011), in studying Melon-de-São-Caetano (*Momordica charantia* L.), verified that the rate of germination was unaffected by the presence of light.

According to Taiz et al. (2017), seeds can be classified by their phytochrome form, being photoblastic positive when phytochrome phyB is present, which controls the germination process based on the amount of light required, light or insensitive photoblastic. Thus, it is possible to verify that cucurbitaceae present differentiated responses to luminosity conditions during the germination process, because germination occurred both in the dark and in the presence of light in different spectral qualities.

The different spectral qualities of light did not influence the percentage of normal seedlings in the first count for cucumber, which can be explained by the genetic superiority of the hybrid seeds of this crop. In studies with *Salvia splendens*, Menezes et al. (2004) also did not observe differences according to the qualities of light in the first count. The first count is a test that characterizes the vigor of the seeds in their environment; as such, it is inferred that melon seeds in dark conditions presented a higher percentage of germination in the first count, thus, providing greater vigor. For the watermelon culture, the red LED, followed by the white LED promoted greater germination (Table 1). In an experiment with *Stevia rebaudiana*, Abdullateef and Osman (2011) also observed a positive effect of red LED on seed germination.

The spectral qualities did not change the percentage of normal cucumber seedlings. The dark condition led to a higher percentage of normal seedlings in melons. For the watermelon culture, white LED led to the highest percentages of normal seedlings; the lowest percentages were found with the blue, fluorescent and blue + red LEDs (Table 2). The lowest percentage of normal seedlings for these treatments may have occurred because these spectra may act as stressing factors for development, also called photo-destructive factors (Taiz et al., 2017).

In terms of the percentage of dead seeds, there was no significant difference between spectral qualities for the cucumber and melon crops. For the watermelon culture, blue LED, red + blue and dark LED promoted a higher percentage of dead seeds. White LED led to the lowest percentages of dead seeds, with 13.25% for watermelon (Table 2). *Ocimum basilicium* seeds also show a germination preference for white light, leading to more than 95% germination (Mendes et al., 2016). The same authors verified that attributes such as germination speed and dry mass also increased when the seeds were submitted to white light. Considering that the other treatments led to a high percentage of dead seeds, it is believed that the white LED stimulated the germinative process in the watermelon seeds, standing out.

For the cucumber crop, the highest root lengths were noted in the treatments with fluorescent light and the red LED, differing statistically from the dark condition (Table 3). Images of the cucumber experiment can be seen in the Fig. 1. Red light has been reported to stimulate the development of *Jatropha curcas* L. roots in *in vitro* culture (Daud et al., 2013). As for the cultivation of *Pogostemon cablin*, Coelho (2016) found that red light positively contributed to the root development processes, in addition to contributing to greater photosynthetic efficiency.

Table 1: Index of germination speed and first count of cucumber, melon and watermelon seeds submitted to different spectral qualities of light

Spectral quality	Index of germination speed (IVG)		
	Cucumber	Melon	Watermelon
Blue+Red LED	49.25^{aA}	33.00^{bB}	16.75^{cdC}
Blue LED	48.62^{aA}	$33.50a^{bB}$	10.75^{dC}
Fluorescent	48.75^{aA}	$39.75a^{bB}$	13.37^{cdC}
White LED	48.50^{aA}	41.75^{aA}	43.37^{aA}
Red LED	49.00^{aA}	35.62^{abB}	27.62^{bC}
Dark	40.00^{aA}	41.00^{abB}	19.87^{bcC}
CV (%)		11.08	
		First count (PC - %)	
Blue+Red LED	96.00^{aA}	16.75^{bB}	9.50^{cB}
Blue LED	94.25^{aA}	26.00^{bB}	6.25^{cC}
Fluorescent	95.25^{aA}	25.25^{bB}	5.75^{cC}
White LED	93.00^{aA}	15.00^{bC}	32.25^{abB}
Red LED	95.25^{aA}	25.75^{bB}	35.00^{aB}
Dark	88.50^{aA}	63.50^{aB}	13.50^{bcC}
CV (%)		21.00	

*Means followed by the same lowercase letter within columns and the same uppercase letter within rows are not statistically different according to a Tukey's test (5% error probability)

Table 2: Percentage of normal seedlings and dead seeds of cucumber, melon and watermelon submitted to different spectral qualities of light

Spectral quality	Percentage of normal seedlings (%)		
	Cucumber	Melon	Watermelon
Blue+Red LED	92.25^{aA}	25.25^{bB}	9.50^{cdC}
Blue LED	85.75^{aA}	26.25^{bB}	5.00^{dC}
Fluorescent	89.00^{aA}	31.25^{bB}	7.00^{dC}
White LED	86.25^{aA}	34.75^{bC}	64.25^{aB}
Red LED	87.00^{aA}	25.50^{bB}	33.25^{bB}
Dark	88.25^{aA}	51.50^{aB}	22.75^{bcC}
CV (%)		40.26	
		Percentage of dead seeds (%)	
Blue + Red LED	2.25^{aC}	34.00^{aB}	66.50^{abA}
Blue LED	2.75^{aC}	33.00^{aB}	78.50^{aA}
Fluorescent	2.50^{aB}	20.50^{aB}	54.75^{bA}
White LED	3.50^{aA}	16.50^{aA}	13.25^{cA}
Red LED	3.75^{aB}	28.75^{aA}	44.75^{bA}
Dark	4.00^{aB}	18.50^{aB}	60.35^{abA}
CV (%)		40.26	

*Means followed by the same lowercase letter within columns and the same uppercase letter within rows are not statistically different ^{ac}cording to a Tukey's test (5% error probability)

Table 3: Cucumber, melon and watermelon root lengths after being submitted to different spectral qualities of light

Spectral quality	Root length (cm)		
	Cucumber	Melon	Watermelon
Blue+Red LED	4.91^{abA}	1.08^{aB}	1.37^{aB}
Blue LED	5.69^{abA}	1.50^{aB}	1.08^{aB}
Fluorescent	7.04^{aA}	1.09^{aB}	3.25^{aB}
White LED	5.76^{abA}	1.16^{aB}	1.41^{aB}
Red LED	6.83^{aA}	1.13^{aB}	1.77^{aB}
Dark	3.66^{bA}	1.65^{aB}	2.68^{aAB}
CV (%)		37.05	

*Means followed by the same lowercase letters within the columns and the same uppercase letters within the rows do not differ statistically from each other according to a Tukey's test at 5% error probability

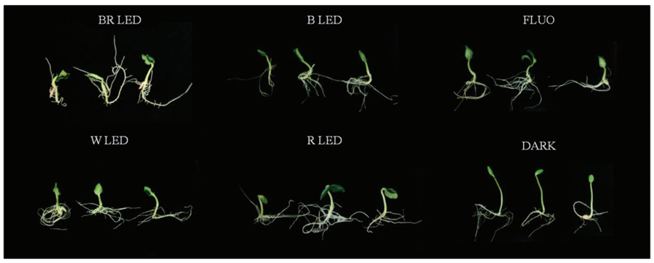

Fig 1. Visual aspect of cucumber plants submitted to different spectral qualities after eight days of incubation.

For the melon and watermelon cultures, the spectral qualities did not lead to significant differences in root length. The cucumber culture showed superiority in root length, compared to the other cucurbitaceae; for the dark treatment only, it was similar to the watermelon culture (Table 3).

The growth, development, production, and vigor of seedlings, and photosynthetic efficiency responses to spectral qualities have already been reported for other species (Ferrari et al., 2016). Although several authors have demonstrated the effects of spectral qualities on plant growth and development, the obtained responses vary for each crop (Dignart, 2006).

In their work with *Anthurium andraeanum*, Gu et al. (2012) noted the highest root length under the red + blue LED and white LED. Ferrari et al. (2016) noted the largest root length with blue LED followed by white LED. Su et al. (2014) also reported that spectral red LED had a stimulating effect on root length.

The root length results noted for the cucumber can be explained by the physiological quality of the seeds used, compared to those of the other cucurbitaceae, because this is a hybrid. In this sense, Godoy et al. (2008) also showed the genetic superiority of hybrid seeds. In general, plants with a good initial development, such as a well-formed root system, have a faster acclimatization and better survival rates in the field (Gruszecki et al., 2010).

In terms of the percentage of abnormal seedlings, the highest values were obtained for the melon crop, followed by the watermelon and cucumber crops (Fig. 2A). However, for shoot length and fresh shoot mass, there were no statistical differences between the cucurbits (Fig. 2C and 2E).

In terms of abnormal seedlings, shoot length and fresh shoot mass, the melon crop had the lowest values. This result indicates the low physiological quality of the seeds of this crop in relation to those of cucumber and watermelon. In general, authors such as Pêgo et al. (2011) and Kissmann et al. (2010) consider that seeds with a lower physiological quality present a reduced fresh seedling mass increment. The percentage of abnormal seedlings and fresh shoot mass were not influenced by the spectral qualities, however, their means are presented in Fig. 2B and 2F.

The dark treatment provided the highest shoot length values for cucurbitaceae, differing statistically from the other spectral qualities (Fig. 2D). According to Taiz et al. (2017), the stems of plants grown in the dark elongate faster in search of light, exhibiting stapling and a decreased chlorophyll content. This may have also contributed to the fact that there was a greater increase of fresh mass (although not statistically different from the other spectra), because the seedlings conditioned in the dark showed a high elongation of the stem.

Treatments with fluorescent light and dark (no light) led to a higher fresh shoot mass for the tested crops, although they were not statistically different from each other (Fig. 2C). Positive results in terms of the increase in fresh shoot mass have already been reported for *Curcuma longa* in fluorescent light, followed by red light (~ 625–440 nm) and yellow light (~ 565–590nm; Ferrari et al., 2016). In contrast, Gu et al. (2012), working with *Anthurium andraeanum*, noted the largest fresh mass with red + blue light, followed by white light.

Each spectral quality is capable of stimulating a different or equal photoreceptor, being able to trigger the morphogenic process; however, the general objective of the complementary light supply (LED) and the commercialization product of the culture of interest should be considered (Bures et al., 2018).

In an experiment with baby leaf lettuce, with 100 μmol m^{-2} s^{-2}, submitted to fluorescent and red + blue LED lamps, a 58% increase in biomass was observed with LED lamps, demonstrating balanced plant growth. However, as plants also exhibit pigments that absorb distinct red and blue wavelengths, light sources containing only these two

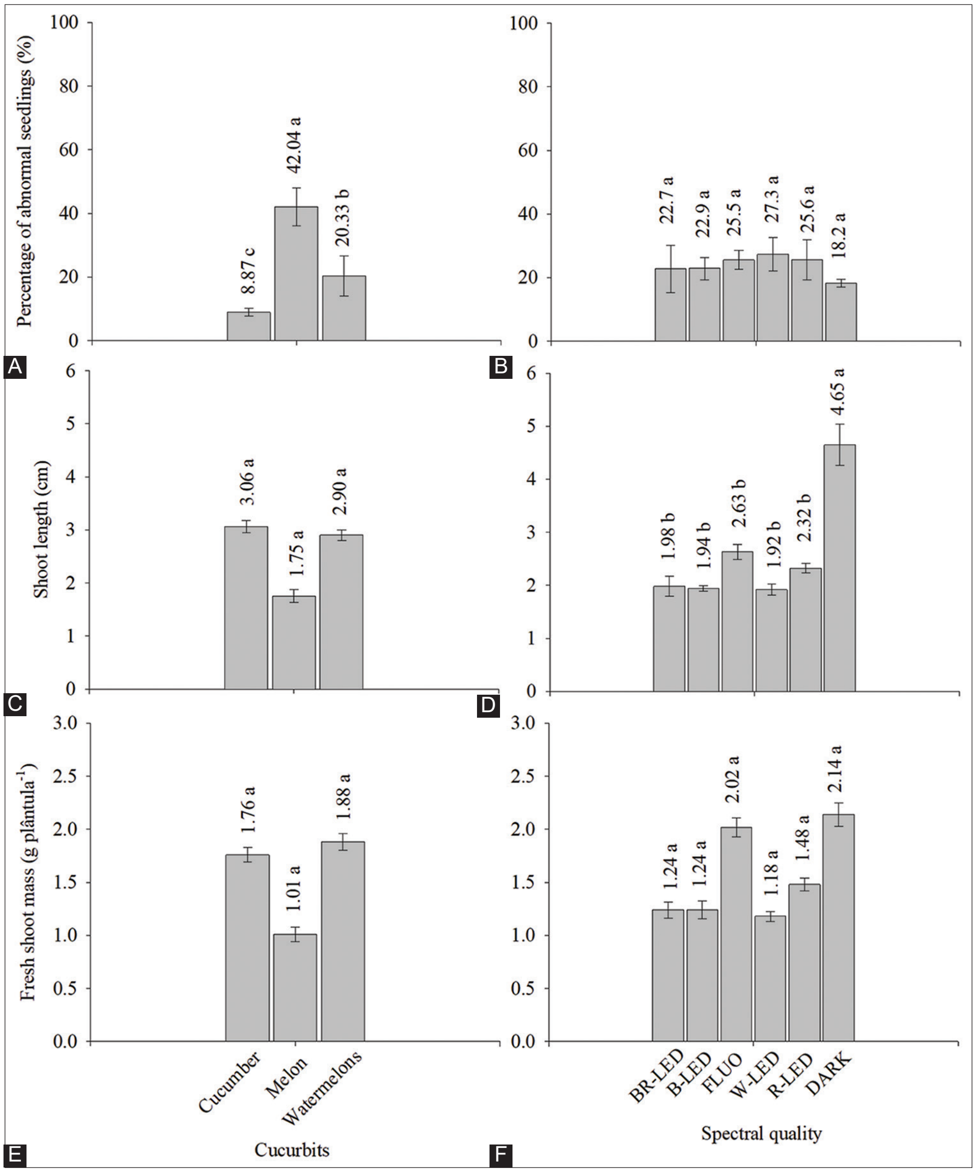

Fig 2. Percentage of abnormal seedlings (AB), shoot length (CD), and fresh shoot mass (EF) for cucumber, melon and watermelon, submitted to different luminous spectra (BR-LED Blue + Red LED; BLED Blue LED; FLUO fluorescent; W-LED White LED; R-LED Red LED and DARK). *Means followed by different lowercase letters are statistically different according to a Tukey's test (5% error probability). *Error bars represent the mean standard deviation of treatments.

spectra may promote deficient plant growth (Bures et al., 2018). Therefore, white LEDs with a set of wavelengths can produce satisfactory results, since they stimulate all the photoreceptors, and are able to replace fluorescent lamps, because these lamps provide lower heat emission.

The cucumber culture had the highest average chlorophyll a content, differing only from the melon culture, which presented the lowest results (Fig. 3B). Although the cucumber crop presented a higher chlorophyll b content, there was no statistical difference between cultures (Fig. 3D). In terms of carotenoid content, the cucumber crop was superior, compared to the other cultures (Fig. 3F).

The photosynthetic efficiency of plants is related to their ability to adapt and develop in the various conditions imposed by the environment, influencing, among other factors, the chlorophyll content of the leaves. Several external and internal factors influence the biosynthesis of chlorophylls, and for this reason, there may be significant variations in leaf content (Almeida et al., 2004). Bisognin et al. (2004) emphasized the importance of cotyledon leaves in the production of chlorophyll, demonstrating the advantage of seedlings with high physiological potential. In this study, the spectral qualities did not influence the chlorophyll a and b contents; however, the fluorescent spectrum conditioned the highest averages (Fig. 3B and D).

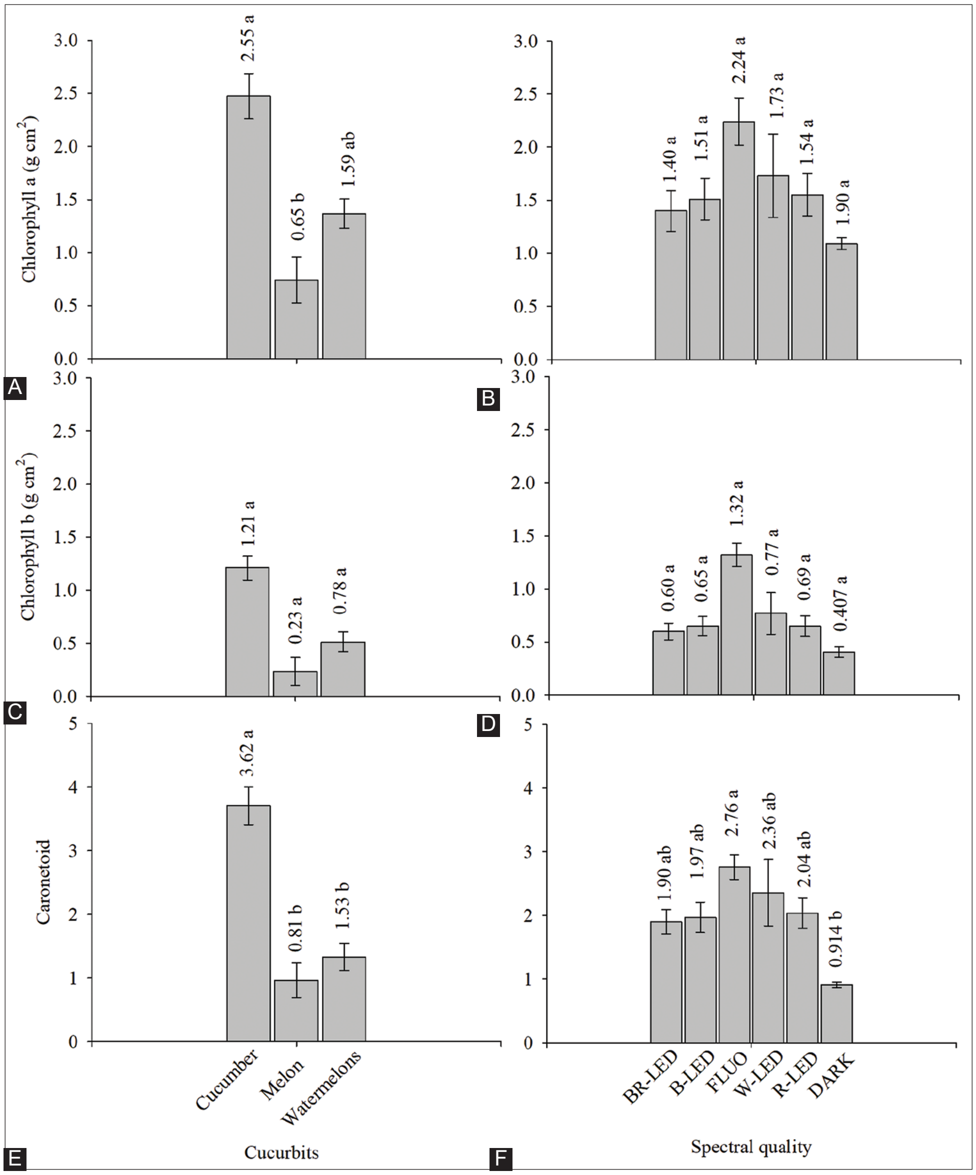

Fig 3. Chlorophyll a (AB), chlorophyll b (CD) and carotenoid (EF) contents in cucumbers, melons and watermelons submitted to luminous spectra (BR-LED Blue + Red LED; BLED Blue LED; FLUO fluorescent; W-LED White LED; R-LED Red LED and DARK). *Means followed by different lowercase letters are statistically different according to a Tukey's test (5% error probability). *Error bars represent the mean standard deviation of treatments.

The fluorescence spectrum also led to higher carotenoid contents, differing statistically from the dark treatment (Fig. 3F). The low levels of chlorophyll and carotenoids observed in the dark treatment are justified by the lack of light, a prime factor for the chemical stimulation of photosynthetic pigments (Taiz et al., 2017).

The obtained results corroborate with those of Victório et al. (2007), who, in studying *Phyllanthus tenellus*, verified the highest levels of chlorophyll a, chlorophyll b and carotenoids under yellow fluorescent light. However, our results disagree with those of Coelho (2016), who, when working with *Pogostemon cablin,* obtained the highest chlorophyll a and b levels under white and blue + red (3:1) LEDs, and the highest carotenoid levels under white and red LEDs. This is in contrast to Smilat et al. (2016), who verified a higher carotenoid content in *Stevia rebaudiana* seedlings after being submitted to blue and red + white LEDs (1:1).

In general, the results obtained for cucurbits disagree with the work of Sanoubar et al. (2018); they found that red + blue LEDs in a proportion of 3:1 promoted greater stimulation of germination and greater initial performance of nine species of aromatic plants, compared to fluorescent lamps, highlighting that LEDs have an alternative use in the germination of positive photoblastic seeds. These studies suggest that plant species differ in their responses to LED treatments and exhibit a high degree of morphological and physiological plasticity (Manivannan et al., 2015; Su et al., 2014).

Another factor to consider is the intensity of the light supply, since high intensities can overestimate the photoreceptors and damage the cells through the production of reactive oxygen species, whereas low light intensity may not be enough to trigger the morphogenic processes of interest, given its energy efficiency (Bures et al., 2018).

Each LED has a different wavelength, and when combinations of spectra are used, spectra with suitable proportions should be applied to the final target. Studies show that, at each stage of plant development, there is a specific spectrum with a certain intensity of light that can modify the growth, freshness and quality of many agricultural crops and can therefore considerably affect their market value (Bures et al., 2018).

CONCLUSIONS

Cucurbitaceae present different responses when submitted to different spectral qualities of light. For cucumber, the luminous spectra does not influence the germination and vigor of the seeds. For melon seeds, the dark promotes a higher percentage of germinated seeds in the first count, and normal seedlings. As for the speed of emergency, only blue + red LED decreases this rate. For watermelon seeds, white LED spectral quality conditions lead to a higher percentage of normal seedlings, high IVG and lower percentage of dead seeds. Red LED conditions lead to high germination at the first count. The dark increases the length of the aerial part of the three cucurbitaceae and only reduces the length of the cucumber root. The chlorophyll content of the seedlings is not altered as a function of the luminous spectra, but carotenoids are reduced in the dark.

Disclosure statement

No potential conflict of interest was reported by the authors.

Contributions of authors

Denise Schmidt and Leticia Fritsch Wust conceived and designed the experiments, analyzed the data and prepared the manuscript; Matheus Milani Pretto, Gabrieli Cristina Vitalli de Azevedo, João Antonio de Cristo and Axel Bruno Mariotto performed the experiments; Daniele Cristina Fontana and Jullie dos Santos analized and prepared the manuscript.

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