Article
ECORFAN Journal-Ecuador
December 2021 Vol.8 No.15 14-18

LED lighting stimulates root development and height in corn seedlings

La iluminación LED estimula el desarrollo radicular y altura en plántulas de maíz

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DOI: 10.35429/EJE.2021.15.8.14.18 Received July 15, 2021; Accepted December 30, 2021

Abstract

The use of LED technology advances rapidly in different fields of agricultural sciences, among others to generate stimulating effects to the physiological development of exposed plants. The objective of the present study was to characterize the physiological response to photoperiod with LED light in corn plants. Four genotypes and four photoperiod treatments were evaluated with LED lighting (white, blue, green, red). The experimental design was randomly complete blocks with three repeats, the treatments were the combination of genotypes and light spectra. The response variables were: height, stem diameter, radicle length, radicle volume and leaf area. The data were analyzed by ANOVA, running a multiple comparison test of means by Tukey. The results showed similarity in the behavior of LED light in some variables, while in the genotypes there was a different interaction before each treatment. For physiological stimulation it was obtained that, blue LED improves root quality (absorbent capillaries and water storage content) in the B1G, RG and B2G genotypes, while the red LED in the WG, B1G and B2G genotypes and in the green LED the B1G, RG and B2G materials, stimulated the vegetative growth of stem in the seedling respectively.

***Zea mays*, Light emitting diode, Root, Seedlings**

Resumen

El uso de tecnología LED avanza rápidamente en diferentes campos de ciencias agrícolas, entre otros para generar efectos estimulatorios al desarrollo fisiológico de plantas expuestas. El objetivo del presente estudio fue caracterizar la respuesta fisiológica al fotoperiodo con luz LED en plantas de maíz. Se evaluaron cuatro genotipos y cuatro tratamientos de fotoperiodo con iluminación LED (blanco, azul, verde, rojo). El diseño experimental fue bloques completos al azar con tres repeticiones, los tratamientos fueron la combinación de genotipos y espectros lumínicos. Las variables respuesta fueron: altura, diámetro del tallo, longitud de radícula, volumen de radícula y área foliar. Los datos se analizaron por ANOVA, corriendo una prueba de comparación múltiple de medias por Tukey. Los resultados mostraron similitud en el comportamiento de luz LED en algunas variables, en cambio en los genotipos se dio una interacción diferente ante cada tratamiento. Para estimulacion fisiologica se obtuvo que, LED azul mejora la calidad radicular (capilares absorbentes y contenido de almacenamiento de agua) en los genotipos GN, GR y GA, mientras que el LED rojo en los genotipos GB,GN y GA y en el LED verde los materiales GN, GR y GA, estimularón el crecimiento vegetativo de tallo en la plántula respectivamente.

***Zea mays*, Diodo emisor de luz, Raíz, Plántulas**

Citation: PÉREZ-JIMÉNEZ Genaro, MARTINEZ-RUIZ, Antonio, QUINTANAR-OLGUIN, Juan and LÓPEZ MORALES, Fernando. LED lighting stimulates root development and height in corn seedlings. ECORFAN Journal-Ecuador. 2021. 8-15:14-18.

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Introduction

In addition to being an indispensable source of energy for photosynthesis in plants, light is also an important factor for their growth and development (Ding *et al*., 2010). Since plants are capable of responding to the intensity and color of light (Johkan *et al*., 2012). Furthermore, the production of plant material can be artificially controlled by the growing environment; regulating the important variables of the environment such as: the intensity of light, temperature and humidity (Ramos and Ramírez, 2016).

Chlorophyll is found in chloroplasts and has the function of absorbing sunlight (mainly they capture red light and blue light) and use its energy to transform water and carbon dioxide into oxygen and organic molecules (sugars and carbohydrates), this process is called photosynthesis (Bures *et al*., 2018). Plants take advantage of light at different wavelengths (Bures *et al*., 2018) and regulating light intensity or wavelength has different effects on plant growth and development (Blanco *et al*., 2015).

Indoor cultivation is appropriate for any type of plant, due to the manipulation of variables such as photoperiod time, temperature, humidity, in addition to regulating LED lighting (Light Emitting Diode - Light Emitting Diode), currently known as lights. of growth, with importance within the emission of artificial light sources, which work in three different ways: 1) providing the light that the plant needs to grow, 2) increasing the photoperiod in order to trigger growth and 3) stimulating flowering (Ramos and Ramírez, 2016).

Corn (*Zea mays* L.) is the staple food consumed by 900 million people, which is why it is considered one of the most important crops in the world (Shiferaw *et al*., 2011); Such cultivation represents a whole productive and consumption tradition, where various food and socioeconomic functions are fulfilled that have transcended to the present day (SAGARPA-SNICS, 2018). In Mexico, approximately 7.5 million hectares were planted in 2020, surpassing sorghum (*Sorgo bicolor* L.), beans (*Phaseolus vulgaris* L.), and sugar cane (*Saccharum officinarum* L.) (GCMA, 2020).

It is also the raw material for the agricultural industry in Mexico and other countries, such as the United States of America, China, Argentina and Brazil (OECD-FAO, 2014).

The objective of this research was to study the physiological response of four maize genotypes with different grain color: white, black, red and blue, and exposed to different wavelengths of the color LEDs of the white, green, blue and red spectrum. The hypothesis proposed for this research is that LED light will stimulate the viability and physiological variables in seedlings of Creole maize.

Materials and method

Four maize genotypes of white grain color (W), black (B1), blue (B2) and red (R) were evaluated, seminal material provided by the Conservation Program of Creole Maize for the State of Puebla of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) in the Experimental Field of San Martinito, Puebla; collections of the year 2018 in the towns of the municipality of Ixtacamaxtitlán, Puebla, and sown in the spring-autumn cycle 2019 in San Salvador El Verde, Puebla.

The experiment was carried out in the general laboratory facilities of the INIFAP of the San Martinito Experimental Field, Mexico-Puebla federal highway km 56.5. The corn kernels were sown in 36 x 20 cm plastic trays, with sand as substrate. Using two trays for each color of light, where each tray was divided into eight equal parts, therefore, the experimental unit was five seeds per row. As the tray was divided into eight parts, each tray had two rows for each different seed color¬: white, black, red and blue. The distribution generated four repetitions with five seeds of different color. The initial irrigation was brought to saturation point with 500 mL of water, and later auxiliary irrigations were carried out every third day with 200 mL, during germination and development of the seedling that lasted 20 days after sowing.

ISSN-On line: 1390-9959

The germination of the seeds was carried out in four treatments of LED light (white, green, blue and red) placing the two trays (already sown with the grains of different colors: white, black, red and blue) on metal shelves; independently lined with black rubber to avoid mixing of lights, where AKSI® LED spotlights with white, green, blue and red light were installed, for each shelf. The wavelength of the lights was determined by a Steren® luxmeter (model HER-408), for white light it was 88.96, blue 83.03, green 53.26 and red 56.36 lux. The established photoperiod was 16 hours of light and eight hours of darkness, programmed by a Steren® timer. The shelf temperature was 20.3 ± 2 °C, with a relative humidity of 45% and an evapotranspiration of water in each light section corresponding to 2.50 mL in white light, 1.86 mL in green light, 2.53 mL in blue light and 2.53 mL in red light, for 24 h.

The study variables were from seedlings of 20 days of germination: height (H) (cm), stem diameter (SD) (mm), radicle length (RL) (cm), fresh root mass (FRM) (g), fresh aerial mass (FAM) (g), radicle volume (RV) (mL) and also the leaf area (LA) (cm2) was calculated with the methodology proposed by Sauceda *et al*. (2017).

The experimental design was completely randomized in blocks, the data obtained were analyzed by checking the assumptions of normality and homogeneity of variances: to then perform an analysis of variance (ANOVA) in genotype (Gen), light (Light) and genotype interaction * light (Gen * Light). For variables that showed significance, the comparison of means was performed by Tukey ($P \leq 0.05$) for the source of Gene, Light and interaction, using the statistical program SAS 9.4 (Institute Inc., 2014).

Results and Discussion

Table 1 shows the analysis of variance (ANOVA) of the physiological variables according to genotype (Gen), light (Light) and genotype * light interaction (Gen * Light). ANOVA detected the mean squares with highly significant differences ($p \leq 0.01$) in Gene for the variables seedling height (H), fresh root mass (FRM), fresh aerial mass (FAM) and leaf area (LA); and significant values ($p \leq 0.05$) in stem diameter (SD) and radicle volume (RV).

Likewise, for the Light source, highly significant values were shown in the mean squares in the variable LA and significant in SD and FRM, while all the other variables were not significant for this source. In the ANOVA for the Gen * Light interaction source, significant values were only shown in SD, FAM and LA, while in the variable radicle length (RL) it was not significant for any of the three sources, which means that this variable does not show affection to LED light at any intensity.

	MS Ŧ						
FV	H	SD	RL	RV	FRM	FAM	LA
Mean	7.93	2.58	21.42	1.20	1.39	0.81	2.42
Gen	28.62**	0.90*	9.89 ns	1.13 *	2.56 **	0.87**	3.78**
Light	1.80 ns	0.98*	142.78 ns	0.41 ns	0.99 *	0.08 ns	2.49**
Gen* Light	1.90 ns	0.39*	58.78 ns	0.09 ns	0.29 ns	0.13 *	0.51 *
Error	1.49	0.19	71.54	0.38	0.21	0.07	0.24
CV ϕ	15.42	17.16	39.47	43.97	32.94	33.01	20.23
R^2	0.69	0.59	0.35	0.38	0.66	0.63	0.75

**, *: significance to p≤ 0.01 y p≤ 0.05, respectively; CMŦ: mean squares; CV ϕ: coefficient of variation; R^2: Determination coefficient; Gen: genotype; H: Height; SD: Stem diameter; RL: radicle length; RV: radicle volume; FRM: Fresh root mass; FAM: Fresh aerial mass; LA: Leaf arear.

Table 1 Analysis of variance (ANOVA) with seven variables according to their physiological response of corn with four different colors of light

Table 2 shows the physiological response by comparison of means by Tukey ($p \leq 0.05$), where the white grain (WG) has a higher physiological response in SD, RV, FRM, FAM, LA, according to the differences of the means obtained, followed by the black grain (B1G) which showed a development in the variables H (9.69 cm) in SD (2.61 cm), RV (1.27) and LA (2.59 cm^2). The author Blanco *et al*. (2015) refer that a crop can continue its vegetative development as the lengthening of the stem or root when conditions are optimal. The red grain (RG) and blue grain (B2G) showed lower values compared to the white and blue grain in the study variables H, SD, RV, FM, FAM, LA.

	Variables						
Genotype	H	SD	RL	RV	FRM	FAM	LA
WG	7.87 b	2.96 a	21.79 a	1.60 a	2.00 a	1.17 a	3.14 a
B1G	9.69 a	2.61 ab	24.56 a	1.27 ab	1.41 b	0.86 b	2.59 a
RG	8.24 b	2.35 b	17.82 a	0.89 b	0.88 c	0.54 bc	1.94 b
B2G	5.94 c	2.42 b	21.51 a	1.05 b	1.27 bc	0.68 bc	2.01 b
MSD*	1.35	0.49	9.35	0.58	0.50	0.29	0.54

MSD*: minimum significant differene; Values with different letters between columns are statistically different (p ≤ 0.5). H: Height; SD: Stem diameter; RL: radicle length; RV: radicle volume; FRM: Fresh root mass; FAM: Fresh aerial mass; LA: Leaf arear. Values with different letters between columns are statistically different.

Table 2 Analysis of physiological development according to corn genotype

Table 3 shows the influence of LED light in the comparison of means by Tukey, which showed differences with respect to the means obtained in the variable of SD, FRM, FAM and LA. It was shown that blue light (B2L) excels in variables associated with vegetative growth such as FRM, FAM and LA, which indicates that blue light stimulates or favors vegetative growth.

According to Kurilčik *et al*. (2008), blue and red light, a synergistic interaction between cryptochromes and phytochromes (blue and red photoreceptors, respectively) occurs, in this way these pigments may be responsible for the perception and activation of the process of rhizogenesis and plant growth, in addition to between 400 and 520 nm range in which the blue LED spectrum is found.

Light	H	SD	RL	RV	FRM	FAM	LA
	Variables						
WL	7.83 a	2.93 a	24.66 a	1.01 a	1.10 b	2.60 a	2.60 a
GL	8.31 a	2.70 ab	22.75 a	1.14 a	1.20 b	2.59 a	2.59 a
BL	7.42 a	2.30 b	21.69 a	1.45 a	1.71 a	2.74 b	2.74 a
RL	8.17 a	2.41 b	16.59 a	1.20 a	1.55 ab	1.74 b	1.74 b
MSD	1.35	0.49	9.35	0.58	0.50	0.54	0.54

MSD*: minimum significant differene; Values with different letters between columns are statistically different (p ≤ 0.5). H: Height; RL: radicle length; RV: radicle volume; FRM: Fresh root mass; FAM: Fresh aerial mass; LA: Leaf arear; WL: white Light; LV: green Light; BL: Blue Light; LR: Red Light.

Table 3 Influence of LED light on corn by multiple comparisons of means by Tukey

In Table 4, the comparison of means by Tukey of Gen * Light and light interaction is shown. Results of the means obtained, it was shown that there is an interaction for the variables measured between the Gen * Light. From the above, it was obtained that in height the red LED for the WG, B1G and B2G genotypes and in the blue LED for B1G, RG and B2G respectively. The effect of promoting stem elongation has also been widely documented for the case of the red LED by Kurilčik *et al*. (2008), however, the effect was not known for the case of the green LED, since they showed a percentage increase effect of 10% compared to the white and blue LED.

Gen	H	SD	RL	RV	FRM	FAM	LA
WHITE LED							
WG	9.5 abc	3.93 a	28 a	1.60 a	1.73 abc	1.51 a	3.76 a
B1G	8.16 abcd	2.50 b	25.50 a	0.76 a	0.76 c	0.61 b	2.36 abcd
RG	6 cd	16.66 e	25.50 a	0.76 a	0.76 c	0.61 b	2.65 abcd
B2G	7.66 abcd	2.83 ab	19.66 a	0.93 a	1.17 abc	0.82 ab	1.93 bcde
RED LED							
WG	10.03 ab	2.73 ab	14.66 a	1.53 a	2.29 ab	0.97 ab	2.34 abcde
B1G	8.33 abcd	2.80 ab	20.26 a	1.40 a	1.92 abc	1 ab	2.21 bcde
RG	5.08 cd	1.96 b	10.43 a	0.73 a	0.58 c	0.35 b	0.88 e
B2G	8.50 abcd	2.16 b	19.66 a	1.13 a	1.42 abc	0.47 b	1.54 de
BLUE LED							
WG	10.40 a	2.30 b	17.66 a	1.83 a	2.46 a	1.11 ab	3.40 ab
B1G	7.63 abcd	2.26 b	25.66 a	1.50 a	1.44 abc	0.74 ab	2.76 abcd
RG	5.50 d	2.33 b	16.36 a	1.26 a	1.44 abc	0.74 ab	2.76 abcd
B2G	6.16 cd	2.30 b	27.06 a	1.23a	1.51 abc	0.60 b	2.05 bcde
GREEN LED							
WG	8.83 abcd	2.90 ab	26.83 a	1.43 a	1.52 abc	1.08 ab	3.05 abc
B1G	8.83 abcd	2.90 ab	26.83 a	1.43 a	1.52 abc	1.08 ab	3.05 abc
RG	6.43 bcd	2.63 ab	19 a	0.80 a	0.76 c	0.46 b	1.75 cde
B2G	9.16 abcd	2.40 b	18.33 a	0.90 a	0.99 bc	0.82 ab	2.53 abcd
MSD	1.35	0.49	9.35	0.58	0.50	0.29	0.54

MSD*: minimum significant differene; Values with different letters between columns are statistically different (p ≤ 0.5). H: Height; RL: radicle length; RV: radicle volume; FRM: Fresh root mass; FAM: Fresh aerial mass; LA: Leaf arear.

Table 4 Comparison of means between four corn genotypes under LED lights

In determining the effects associated with the interaction between genotypes and LED light, it was obtained that for variables associated with root development, the blue LED showed increases of 15% with respect to the means obtained for the white, red and green LEDs.

The B1G, RG and B2G genotypes showed a physiological response of increase in RV and FRM, however, these values were not related to the increase in the length of the root, so it is inferred that the amount of carbohydrates produced in the aerial part they are used in the root zone, increasing the exploration of the roots and their volume.

In the variables SD, FAM and LA, no specific effects were related for the Gen * Light, however it was observed that in B1G and B2G, they showed an increase of 10% with respect to the means obtained for LA in blue and green LEDs, associated with the H obtained in the same spectra. This may be related to the color of the seed, because dark pigments capture more photons through the environment, promoting vegetative development.

Conclusions

The genotypes put into study showed different physiological response, highlighting that the WG obtained better averages in the variables SD, RV, FRM, FAM and LA. The variables showed a specific response to the LED light, therefore the white light stimulated the SD, FAM, the blue LED increased the amount of FAM and FRM, while for the variable H, LR, RV and LF the LEDs stimulate similar effects.

The Gen * Light interaction made it possible to detect that each genotype shows specific responses to each LED intensity. In physiological stimulation of corn, it was obtained that the blue LED improves the root quality (absorbent capillaries and the content of water storage) in the B1G, RG and B2G genotypes, while the red LED in the WG, B1G and B2G genotypes and in the green LED the B1G, RG and B2G materials, stimulated the vegetative growth of the stem in the seedling respectively.

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