Article

Quality of light from fluorescent lamps in cucumber growth and severity of *Oidium* sp.

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Abstract

The quality of light affects the development of plants, due to the specific effects on photosynthesis, photomorphogenesis and other physiological and biochemical processes. It also has an important role in plant-pathogen interactions and controls various metabolic activities of fungi that determine their pathogenicity and severity. Three experiments were carried out under completely randomized designs to know the influence of fluorescent lamps of cool, neutral and warm white light, on the morphology and growth of cucumber plants (*Cucumis sativus* L.) and the severity of powdery mildew (*Oidium* sp.). In the growth chambers used, the photosynthetic photon flux density (PPFD) averaged 305 μmol m^{-2} s^{-1}, but the spectral parameters related to red light (R:WWL> NWL> CWL) and blue light (B:CWL> NWL> WWL) were contrasting. The highest absolute amount of light R (122.04 μmol m^{-2} s^{-1}), relative amount of R:PPFD (40.09%) and proportional amount of R:B (2.67) and R:FR (3.25) of WWL promoted greater height, leaf area, fresh and dry weight of leaves, stem and root of plants, while the greater absolute amount of light B (84.19 μmol m^{-2} s^{-1}), relative amount of B:PPFD (27.48%) and proportional amount of B:R (1.04) and B:FR (2.65) of CWL induced lower plant height and greater stem thickness and leaf greenness index. The spectral parameters of CWL also disturbed the development of *Oidium* sp., which was reflected in less severity of powdery mildew compared to NWL or WWL.

Keywords: *Cucumis sativus* L., blue light, powdery mildew, red light.

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Introduction

Light quality, photon flux and photoperiod are aspects of light that affect plant development, because of the specific effects they have on different types of plant responses, such as photosynthesis, photomorphogenesis and other physiological and biochemical processes (Hogewoning *et al*., 2010; Nelson and Bugbee, 2015; Snowden *et al*., 2016; Yan *et al*., 2019). The compact fluorescent lamp represents a simple and inexpensive way to replace the incandescent lamp used in growth chambers (Runkle *et al*., 2012).

The spectrum of light emitted by a compact fluorescent lamp is different from that of an incandescent lamp. An incandescent lamp emits more far-red light (FR=700-800 nm) than red light (R= 600-700 nm) and has a low R:FR ratio of approximately 0.7 (Runkle *et al*., 2012; Gupta and Jatothu, 2013), which causes stem elongation, leaf expansion and other responses induced by phytochromes (Casal, 2013; Demotes-Mainard *et al*., 2016). In contrast, the compact fluorescent lamp emits more blue light (B= 400-500 nm) and red light, and little far-red light, so the R:FR ratio is between 3 and 8, depending on the wave bands used and the lamp model, which induce more compact plant growth (Runkle *et al*., 2012; Gupta and Jatothu, 2013).

Light-emitting diodes (LEDs) emerged as a novel and efficient light source to promote plant growth in space-limited research chambers (Cope and Bugbee, 2013). With LEDs, monochromatic red or blue light can be provided, but none of these manage to satisfy the requirement of normal plant growth (Wang *et al*., 2016; Yang *et al*., 2017). However, when adequate R:B ratios are supplied, supplemented or not with other wavelengths: UV-A (350-400 nm), green (500-600 nm) or far red, greater compactness in tomato seedling is obtained (Javanmardi and Emami, 2013; Hernández *et al*., 2016), greater biomass, chlorophyll and photosynthetic capacity of seedlings of cucumber (Hogewoning *et al*., 2010; Song *et al*., 2017) and tomato (Xiaoying *et al*., 2012), optimal production of seedlings of lettuce (Yan *et al*., 2019) and potato (Chen *et al*., 2020).

However, several studies have reported higher growth under fluorescent lamps compared to LEDs with the same photonic flux (Lin *et al*., 2013; Chen *et al*., 2014; Wang *et al*., 2014). Fluorescent lamps have more diffused light compared to direct light from LEDs. Diffused light penetrates the plant canopy better than direct light and increases photosynthesis and dry biomass (Li and Yang, 2015). Fluorescent lamps also increase infrared radiation (Nelson and Bugbee, 2015) and have some FR radiation (Snowden *et al*., 2016), which increases leaf and petiole expansion and therefore radiation capture.

A variety of compact fluorescent lamps are available, which differ in luminous flux (lm); luminous efficacy (lm W^{-1}), lifespan (h), color rendering index (CRI) and color appearance, most commonly described as color temperature and expressed in Kelvin units (K). Of which there is greater availability in three main groups: 2 700 to 3 000 K, which produces warm white light similar to that of incandescent lamps, 3 500 to 4 100 K of neutral or natural white light and 5 000 to 6 500 K of cool white light, which provides light with a blue hue (Saavedra *et al*., 2016).

Light is an important environmental factor also for fungi, which has an important role in plant-pathogen interactions and controls various metabolic activities of pathogenic fungi (Rahman *et al*., 2003; Wang *et al*., 2010). More than 100 species of fungi, which represent all phyla, have been found to respond to the effect of light (Tisch and Schmoll, 2010). The metabolic activities it regulates include circadian rhythms, asexual conidiation, pigmentation, secondary metabolism, and sexual development (Purschwitz *et al*., 2006; Suzuki *et al*., 2018).

Although the interaction between light and fungi has been studied and reviewed by several researchers (Idnurm and Heitman, 2005; Purschwitz *et al*., 2006; Chen *et al*., 2009), reports on the effect of light quality on the pathogenicity or virulence of fungi are limited. The objective of the research was to determine the effect of the light spectrum emitted by compact fluorescent lamps of cool, neutral and warm white light, on the growth of cucumber plants (*Cucumis sativus* L.) and the severity of powdery mildew of cucurbits (*Oidium* sp.).

Materials and methods

The research was conducted inside growth chambers of 44 x 70 x 80 cm (246 400 cm^3) with woven mesh of 16 x 16 crystalline monofilaments of high-density polyethylene per cm^2, on all their sides and sides lined with high reflectance Mylar paper (Figure 1) at the Faculty of Agronomy of the Autonomous University of Sinaloa. Seeds of 'Poinsett 76' cucumber were sown in polystyrene trays of 128 cavities and when the seedlings had two true leaves, they were individually transplanted into polystyrene cups of 0.5 L. In both types of containers, peat (Pro-Mix® FLX, Premier Horticulture, USA) was used as a substrate and they were irrigated to saturation with a fertilizer solution (pH= 6.5 to 7 and EC= 1.12 to 1.35 dS m^{-1}) composed of 0.5 to 1.2 g L^{-1} of monopotassium phosphate and 0.3 to 0.7 g L^{-1} of potassium nitrate.

Figure 1. Cucumber plants inside a growth chamber with lighting of fluorescent lamps of cool (CWL, left), neutral (NWL, center) and warm white light (WWL, right).

Fluorescent lamps (FLE23HLX, GE, USA) of cool (CWL= 6 500 K), neutral (NWL= 4 000 K) and warm white light (WWL= 2700 K) were used. The measurement of the photon flux, in the range of 350 to 1 050 nm, was performed with a spectroradiometer (Field SpecPro®Vnir, ASD, USA), obtaining: a) absolute amount of the photosynthetic photon flux density (PPFD= 400 to 700 nm), blue light (B= 400 to 500 nm), red light (R= 600 to 700 nm) and far-red light (FR= 700 to 800 nm); b) relative amount (per cent of total PPFD) of blue light (B:PPFD) and red light (R:PPFD); and c) proportional amount of blue-to-red light (B:R), blue-to-far-red light (B:FR), red-to-blue light (R:B), and red-to-far-red light (R:FR) (Table 1). The light spectrum of the three fluorescent lamps is shown in (Figure 2).

Table 1. Quality parameters of light emitted by fluorescent lamps of cool (CWL), neutral (NWL) and warm white light (WWL).

Parameter/type of lamp	CWL	NWL	WWL
PPFD (400-700 nm)^{x}	306.4	305.25	304.37
B (400-500 nm)^{x}	84.19	64.87	45.74
R (600-700 nm)^{x}	81.34	100.44	122.04
FR (700-800 nm)^{x}	31.79	33.93	37.51
B:PPFD [(400-500/400-700 nm)∗100]^{y}	27.48	21.25	15.03
R:PPFD [(600-700/400-700 nm)∗100]^{y}	26.55	32.9	40.1
B:R (400-500/600-700 nm)^{z}	1.04	0.65	0.37
B:FR (400-500/700-800 nm)^{z}	2.65	1.91	1.22
R:B (600-700/400-500 nm)^{z}	0.97	1.55	2.67
R:FR (600-700/700-800 nm)^{z}	2.56	2.96	3.25

PPFD= photosynthetic photon flux density; B= blue light; R= red light; FR= far-red light. Absolute^{x} (µmol m^{-2} s^{-1}), relative^{y} (%) and proportional^{z} (dimensionless) quantities.

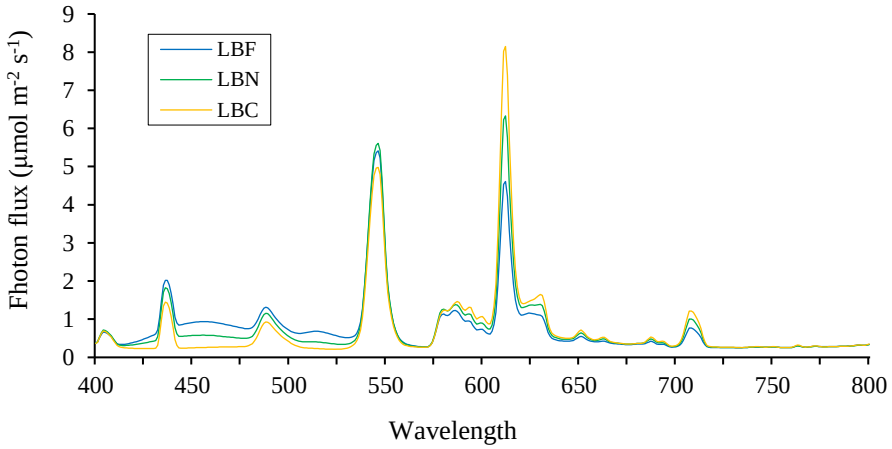

Figure 2. Spectral distribution of light emitted by fluorescent lamps of cool (LBF), neutral (LBN) and warm white light (LBC).

The luminous environment had means of 305.3 µmol m^{-2} s^{-1} of PPFD and 13.2 mol m^{-2} d^{-1} of integrated daily light, suitable for the production of vegetable seedlings (Fan *et al*., 2013). The photoperiod was 12/12 h of light/darkness. The temperature and relative humidity, recorded with

thermohygrometers (CM-DT171, Twilight, Mexico), had means ± standard error of 24.5 ±0.15 °C and 62.5 ± 0.6%, respectively. The CO_2 level was 420 ±20 μmol mol^{-1}, obtained with CO_2 meter (CO2-100, Amprobe, Germany).

For the study of plant growth, a completely randomized experimental design was used, with three treatments: compact fluorescent lamps of cool (CWL), neutral (NWL) and warm white light (WWL) and four repetitions (four plants per repetition). Cucumber plants were evaluated for 35 days after emergence (dae), a period during which they were exposed to lamp light. The experiment was repeated three times, in each of which the following response variables were evaluated: plant height, measured with tape measure, stem diameter, obtained with digital caliper (6MP, Truper, Mexico), foliar greenness, by means of a chlorophyll meter (SPAD 502 Plus, Minolta, Japan), leaf area, obtained with a non-destructive method proposed by Blanco and Follegati (2003), fresh and dry biomass of leaves, stem and root per plant, by analytical balance (SA120, Scientech, USA), after drying in an oven (FE293AD, Felisa, Mexico) at 70 °C, up to constant dry weight.

For the study of the severity of powdery mildew, a completely randomized experimental design was used, with three treatments: compact fluorescent lamps of cool (CWL), neutral (NWL) and warm white light (WWL) and 12 repetitions (one plant per repetition). The primary inoculum of *Oidium* sp. was obtained from naturally infected *Cucurbita pepo* L. plants.

The conidia suspension was prepared by brushing the source leaves with distilled water and maintained at a concentration of approximately 5.1 x 10^4 conidia ml^{-1} by hemocytometer (79003, Cole-Parmer, USA). Inoculation was carried out by foliar spraying of 30 ml of conidial suspension for each tray of 128 seedlings, the day they unfurled the second true leaf. The experiment was repeated three times, and each spanned a period of 35 days after inoculation (dai), during which the percentage of leaf area with symptoms of the disease on each leaf of the plants was determined, as well as the average of the entire plant.

The data obtained from the three experiments were averaged and subjected to the analysis of variance and comparison of means with the Tukey test ($p \leq 0.05$), using the statistical package Statistica version 7.0 (StatSoft, 2004).

Results and discussion

The quality of light emitted by fluorescent lamps (Table 1) caused significant differences ($p \leq 0.05$) in the height, stem diameter, leaf area and greenness of cucumber plants (Table 2). The luminous environment created by WWL lamps showed the highest values of absolute amount of red light (122.04 μmol m^{-2} s^{-1}), R:PPFD ratio (40.1%) and R:B ratio (2.67), which caused increases in plant height from 3.3 to 30.2% and 15.4 to 82.3%, compared to the effect caused by NWL and CWL lamps, which emitted 17.5 and 45.1% less red light than WWL, respectively. The result of increased plant height due to red light is consistent with that described in *Paeonia suffruticosa* (Ding *et al*., 2010), *Solanum lycopersicum* (Xiaoying *et al*., 2012), *Morus alba* (Hu *et al*., 2016), *Camptotheca acuminata* (Yu *et al*., 2017) and *Solanum tuberosum* (Chen *et al*., 2020).

Phytochromes, red and far-red light receptors, regulate stem elongation by both cell division and extension (Neff *et al*., 2000). The activity of phytochromes during cell elongation is controlled by the biosynthesis of gibberellins AG_1 and AG_4, mainly, and auxin IAA (Damayanthi-Ranwala and Decoteau, 1998; Kurepin *et al*., 2007; Fukuda *et al*., 2016; Li *et al*., 2017).

The CWL lamps emitted the highest absolute amount of blue light (84.19 μmol m^{-2} s^{-1}), 29.8 and 90.3% higher compared to the respective NWL and WWL lamps, which contained the elongation of the stem, as it was negatively correlated with plant height. These lamps also produced the highest B:PPFD ratio (27.48%) and the highest B:R ratio (1.04), in addition to the lowest R: PPFD ratio (26.55%) and the lowest R:B ratio (0.97). This result is related to the ability of blue light to inhibit stem elongation (Ding *et al*., 2010; Xiaoying *et al*., 2012; Hu *et al*., 2016; Yu *et al*., 2017; Chen *et al*., 2020), in response to synergistic interactions between phytochromes and cryptochromes, red and blue light receptors; respectively, in the promotion or inhibition of stem elongation (Heo *et al*., 2002).

The spectral characteristics of the light emitted by the CWL lamps, referred to above, also increased the stem diameter from 0.1 to 9.1% and 5.1 to 13.2% compared to that of the plants that grew with light from NWL and WWL lamps, respectively, which emitted light with a B:PPFD ratio (15.03 and 21.25%) and a B:R ratio (0.37 and 0.65) lower than those of CWL. Li *et al*. (2017); Chen *et al*. (2020) point out that blue light stimulates a greater expression of proteins associated with plant microtubules and tubulin, which promote secondary cell wall formation and atherefore thickening of the stem.

The quality of light emitted by WWL lamps, with relevance in red light, promoted increases of 2.2 to 14.2% and 18.6 to 25.5% in the leaf area per seedling, compared to the effect caused by NWL and CWL lamps, respectively.

Consistent result with those obtained by Cope and Bugbee (2013) in *Raphanus sativus* and *Glycine max*, and by Hernández and Kubota (2016) in *Cucumis sativus*, where the leaf area grew as blue light decreased and red light increased. Both blue and red light stimulate the flux of protons in cells, apoplastic acidification, cell wall elasticity and the accumulation of solutes for the maintenance of the turgor of growing leaves, through separate mechanisms. Blue light induces a direct interaction between the proton pump and a blue light photoreceptor, while red light indirectly influences the proton pump, modulating calcium and potassium channels (Staal *et al*., 1994; Van Volkenburgh, 1999).

While the spectral parameters in the light emitted by CWL (Table 1) with relevance in blue light, increased the foliar greenness of the plants from 2.1 to 8% and 10.1 to 18% compared to the effect caused by the NWL and WWL lamps, respectively. This is consistent with studies conducted on seedlings of *Solanum lycopersicum* (Hernández and Kubota, 2016) and *Cucumis sativius* (Hogewoning *et al*., 2010; Hernández *et al*., 2016), which showed a higher concentration of foliar chlorophyll as the flux of blue photons increased, due to the additive effect of cryptochromes and phytochromes, compared to lower biosynthesis of chlorophyll in plants grown under monochromatic blue or red light.

Table 2. Plant height (PH), stem diameter (SD), leaf area per plant (LAP) and leaf greenness (LG) of cucumber plants *cv* Poinsett 76 grown in a growth chamber with lamps of cool (CWL), neutral (NWL) and warm white light (WWL).

Parameter	Treatment	Days after the emergence				
		7	14	21	28	35
PH (cm)	CWL	3.98 c	4.5 c	11.7 b	17.8 c	43.3 b
	NWL	5.4 b	5.59 b	12.5 b	26.2 b	48.4 ab
	WWL	6.92 a	7.28 a	14.7 a	32.4 a	50 a
	HMSD	0.97	0.96	1.5	5.1	5.48
SD (mm)	CWL	2.3 a	3.3 a	4.4 a	5.83 a	5.98 a
	NWL	2.1 b	3.2 ab	4.4 a	5.34 b	5.51 b
	WWL	2.1 b	2.9 b	4.2 b	5.21 b	5.42 b
	HMSD	0.13	0.32	0.16	0.2	0.31
LAP (cm^2)	CWL	30 b	163.6 b	529.5 b	936.1 b	1319.3 b
	NWL	48.4 a	200.9 a	579.6 b	1065.3 a	1525.1 a
	WWL	37 b	205.3 a	661.7 a	1114.8 a	1564.4 a
	HMSD	8.52	27.4	59.28	103.6	119.4
LG (SPAD u)	CWL	30.1 a	41.6 a	43.5 a	41.5 a	36.4 a
	NWL	27.9 ab	39.7 b	42 a	38.4 b	35.7 a
	WWL	25.5 b	37.8 c	37.8 b	36.1 c	33 b
	HMSD	2.94	1.84	1.63	1.99	1.82

Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). HMSD= honest minimum significant difference.

The production of biomass of leaves, stem and roots by cucumber plants also showed significant differences ($p \leq 0.05$) due to the quality of light emitted by fluorescent lamps (Table 3).

Table 3. white light (Fresh weight (FW) and dry weight (DW) of leaves, stem and root of cucumber plants *cv* Poinsett 76 grown in a growth chamber with lamps of cool (CWL), neutral (NWL) and warm WWL).

Parameter	Treatment	Days after the emergence				
		7	14	21	28	35
FW/Leaves (g)	CWL	0.17 b	3.93 a	11.52 b	16.21 b	20.18 b
	NWL	0.2 ab	5.22 a	12.24 ab	16.25 b	20.97 b
	WWL	0.23 a	5.43 a	13.29 a	17.99 a	22.69 a
	HMSD	0.03	1.57	1.42	1.02	1.4
DW/leaves (g)	CWL	0.02 b	0.37 b	1.06 a	1.58 b	2.09 b
	NWL	0.02 b	0.47 a	1.11 a	1.68 ab	2.21 ab
	WWL	0.03 a	0.47 a	1.14 a	1.8 a	2.49 a
	HMSD	0.006	0.096	0.109	0.167	0.291

Parameter	Treatment	Days after the emergence				
		7	14	21	28	35
FW/Stem (g)	CWL	0.41 b	1.58 b	5.18 a	7.12 a	8.06 b
	NWL	0.43 ab	2.36 a	5.18 a	7.1 a	9.02 a
	WWL	0.49 a	2.8 a	5.31 a	7.42 a	9.53 a
	HMSD	0.068	0.598	1.086	0.963	0.878
DW/Stem (g)	CWL	0.03 b	0.04 a	0.18 a	0.34 b	0.5 b
	NWL	0.03 b	0.05 a	0.17 a	0.37 ab	0.56 a
	WWL	0.04 a	0.05 a	0.22 a	0.39 a	0.58 a
	HMSD	0.01	0.019	0.073	0.046	0.056
FW/Root (g)	CWL	0.42 b	0.99 b	2.05 b	5.03 b	8.01 b
	NWL	0.55 a	1.21 a	2.07 b	5.33 b	8.59 ab
	WWL	0.5 a	1.2 a	2.62 a	5.81 a	9 a
	HMSD	0.058	0.12	0.15	0.429	0.712
DW/Root (g)	CWL	0.018 a	0.065 b	0.085 b	0.213 b	0.341 b
	NWL	0.019 a	0.07 ab	0.105 a	0.263 a	0.42 a
	WWL	0.017 a	0.075 a	0.1 a	0.256 a	0.413 a
	HMSD	0.004	0.006	0.006	0.023	0.04

Means with the same letter are statistically equal (Tukey, $p \leq 0.05$). HMSD= honest minimum significant difference.

The red light parameters (R= 122.04 μmol m^{-2} s^{-1}; R:PPFD= 40.9%; R:B= 2.67) of WWL lamps caused plants to increase the fresh leaf weight, from 3.9 to 15.4% compared to the effect caused by NWL lamps (R= 100.44 μmol m^{-2} s^{-1}; R:PPFD= 32.9%; R:B= 1.55) and from 8.6 to 38% in relation to CWL (R= 81.34 μmol m^{-2} s^{-1}; R:PPFD= 26.55%; R:B= 0.97). With WWL, the dry weight of leaves also increased from 0 to 12.6% and from 8.9 to 27.4%, with respect to that obtained from plants grown with NWL and CWL, respectively.

The morphological response influenced those of plant growth, since the fresh and dry biomass of leaves (growth parameters) coincided closely with the leaf area per plant (morphological parameter), as observed by Hogewoning *et al*. (2010); Hernández and Kubota (2016). These authors indicated that the seedlings of *Cucumis sativus*, grown under combinations of red and blue light, require 15 to 50% blue light to have adequate growth and development, since such proportions of light were associated with increases in biomass per unit of leaf area, foliar nitrogen and chlorophyll content, photosynthetic assimilation of CO_2 and stomatal conductance, which were lower with monochromatic red light, where plants showed a dysfunctional photosynthesis system.

The accumulation of biomass in the stem of the plants did not present significant differences ($p \leq 0.05$) during the first 28 days after the emergence (dae). However, at 35 dae, the stem biomass was more related to its length (plant height) than to its diameter, since the red-light parameters of the WWL lamps caused increases of 5.7 and 18.2% in the fresh weight of the stem and 0 and 12.2% in the dry weight of the stem, compared to those obtained with NWL and CWL lamps, respectively, where the stems elongated less and thickened more.

In this sense Ayala-Tafoya *et al*. (2015) observed increases in the dry weight of leaves and stem of *Cucumis sativus* plants grown under red mesh, due to the confluence of more PPFD and red light, compared to responses to blue mesh. Similarly, after 21 dae, with WWL lamps, the fresh root weight increased from 4.7 to 26.7% and from 12.4 to 28.1%, compared to NWL and CWL lamps, respectively. While, with WWL and NWL lamps, the dry root weight exceeded from 17.6 to 21% that obtained with CWL lamps.

Cucumber plants grown with CWL lamps showed a severity of powdery mildew (*Oidium* sp.) of 0.8% at 10 days after inoculation (dai) and 3% at 12 dai, which was lower from 4.9 and 5.3 times to 3 and 4 times compared to plants grown with NWL and WWL lamps, respectively. In the rest of the study, CWL lamps induced severity values of 7.9% at 14 dai and 62.5% at 35 dai, lower from 109.2 and 136.2% to 15.7 and 23.6%, compared to NWL and WWL lamps, respectively. However, the severity values of powdery mildew obtained with the three types of fluorescent lamps, throughout the study period, showed linear increases with similar coefficients of determination (Figure 3).

In the same sense, other studies showed that blue light reduced the severity of *Botrytis cinerea* in *Solanum lycopersicum* (Xu *et al*., 2017) and *Podosphaera xanthii* in *Cucumis melo* (Jing *et al*., 2018), by increasing the expression of defense-related genes in plants, which induced accumulation of: proline, H_2O_2, phenolic compounds, flavonoids, tannins and lignin, in addition to promoting a compact morphology and increased thickness of the cell wall in plant tissue.

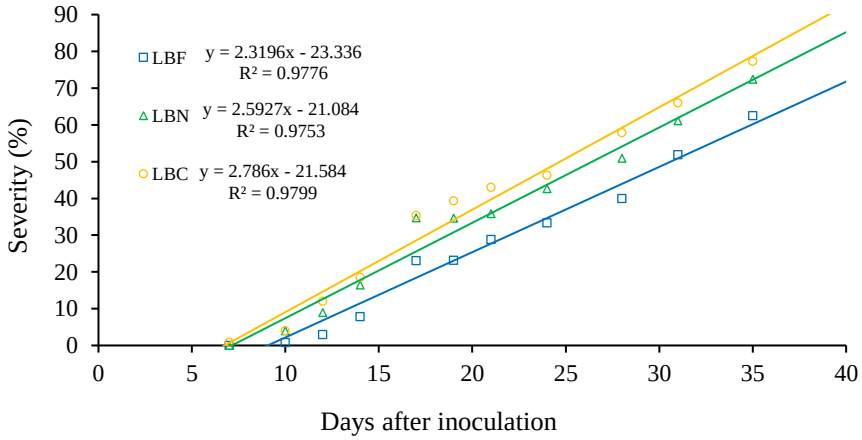

Figure 3. Severity of powdery mildew (*Oidium* sp.) in 'Poinsett 76' cucumber plants grown in a growth chamber with fluorescent lamps of cool (LBF), neutral (LBN) and warm white light (LBC).

Conclusions

Compact fluorescent lamps of warm white light promoted greater height, leaf area, fresh and dry weight of leaves, stem and root of plants. While compact fluorescent lamps of cool white light induced lower plant height and greater stem thickness and leaf greenness index. The spectral parameters of compact fluorescent lamps of cool white light also induced lower severity of the powdery mildew in cucumber plants, compared to lamps of neutral or warm white light.

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