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The responses of photosynthesis, fruit yield and quality of mini-cucumber to LED-interlighting and grafting

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ABSTRACT

Supplemental lighting is becoming a common practice for horticultural greenhouse industries, especially at high-latitude countries. However, no scientific reports were found on this topic in tropical climate countries. This study investigates the effects of LED-interlighting and grafting on photosynthetic response and yield and quality of mini cucumber (hybrid Larino). The experiment took place from April to August in a greenhouse located at a Cwa climate type in Piracicaba (SP), Brazil (22°42'S; 47°37'W; 541 m altitude). The experiment was arranged in completely randomized block design composed of three types of seedlings (ungrafted hybrid, hybrid grafted onto rootstock cultivar Keeper and hybrid grafted onto rootstock cultivar Shelper) and two environments related to light condition (LED supplemental light and natural light as control). The LED devices were placed horizontally at 15 cm from the plants and at 1,5 m height from the floor. The LEDs emitted a photon flux of 220 µmol m^{-2} s^{-1} by red light (80%) with a peak wavelength of 662 nm and blue light (20%) with a peak wavelength of 452 nm. Lighting was used for 12 h d^{-1} from 30 days after seedling transplanting until the end of the growth period. The air temperature and relative humidity (RH) were maintained at 23.5±4°C and 72±10% during the light period, respectively. At night, average temperature was 18.6±5°C and the RH was 90±5%. The LED-interlighting treatment increased in 40% the plant CO_2 net assimilation rate compared to plants grown under natural light in the greenhouse. Plants grafted onto both rootstocks had higher CO_2 net assimilation rate (µmol CO_2 m^{-2} s^{-1}), apparent carboxylation efficiency (µmol CO_2 mol air^{-1}) and apparent electron transport rate (µmol electrons m^{-2} s^{-1}) than non-grafted ones. The early yield increased 11.6% and 24% in response to LED-interlighting and grafting, respectively. The commercial yield also increased with LED light at rate of 13% but did not enhance with grafting. Postharvest quality parameters as titratable acidity, total soluble solids and shelf life were not affected by the LED light supplementation. Our study shows that even in tropical climate conditions LED-interlighting can be used as a tool to improve commercial cucumber production.

Keywords: *Cucumis sativus*, supplemental lighting, grafting, CO_2 rate, postharvest.

RESUMO

Respostas da fotossíntese, produtividade e qualidade de mini pepino à iluminação com barras de LED no interior do dossel e à enxertia

A suplementação luminosa vem se tornando uma prática comum na indústria do cultivo protegido de hortaliças, especialmente em países de alta latitude. No entanto, não foram encontrados relatos científicos sobre esse tema em países de clima tropical. Este estudo investiga os efeitos da iluminação intra-dossel com lâmpadas de LED e da enxertia na resposta fotossintética, na produtividade e na qualidade de frutos de pepino tipo snack (híbrido Larino). O experimento ocorreu nos meses de abril a agosto, em uma casa-de-vegetação localizada em clima Cwa, em Piracicaba (SP), Brasil (22°42'S; 47°37'W, altitude 541 m). O experimento foi realizado no delineamento em blocos casualizados com três tipos de mudas (híbrido não enxertado, híbrido enxertado em porta-enxerto cultivar Keeper e híbrido enxertado em porta-enxerto cultivar Shelper) cultivadas em dois ambientes relacionados à iluminação (suplementação luminosa com luz de LED e iluminação natural como controle). No tratamento com iluminação artificial, as barras de LED, instaladas a 15 cm de distância das plantas (na horizontal) e 1,5 m de altura em relação ao chão, permitindo um fluxo de fótons de 220 µmols m^{-2} s^{-1}, emitiam luz vermelha (80%) num comprimento de onda de 662 nm, e luz azul (20%) num comprimento de onda de 452 nm. A iluminação suplementar foi utilizada por 12 h d^{-1}, com início 30 dias após o transplante das plântulas e término no final do período de cultivo. A temperatura do ar e a umidade relativa (UR) foram mantidas em 23,5±4°C e 72±10% durante o período de luz, respectivamente. À noite, a temperatura média foi de 18,6°C±5°C e a UR foi de 90±5%. O tratamento com iluminação suplementar no interior do dossel aumentou em 40% a taxa de assimilação líquida de CO_2 da planta em comparação com as plantas cultivadas apenas em luz natural. As plantas enxertadas nos dois porta-enxertos apresentaram maior taxa de assimilação líquida de CO_2 (µmol CO_2 m^{-2} s^{-1}), eficiência de carboxilação aparente (µmol CO_2 mol ar^{-1}) e taxa de transporte de elétrons aparente (µmol elétrons m^{-2} s^{-1}) quando comparadas às plantas não enxertadas. A produtividade inicial aumentou 11,6% e 24% em resposta à iluminação artificial no interior do dossel e à enxertia, respectivamente. A produtividade de frutos da categoria comercial aumentou em 13% devido às luzes de LED, mas não aumentou com a enxertia. Os parâmetros de qualidade pós-colheita como acidez titulável, sólidos solúveis totais e vida de prateleira não foram afetados pela suplementação luminosa. Nosso estudo mostra que, mesmo em condições de clima tropical, a suplementação luminosa com lâmpadas LED pode ser usada como uma ferramenta para melhorar a produção comercial de pepino.

Palavras-chave: *Cucumis sativus*, suplementação luminosa, enxertia, taxa de CO_2, pós-colheita.

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Cucumber is one of the main crops cultivated in protected environment. Particularly specialty cultivars with high market value as snack cucumber, with great flavor and reduced size fruits, favor the fresh consumption by an increasing consumer sector more exigent on food quality and healthy products.

Cucumber fruit yield and quality are influenced by light quantity and quality as well as the localization of the light source in relation to the position of the photosynthetic plant surface. The lamp design defines the light's orientation angle and height at canopy. LEDs and interlighting have been used successfully to grow tomatoes, bell peppers and cucumbers (Massa *et al.*, 2008; Fan *et al.*, 2013). Cucumber plants are grown vertically, and intra-canopy artificial radiation assists in reducing self-shading of the lower canopy. Therefore, particularly in temperate climates, the use of top and interlighting lamps with light emitting diodes, known as LED technology, has increased in protected cultivation. LED technology has many advantages over traditional lighting sources, such as the possibility to calibrate the spectrum radiation for different species, low power consumption, prolonged equipment life and low heat, enabling the development of intra-canopy lighting systems (Mitchell *et al.*, 2012). Artificial lighting with LED lamps may increase the carbon assimilation rate, which is related to the active photosynthetically radiation intercepted by the leaves, converting light energy into chemical energy by photosynthesis. Positive results have been reported for several crops grown under different lighting arrangements of blue, red and far red LEDs (Fan *et al.*, 2013; Olle & Viršillė, 2013, Park & Runkle, 2017). Such arrangements allow a good correspondence between the blue and red lights with the light absorption by chlorophyll and carotenoids. Terashima *et al.* (2009) reported that leaves might absorb 90% of the available blue and red light. The ratio of blue to red light provided by LED to cucumber showed that leaves illuminated only with red wavelength are photosynthetically dysfunctional. This problem was prevented with only 7% blue light, which photosynthetic capacity increased up to 50%. Blue light also increases plant biomass and fruit yield in cucumber plants (Menard *et al.*, 2006). Hernández & Kubota (2014) used the total light energy during the day [day light integral (DLI)] to calibrate the proportion of blue and red lights provided by LED. Under high DLI conditions (16.2±5.3 mol m^{-2} d^{-1}) no differences were observed on dry weight, leaf number and leaf area of cucumber plants, but at low DLI (5.2±1.2 mol m^{-2} d^{-1}), these characteristics improved with red:blue ratio of 80%:20% supplied by LED light.

The response of cucumber plants to supplemental LED light also may vary as function of rootstock-scion combination. Grafting is a useful practice to increase the vigor and yield of plants as compared to those cultivated from conventional seedlings in greenhouses (Liu *et al.*, 2015). Grafted plants have vigorous roots, whose plant root system is more able to improve the water and nutrient uptake. Appearance and postharvest quality of the fruits also can be strongly affected by grafting (Fallik & Ilic, 2014).

No papers about LED-interlighting use were found on scientific literature for tropical climate countries. The aim of this study was to evaluate the photosynthetic parameters, yield and quality of snack cucumber plants grafted on two rootstock cultivars under supplemental LED lighting in greenhouse.

MATERIAL AND METHODS

Experimental site

The experiment was carried out from April to August 2015 in the experimental site of Crop Science Department of University of São Paulo, Piracicaba (SP), Brazil (22°42´S, 47°37'W, 541 m altitude). According to Köppen, the climate is altitude tropical, type Cwa. The cucumber plants were grown in a greenhouse with 345 m^2 floor area and 3.4 m gutter height. The greenhouse structure had a climate control evaporative cooling system (pad and fan) activated when temperature raised higher than 25±2°C. Temperature, humidity and PAR radiation inside the greenhouse were registered continuously by meteorological station (WatchDog 2400 Mini Station External Sensor, Spectrum® Technologies, Inc.; Aurora, Illinois, USA) placed at 1.5 m height at the middle of the greenhouse. Temperature and air relative humidity (RH) were maintained at 23.5±4°C and 72±10%, respectively, during the daytime. At night, the temperature and RH ranged from 18.6°C to 23.6°C and from 90 to 95% respectively. The PAR radiation where the meteorological station was located was in average 9.80 mol m^{-2} day^{-1}. The total PAR radiation accumulated over the cycle was 1196.10 mol m^{-2}.

Treatments and cultivars

The experiment was arranged in a complete randomized block design composed of three types of seedlings [ungrafted hybrid, hybrid grafted onto rootstock cultivar Keeper (pumpkin hybrid) and hybrid grafted onto rootstock cultivar Shelper (*C. moschata*, pumpkin hybrid)] with three replications, which were grown in two environments related to light condition (LED supplemental light and natural light as control), totalizing eighteen plots with sixteen plants each (nine plots per environment). The plants were grown in pots, which were distributed in double lines, with 0.4 m spacing between plants, 0.8 m between lines and 2.0 m between the double lines, resulting in a density of 2.5 plants m^{-2}.

The cultivar used at the experiment was the mini-cucumber hybrid Larino (Rijk Zwaan®). Fruits of this hybrid are parthenocarpic and 9 to 11 cm long and have great shelf-life compared to other cucumber genotypes. They may be consumed as a fresh-tasty snack. This cultivar needs vertical conduction system and can produce three to five fruits per bud in a period of two to four months.

Lighting

Light supplementation was provided by LED-interlighting lamps (Philips GreenPower LED, Philips Lighting Holding B.V., Amsterdam, The Netherlands). The LED bar dimensions were 250 cm length, 4.2 cm width and 7 cm height, with light linear arrangement. They were placed horizontally at 15 cm from the plants (horizontal distance) and 1.5 m height from the floor, in the middle of a double row of cucumber plants. Light colors emitted were red and blue in a ratio of 80% red light and 20% blue light. The light intensity emitted by the LEDs device was in a range near to 220 μmol photons m^{-2} s^{-1}. This extra photosynthetic photon flux density was provided for 12 hours per day, from 9:00 AM to 9:00 PM. Light quantity and quality were the same for all the supplemental LED light treatments.

Growth conditions

Both grafted and ungrafted cucumber seedlings were produced in 200 mL pots in a nursery company (Hidroceres®). All the seedlings had two fully expanded true leaves when they were transplanted (one plant per pot) to 8 L capacity plastic containers filled with coconut fiber (medium texture) substrate. This growing medium had a cation exchange capacity (CEC) of 220 mmol kg^{-1}, pH of 5.7 and an electrical conductivity of 2.07 dS m^{-1}.

The nutrient solution was applied by drip irrigation controlled by moisture-sensors (Irrigation controler-MRI, Hidrosense, Jundiai, Brazil), six sensors by treatment, to maintain the substrate moisture at field capacity. Sensors and substrate were previously calibrated to ensure greater accuracy and reliability. Watering started when the substrate humidity was 3.5 kPa. The two following nutrient solutions were used (mg L^{-1}): Vegetative period: 120 N, 42 P, 120 K, 108 Ca, 32 Mg and 60 S; Reproductive period: 150 N, 105 P, 200 K, 133 Ca, 50 Mg and 84 S. In both mineral solutions, micronutrients were supplied as a cocktail fertilizer (1.82% B, 1.82% Cu, 7.26% Fe, 1.82% Mn, 0.73% Zn and 0.36% Mo) at rate of 25 mg L^{-1}. The average electrical conductivity (EC) and pH of nutrient solutions were 2.2 dS m^{-1} and 6.5, respectively.

Plants were grown vertically by plastic strips and supported by horizontal wires, which were positioned at 3 m height. Plants were pruned at the beginning of the growth period to grow only one main haulm. This plant material did not produce secondary haulms.

Photosynthetic parameters

Photosynthesis was evaluated at 55 DAT using a portable infrared gas analyzer (IRGA, LI 6400XT, LI-COR; Lincoln, Nebraska, USA). 55 DAT represents a representative period of plenty metabolic activity of the plant (vegetative and reproductive active growth). The photosynthesis was measured in the third fully expanded leaf between 8:30 and 11 am in a completely sunny day, considering three replications. The photosynthetic parameters recorded were net assimilation rate (A, μmol CO_2 m^{-2} s^{-1}), stomatal conductance (g_s, mol $m^{-2}s^{-1}$), transpiration rate (E, mmol H_2O $m^{-2}s^{-1}$), internal CO_2 leaf concentration (Ci, μmol CO_2 mol^{-1} air), apparent electron transport rate (ETR, μmol electrons m^{-2} s^{-1}) as a parameter of chlorophyll *a* fluorescence, A/E and A/Ci. A/E determined the water use efficiency [WUE, μmol CO_2 (mol $H_2O)^{-1}$] and A/Ci the apparent carboxylation efficiency (μmol CO_2 mol^{-1}), determined by the relationship between the CO_2 assimilation rate and the intercellular CO_2 concentration. Photosynthesis parameters were obtained under a constant light of 500 μmol m^{-2} s^{-1} in the chamber for all the treatments. This higher value of light supply was used to ensure a greater photosynthetic response and the same light quality and intensity for all evaluated plants. Also, an ambient value of approximately 380 μmol mol^{-1} of air was considered, as a reference for the CO_2 concentration; according to Pimentel (2011), this value may represent the CO_2 level in a protected condition, when the environment is more stable and the increase in the atmospheric concentration of carbonic gas is lower than in the open field.

Agronomic parameters

The same leaves used to analyze photosynthesis were collected, in a total of five leaves per plot, sent to laboratory, rinsed with tap water, dipped in a phosphate free detergent solution (0.1% w/v), and rinsed three times with deionized water. Leaves were dried at 68ºC until they reached a constant weight and analyzed for N, P, K, Ca, Mg and S contents. At the end of the growth period (124 DAT), two plants of each plot were collected to measure the internodes length (IL). Later, the plants were dried at 68ºC to determine the dry weight.

Fruits from each plot were harvested three to four times per week, counted, weighted, and classified to determine the commercial yield and curved fruit yield. Well-shaped straight fruits, without injury and size between 9 and 11 cm length were classified as commercial fruits. Curved fruits were those with a gradient greater than 10% (maximum height of the arc 1 cm per 10 cm length).

Postharvest quality

Fruit quality was evaluated by titratable acidity (TA) and total soluble solids (TSS) at harvest and 20 days postharvest. TA was determined through 10 g of aliquot pulp diluted in 100 mL distilled water with 0.1N NaOH until the solution reached a pH of 8.1, according to the method of AOAC (2010). TSS was measured in a digital refractometer (Atago Co., Tokyo, Japan) using an aliquot of cucumber pulp. In addition, mass loss of cucumber fruit was evaluated every two days during 20 days after harvest. During this period, the fruits were kept in open plastic boxes placed inside a chamber at 10°C and 90% relative humidity.

Statistical analysis

For the statistics of the results obtained in the different evaluations, homogeneity and variance analyses were made by the Shapiro-Wilk and the F tests, respectively. The means were compared by Tukey test ($P<0.05$) using SAS/STAT® program (SAS Institute, Cary, NC). Data were compared in joint analysis.

RESULTS AND DISCUSSION

Close to Capricorn tropic, southeastern Brazil is considered a tropical climate region, thus it is not

Table 1. Effects of LED interligthing and grafting on CO_2 net assimilation rate (*A*, µmol CO_2 m^{-2} s^{-1}), stomatal conductance (G_s, mol H_2O $m^{-2}s^{-1}$), internal CO_2 leaf concentration (*Ci*, µmol CO_2 mol^{-1}), transpiration rate (*E*, mmol H_2O $m^{-2}s^{-1}$), water use efficiency (*WUE*, (*A/E*) µmol CO_2 (mol H_2O^{-1}), apparent carboxylation efficiency (*A/Ci*) and electron transport rate (*ETR*, µmol electrons $m^{-2}s^{-1}$) in mini-cucumber plants cultivated in greenhouse. Piracicaba, ESALQ, 2015.

Main effects	*A*	G_s	*Ci*	*E*	*WUE*	*A/Ci*	*ETR*
Interlighting (I)							
Control	9.22 b[z]	0.395 a	352.51 a	8.703 a	1.018 b	0.027 a	59.04 a
LED	12.93 a	0.423 a	342.96 a	6.412 b	2.059 a	0.038 a	65.84 a
Grafting (G)							
Ungrafted	5.36 b	0.405 a	372.12 a	7.045 a	0.820 b	0.015 b	51.85 b
Keeper	13.37 a	0.428 a	330.86 b	8.190 a	1.747 a	0.041 a	64.56 a
Shelper	14.48 a	0.395 a	340.23 ab	7.438 a	2.048 a	0.043 a	70.92 a
Interaction effects							
I*G	ns	ns	ns	ns	ns	ns	ns
CV (%)	27.4	15.35	6.36	13.16	35.92	35.17	12.16

[z]Means followed by the same letter in the column did not differ from each other by Tukey range test at P≤0.05.

Table 2. Effects of LED interlighting and grafting on commercial and curved fruit (not marketable) yield, in three different periods after transplant, 27 to 55 days after transplant (DAT), 56 to 107 DAT, and 27 to 107 DAT, in mini-cucumber plants cultivated in greenhouse. Piracicaba, ESALQ, 2015.

Main effects	Commercial yield (kg $plant^{-1}$)			Curved fruit yield (kg $plant^{-1}$)		
	27-55	**56-107**	**27-107**	**27-55**	**56-107**	**27-107**
Interlighting (I)						
Control	0.67 b[z]	3.05 b	3.72 b	0.11 a	1.08 a	1.20 a
LED	0.78 a	3.43 a	4.21 a	0.11 a	0.84 b	0.95 b
Grafting (G)						
Ungrafted	0.63 b	3.41 a	4.04 a	0.11 a	0.96 a	1.07 a
Keeper	0.77 a	3.13 a	3.90 a	0.11 a	0.96 a	1.07 a
Shelper	0.78 a	3.17 a	3.95 a	0.11 a	0.96 a	1.08 a
Interaction effects						
I*G	ns	ns	ns	ns	ns	ns
CV (%)	9.49	7.34	7.18	25.72	6.04	4.16

[z]Means followed by the same letter in the column did not differ from each other by Tukey range test at P≤0.05.

a light-limited region during most part of the year. However, during the winter season, the location of our study (Piracicaba, SP) has about 11 hours of photoperiod and moderate daily light integral (DLI); therefore, this period is not suitable for achieving high cucumber fruit yields, what justifies the use of supplemental lighting during this season. Moreover, interlighting or intra-canopy illumination technology can help reducing the impact of self-shading in high-wire vegetable growth (Joshi *et al*., 2019). The use of light supplementation in the tropics is not common, but the results of this research suggest that an increment in yield can be expected when adding light to high-wire mini-cucumber plants.

Plants under LED interlighting treatment showed higher CO_2 net assimilation rate (*A*) at 55 DAT than plants grown under natural light in the greenhouse (Table 1). The LEDs did not influence the stomatal conductance (G_s), internal CO_2 leaf concentration (*Ci*), electron transport rate (*ETR*) and apparent carboxylation efficiency (*A/Ci*) (Table 1). The water use efficiency (*WUE*) and the transpiration rate (E) also increased in plants under LED interlighting. Since the water use efficiency (*WUE*) is the ratio between the CO_2 net assimilation rate (*A*) and the transpiration rate (E), plants illuminated with LEDs used water more efficiently than the control (without LED) because photosynthesis was 1.4 times higher and the transpiration rate (*E*) was 26.3% lower with LEDs as compared to the control. Plants grafted onto both rootstocks showed higher CO_2 net assimilation rate (*A*), water use efficiency (*WUE*), apparent carboxylation efficiency (*A/Ci*) and electron transport rate (*ETR*) than ungrafted plants of snack cucumber (Table 1). Plants grafted on Keeper rootstock had the lowest internal CO_2 leaf concentration (*Ci*).

The increase of CO_2 net assimilation rate (*A*), even in a condition with more daylight hours compared to temperate climate countries, may be firstly explained by the direct effect of the increment in the photosynthetic photon flux by the LEDs. Plants treated with supplemental lighting received higher light intensity than control plants. Secondly, the ratio between red (662 nm) and blue (452 nm) LEDs of 80%/20%, improved light quality favoring the CO_2 assimilation. The red light is the main wavelength for chlorophyll excitation and has a direct impact on plant growth. Additionally, red light also stimulates chlorophyll synthesis and chloroplast development (Olle & Viršillė, 2013). Blue light is involved in many processes such as stomatal opening, phototropism, biomass production, photomorphogenesis and photosynthetic capacity (Hogewoning *et al.*, 2010). According to the last authors an adequate red:blue light combination is required for enhancing the photosynthetic machinery. The absence of blue light results on dysfunctional photosynthetic operation. Leaves grown at an irradiance containing less than 15% blue light may lead to reductions in CO_2 net assimilation rate (*A*).

Although our results did not show a significant increment in stomatal conductance (*Gs*), a previous study with bell peppers in Jordan Valley showed a substantial increase in this photosynthetic parameter due to intra-canopy illumination (Joshi *et al.*, 2019). Perhaps the LED spectra had little blue light rate (20%) to substantially increase the stomatal conductance (*Gs*). An increase of apparent carboxylation efficiency was also expected (*A/Ci*) and electron transport rate (*ETR*) (Pettersen *et al.*, 2010). However, these parameters were not significantly influenced by the LEDs. The interlighting effects on photosynthetic parameters could have been more evident in more restricted light circumstances, as example of high latitude countries during winter season.

It is known that grafting can improve the net photosynthesis of cucumber plants (Rouphael *et al.*, 2012) and photosynthetic parameters related to this metabolic change as *A/Ci* and *ETR*, and our results agree with that. ETR is an indicator of the photosystem II (PSII) operating efficiency and electron flux through PSII reaction centers. Therefore, it has direct connection with CO_2 assimilation process.

As a result of this increase on photosynthetic metabolism, grafted plants had enhanced 22 to 24% the early yield (27 to 55 DAT). However, ungrafted plants broke even the fruit yield in the total plant cycle length (Table 2). A substantial increase in yield was reported by Farhadi & Malek (2015) on cucumber grafted plants. Grafting may affect uptake, synthesis and translocation of water, nutrients, and plant hormones. For Hu *et al.* (2006) and Zhu *et al.* (2006), increased nutrient uptake in grafted plants increases photosynthesis, yield and sometimes fruit quality of cucumber. Zhou *et al.* (2009) reported in grafted cucumber plants that cytokinin was directly related to synthesis of chlorophyll resulting in an increase of ribulose-1,5-bisphospate (Rubisco) enzyme and photosynthetic performance. It is known that cytokinin controls chlorophyll biosynthesis (Cortleven *et al.*, 2016). After grafting, plant vasculature needs to be connected and the healing process seems to be strongly affected by cytokinin and auxin, as they promote cell proliferation (Melnyk *et al.*, 2015). Several studies report variable effects on yield of grafted vegetables with different rootstocks genotypes. Environmental conditions, specific interaction and compatibility between the scion and the rootstocks may be responsible for this growth response, since there is not a trend that all grafted plants are necessarily more vigorous and accumulate higher biomass (Lee *et al.*, 2010; Huang *et*

Table 3. Effects of LED interlighting and grafting on the number of fruits per plant, in three different periods after transplant, 27 to 55 days after transplant (DAT), 56 to 107 DAT, and 27 to 107 DAT, in mini-cucumber plants cultivated in greenhouse. Piracicaba, ESALQ, 2015.

Main effects	Commercial yield (fruits $plant^{-1}$)		
	27-55	**56-107**	**27-107**
Interlighting (I)			
Control	15.59 b[z]	57.71 b	73.30 b
LED	18.58 a	62.34 a	80.92 a
Grafting (G)			
Ungrafted	14.33 b	62.65 a	76.98 a
Keeper	18.52 a	58.15 a	76.67 a
Shelper	18.40 a	59.28 a	77.68 a
Interaction effects			
I*G	ns	ns	ns
CV (%)	6.2	5.87	5.48

[z]Means followed by the same letter in the column did not differ from each other by Tukey range test at P≤0.05.

Table 4. Internode length (IL) and biomass dry weight of grafted and ungrafted cucumber plants cultivated in greenhouse with LED interlighting and without light supplementation (control). Piracicaba, ESALQ, 2015.

Main effects	IL (cm)	Biomass dry weight (g)
Interlighting (I)		
Control	8.92 a[z]	64.84 a
LED	8.60 a	65.76 a
Grafting (G)		
Ungrafted	10.55 a	67.53 a
Keeper	7.92 b	62.57 a
Shelper	7.82 b	65.80 a
Interaction effects		
I*G	ns	ns
CV (%)	10.3	13.4

[z]Means followed by the same letter in the column did not differ from each other by Tukey range test at P≤0.05.

al., 2013).

The early yield of cucumber plants (27 to 55 DAT) increased 16.4% with LED interlighting compared to control (Table 2), suggesting greater precocity in cucumber production due to light supplementation. The yield in the period between 56 and 107 DAT and total yield (27 to 107 DAT) also were 12.4% and 13% higher with intra-canopy light than control, respectively. This greater yield was due to the higher number of fruits produced by plant (Table 3). LED interlighting also improved cucumber fruit quality by reducing curved fruit yield (Table 2). According to Kanahama & Saito (1988), bent cucumber fruits are developed when translocation of the photosynthate to the fruit is limited. This condition is affected by shading and defoliation among other factors. Thus, as the interlighting treatment reduced self-shading of cucumber plants, reduced total bent fruit yield, and increased total commercial yield, this technology can also contribute to enhance cucumber fruit quality in moderate daily light integral conditions. Shape, uniformity, defects, and color are important quality attributes to commercial sell of cucumber fruits.

Our results of fruit yield are remarkably similar to those obtained by Hao *et al.* (2012), who observed that LED interlighting increased cucumber fruit yield in early production period. For Marcelis (1993), the early yield of cucumber plants grown under intra-canopy lighting system is resulted from a higher rate of individual fruit growth associated with a greater number of fruits growing at the same time on the plants. Our results indicate that this yield increment is due to the increased absorbed radiation in the lower part of the canopy. According to Pettersen *et al.* (2010), as LED interlighting technology alters the spectral distribution in the canopy by enhancing the red and blue intensity, it increases photosynthetic rates and consequently the assimilate supply to the fruits. The increased yield (13% in southeastern Brazil conditions) and reduced curved fruit observed considering all mini-cucumber cycle may be interesting for the growers in tropical regions.

Scion growth could be influenced by hormones from the rootstock that could alter shoot physiology, indicating that roots can be involved in control of stem elongation (Pérez-Alfocea *et al.*, 2010) what was also observed in this experiment by the reduction of internode length by grafting (Table 4). Light also interferes in stem length. Internode length may be reduced with interlighting (Hao & Papadopoulos, 2005), but the climatic conditions on this study might have reduced the effect of LEDs on the observed plant growth pattern; therefore, it was not possible to observe any differences between control and LED environments (Table 4). Biomass accumulation was not affected neither by intra-canopy illumination nor grafting (Table 4), despite the greater CO_2 net assimilation rate (*A*) (Table 1).

LED interlighting was not able to decrease the loss of mass (LM) (Table 5). Neither titratable acidity (TA) at harvest nor total soluble solids (TSS) at harvest and 20 days after harvest were affected by LED interlighting in our study (Table 5). However, plants grafted onto “Keeper” rootstock produced fruits with higher titratable acidity (TA) at harvest compared to “Shelper” rootstock, but it did not differ from the ungrafted treatment (Table 5). There was an interaction (p=0.0021) between LED interlighting and grafting to fruit titratable acidity (TA) at 20 days after harvest (Table 4). Snack cucumber fruits from plants grafted in “Keeper” rootstock showed higher titratable acidity (TA) at 20 days after harvest in the treatment with LED interlighting rather than in the control environment

Table 5. Titratable acidity (TA) and total soluble solids (TSS) at harvest (0) and 20 days after harvest, and loss of mass (LM) 20 days after harvest of cucumber fruits from grafted and ungrafted plants cultivated in greenhouse with LED interlighting and without light supplementation (control). Piracicaba, ESALQ, 2015.

Main effects	TA (%)		TSS (ºBrix)		LM (%)
	0	20	0	20	20
Interlighting (I)					
Control	1.40 a[z]	2.18	2.42 a	2.76 a	23.18 a
LED	1.43 a	2.36	2.54 a	2.78 a	23.49 a
Grafting (G)					
Ungrafted	1.42 ab	2.30	2.56 a	2.73 a	25.82 a
Keeper	1.50 a	2.31	2.47 a	2.72 a	22.95 a
Shelper	1.32 b	2.21	2.39 a	2.84 a	21.24 a
Interaction effects					
I*G	ns	*	ns	ns	ns
CV (%)	6.78	7.62	12.42	11.40	14.74

[z]Means followed by the same letter in the column did not differ from each other by Tukey range test at P≤0.05. *Significant at P≤0.05.

Table 6. Interaction between the treatments with LED interlighting and grafting for titratable acidity (TA) of cucumber fruits at 20 days after harvest. Piracicaba, ESALQ, 2015.

Main effects		Interlighting	
		Control	LED
Grafting	Ungrafted	2.42 aB[z]	2.18 aB
	Keeper	2.02 bB	2.60 aA
	Shelper	2.10 bB	2.31 aB

[z]Means followed by the same capital letters in the lines and small letters in the columns did not differ from each other by Tukey range test at P≤0.5.

(Table 6). Grafting did not affect total soluble solids (TSS) and loss of mass (LM) (Table 5).

Cucumber fruits are extremely sensitive to water loss, main factor for deterioration, dehydration, and poor visual quality (Hochmuth, 2012). More than 21% of mass was lost at 20 days after harvest, which means around 1% of daily weight loss (Table 5). These results in cucumber fruits are similar with those found by dos Reis *et al.* (2006) who reported 9% of mass loss after 8 days of storage also on cold chamber. However, neither grafting nor interlighting was able to decrease fruit loss of mass (Table 4). Hovi & Tahvonen (2008) also reported that cucumber fruits grown with interlighting LED did not extend long shelf life either.

The correct selection of a rootstock is fundamental to achieve great cucumber fruit quality (Fallik & Ilic, 2014). Huang *et al.* (2009) found that grafted cucumber plants in Fig leaf Gourd and Chaofeng Kangshengwang had fruits with higher titratable acidity than other rootstocks. Liu *et al.* (2015), comparing cucumber rootstocks did not find benefits of grafting on total soluble solids. Discrepancies between beneficial and detrimental effects on the scion fruit vegetable quality attributes are common, but it is agreed that the rootstock/scion combination and the environment conditions strongly interfere in fruit flavor (Davis *et al.*, 2008).

In summary, LED interlighting had a positive effect on photosynthesis, commercial early yield, and total yield of snack cucumber. Postharvest benefit due to LEDs was not verified. Grafting increased photosynthetic parameters, water use efficiency (WUE) and early yield, but it did not affect the total yield. In conclusion, supplemental LED interlighting technology may be used to enhance the yield of snack cucumber during winter season.

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REFERENCES

AOAC. 2010. Official methods of analysis of the Association of Analytical Chemists International. Association of Official Agricultural Chemistry. 18th ed. Washington.

CORTLEVEN, A; MARG, I; YAMBURENKO, MV; SCHLICKE, H; HILL, K; GRIMM, B; SCHALLER, GE; SCHMÜLLING T.. 2016. Cytokinin regulates etioplast-chloroplast transition through activation of chloroplast-related genes. *Plant Physiology* 172: 464-478.

DAVIS, A; PERKINS, P; HASSELL, R; LEVI, A; KING SR; ZHANG X. 2008. Grafting effects of vegetable quality. *HortScience* 43:1670-1672.

FALLIK, E; ILIC Z. 2014. Grafted vegetables – the influence of rootstock and scion on postharvest quality. *Folia Horticulturae* 26: 79-90.

FAN, XX; XU, ZG; LIU, XY; TANG, CM; WANG, LW; HAN, XI. 2013. Effects of light intensity on the growth and leaf development of young tomato plants grown under a combination of red and blue light. *Scientia Horticulturae* 153: 50-55.

FARHADI, A; MALEK, S. 2015. Evaluation of graft compatibility and organoleptic traits of greenhouse cucumber seedlings grafted on different rootstocks. *Acta Horticulturae* 1086: 219-224.

HAO, X; LITTLE, C; KHOSLA, S. 2012. LED inter-lighting in year-round greenhouse mini-cucumber production. *Acta Horticulturae* 956: 335-340.

HAO, X; PAPADOPOULOS, A. 2005. Supplemental lighting in high-wire cucumber production on raised-throughs. *Acta Horticulturae* 691: 209-216.

HERNÁNDEZ, R; KUBOTA. C. 2014. Growth and morphological response of cucumber seedlings to supplemental red and blue photon flux ratios under varied solar dailylight integrals. *Scientia Horticulturae* 173: 92-99.

HOCHMUTH, RC. 2012. *Greenhouse cucumber production – Florida. Greenhouse vegetable Handbook* 3. IFAS Extension, Florida. HS790. Available <http://edis.ifas.ufl.edu/cv268>. Accessed September 5, 2017.

HOGEWONING, SW; TROUWBORST, G; MALJAARS, P; POORTER, H; IEPEREN, W.; HARBINSON, J. 2010. Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light. *Journal of Experimental Botany* 61: 3107-3117.

HOVI, T; TAHVONEN, R. 2008. Effects of interlighting on yield and external fruit quality in year-round cultivated cucumber. *Scientia Horticulturae* 116: 152-161.

HU, CM; ZHU, YL; YANG, LF; CHEN, SF; HUANG, YM. 2006. Comparison of photosynthetic characteristics of grafted and own-root seedling of cucumber under low temperature circumstances. *Acta Botanica Boreali-Occidentalia Sinica* 26: 247-253.

HUANG, Y; BIE, Z; LIU, P; NIU, M; ZHEN, A; LIU, Z; LEI, B; GU, D; LU, C; WANG, B. 2013. Reciprocal grafting between cucumber and pumpkin demonstrates the roles of the rootstock in the determination of cucumber salt tolerance and sodium accumulation. *Scientia Horticulturae* 149: 47-54.

HUANG, Y; TANG, R; CAO, Q; BIE, Z. 2009. Improving the fruit yield and quality of cucumber by grafting onto the salt tolerant rootstock under NaCl stress. *Scientia Horticulturae*. 122: 26-31.

JOSHI, NC; RATNERA, K; EIDELMANA, O; BEDNARCZYKA, D; ZURA, N; MANYA, Y; SHAHAKA, Y; AVIV-SHARONB, E; ACHIAMC, M; GILADC, Z; CHARUVI, D. 2019. Effects of daytime intra-canopy LED illumination on photosynthesis and productivity of bell pepper grown in protected cultivation. *Scientia Horticulturae* 250: 81-88.

KANAHAMA, K; SAITO, T. 1988. Carbohydrate distribution and ^{14}C-photosynthates uptake in the curved fruits of cucumber. *Journal of the Japanese Society for Horticulturae Science* 57: 448-453.

LEE, JM; KUBOTA, C; TSAO, SJ; BIE, Z; HOYOS, P; MORRA, L; ODA, M. 2010. Current status of vegetable grafting: Diffusion, grafting techniques, automation. *Scientia Horticulturae* 127: 93-105.

LIU, B; REN, J; YAN ZHANG, Y; AN, J; CHEN, M; CHEN, H; XU, C; REN, H. 2015. A new grafted rootstock against root-knot nematode for cucumber, melon, and watermelon. *Agronomy Sustainable Revision* 35: 251-259.

MARCELIS, LFM. 1993. Fruit growth and biomass allocation to the fruits in cucumber. 2. Effect of irradiance. *Scientia Horticulturae* 54: 123-130.

MASSA, GD; KIM, HH; WHEELER, RM; MITCHELL, CA. 2008. Plant productivity in response to LED lighthing. *HortScience* 43: 1951-1956.

MELNYK, CW; SCHUSTER, C; LEYSER, O; MEYEROWITZ, EM. 2015. A developmental framework for graft formation and vascular reconnection in *Arabidopsis thaliana*. *Current Biology* 25: 1306-1318.

MENARD, C; HOVI, T; GOSSELIN, A; DORAIS, M. 2006. Developmental and physiological responses of tomato and cucumber to additional blue light. *Acta Horticulturae* 711: 291-296.

MITCHELL, CA; BOTH, AJ; BOURGET, CM; BURR, JF; KUBOTA, C; LOPEZ, RG; MORROW, RC; RUNKLE, ES. 2012. LEDs: The future of greenhouse lighting! *Chronica Horticulturae* 52: 6-12.

OLLE, M; VIRŠILLĖ, A. 2013. The effects of light-emitting diode lighting on greenhouse plant growth and quality. *Agricultural and Food Science* 22: 223-234.

PARK, Y; RUNKLE, ES. 2017. Far-red radiation promotes growth of seedlings by increasing leaf expansion and whole-plant net assimilation. *Environmental and Experimental Botany* 136: 41-49.

PÉREZ-ALFOCEA, F; ALBACETE, A. GHANEM, ME; DODD, IC. 2010. Hormonal regulation of source-sink relations to maintain crop productivity under salinity: a case study of root-to-shoot signalling in tomato. *Functional Plant Biology* 37: 592-603.

PETTERSEN, RI; TORRE, S; GISLERØD, HR. 2010. Effects of intracanopy lighting on photosynthetic characteristics in cucumber. *Scientia Horticulturae* 125: 77-81.

PIMENTEL, C. 2011. Metabolismo de carbono de plantas cultivadas e o aumento de CO_2 e de O_3 atmosférico: situação e previsões. Bragantia. 70: 1-12.

REIS, KC; ELIAS, HH; LIMA, LC; SILVA, JD; PEREIRA, J. 2006. Pepino japonês (*Cucumis* sativus L.) submetido ao tratamento com fécula de mandioca. *Ciência e Agrotecnologia* 30: 487-493.

ROUPHAEL, Y; CARDARELLI, M; REA, E; COLLA, G. 2012. Improving melon and cucumber photosynthetic activity, mineral composition, and growth performance under salinity stress by grafting onto Cucurbita hybrid rootstocks. *Photosynthetica* 50: 180-188.

TERASHIMA, I; FUJITA, T; INOUE, T; CHOW, WS; OGUCHI, R. 2009. Green light drives leaf photosynthesis more efficiently than red light in strong white light: revisiting the enigmatic question of why leaves are green. *Plant and Cell Physiology* 50: 684-697.

ZHOU, Y; ZHOU, J; HUANG, L; DING, X; SHI, K; YU, J. 2009. Grafting of *Cucumis sativus* onto *Cucurbita ficifolia* leads to improved plant growth, increased light utilization and reduced accumulation of reactive oxygen species in chilled plants. *Journal of Plant Research* 122: 529-540.

ZHU, J; BIE, ZL; HUANG, Y; HAN, XY. 2006. Effects of different grafting methods on the grafting work efficiency and growth of cucumber seedlings. *China Vegetation* 9: 24-25.