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 ($\mu$mol CO$_2$ m$^{-2}$ s$^{-1}$), apparent carboxylation efficiency ($\mu$mol CO$_2$ mol air$^{-1}$) and apparent electron transport rate ($\mu$mol 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.
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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 m² 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), totaling 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 controller-MRI, Hidrosense, Jundiaí, 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 ($g_s$, mmol m$^{-2}$ s$^{-1}$), transpiration rate ($E$, mmol H$_2$O 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$_2$O)] 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 68°C 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 68°C 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
The responses of photosynthesis, fruit yield and quality of mini-cucumber to LED-interlighting and grafting

Table 1. Effects of LED interlighting and grafting on CO\(_2\) net assimilation rate (\(A\), µmol CO\(_2\) m\(^{-2}\)s\(^{-1}\)), stomatal conductance (\(G_s\), mol H\(_2\)O m\(^{-2}\)s\(^{-1}\)), internal CO\(_2\) leaf concentration (\(Ci\), µmol CO\(_2\) mol\(^{-1}\)), transpiration rate (\(E\), mmol H\(_2\)O m\(^{-2}\)s\(^{-1}\)), water use efficiency (\(WUE\), (A/E) µmol CO\(_2\) (mol H\(_2\)O)), 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.

| Interaction effects | A | \(G_s\) | \(Ci\) | E | WUE | A/Ci | ETR |
|---------------------|---|--------|--------|---|------|------|------|
| Control             | 9.22 b\(^\dagger\) | 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              |    |        |        |    |      |      |      |
| CV (%)              | 27.4 | 15.35 | 6.36 | 13.16 | 35.92 | 35.17 | 12.16 |

\(^\dagger\)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\(^{-1}\)) |
|--------------|-------------------------------------|--------------------------------------|
| Interlighting (I) | 27-55 | 56-107 | 27-107 | 27-55 | 56-107 | 27-107 |
| Control      | 0.67 b\(^\dagger\) | 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       |    |        |        |    |      |      |      |
| CV (%)       | 9.49 | 7.34 | 7.18 | 25.72 | 6.04 | 4.16 |

\(^\dagger\)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 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 & Viršillé, 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 CO₂ net assimilation rate ($A$).

Although our results did not show a significant increment in stomatal conductance ($G_s$), a previous study with bell peppers in Jordan Valley showed a substantial increase in this photosynthetic parameter due to intracanopy illumination (Joshi et al., 2019). Perhaps the LED spectra had little blue light rate (20%) to substantially increase the stomatal conductance ($G_s$).

An increase of apparent carboxylation efficiency was also expected ($A/C_i$) 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 $A/C_i$ 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 CO₂ 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-bisphosphate (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 al., 2016). After grafting, 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 $A/C_i$ and $ETR$ (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.

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### 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| 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   |

*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  | 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                   |

*Means followed by the same letter in the column did not differ from each other by Tukey range test at $P$≤0.05.
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 CO₂ net assimilation rate (4) (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 of cucumber fruits 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=0.002) 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 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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