Tomatoes Grown with Light-emitting Diodes or High-pressure Sodium Supplemental Lights have Similar Fruit-quality Attributes

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Abstract. Light-emitting diodes (LEDs) are an attractive alternative to high-pressure sodium (HPS) lamps for plant growth because of their energy-saving potential. However, the effects of supplementing broad-waveband solar light with narrow-waveband LED light on the sensory attributes of greenhouse-grown tomatoes (*Solanum lycopersicum*) are largely unknown. Three separate studies investigating the effect of supplemental light quantity and quality on physicochemical and organoleptic properties of greenhouse-grown tomato fruit were conducted over 4- or 5-month intervals during 2012 and 2013. Tomato cultivars Success, Komeett, and Rebelski were grown hydroponically within a high-wire trellising system in a glass-glazed greenhouse. Chromacity, Brix, titratable acidity, electrical conductivity (EC), and pH measurements of fruit extracts indicated plant response differences between lighting treatments. In sensory panels, tasters ranked tomatoes for color, acidity, and sweetness using an objective scale, whereas color, aroma, texture, sweetness, acidity, aftertaste, and overall approval were ranked using hedonic scales. By collecting both physicochemical as well as sensory data, this study was able to determine whether statistically significant physicochemical parameters of tomato fruit also reflected consumer perception of fruit quality. Sensory panels indicated that statistically significant physicochemical differences were not noticeable to tasters and that tasters engaged in blind testing could not discern between tomatoes from different supplemental lighting treatments or unsupplemented controls. Growers interested in reducing supplemental lighting energy consumption by using intracanopy LED (IC-LED) supplemental lighting need not be concerned that the quality of their tomato fruits will be negatively affected by narrow-band supplemental radiation at the intensities and wavelengths used in this study.

The negative reputation associated with the quality of off-season tomatoes has long been a subject of investigation (Stevens et al., 1977, 1979). It has been confirmed through sensory studies that consumers tend to be dissatisfied with tomatoes grown during the off-season (Kader et al., 1977; Watada and Aulenbach, 1979) and prefer vine-ripened tomatoes grown in the field during the summer compared with indoor-ripened fruits (Bisogni and Armbruster, 1966). Greenhouse tomatoes grown during the off-season in

sunny, warm regions are shipped at least 2300 km to consumers in the northern United States (Pirog and Van Pelt, 2002). Many of these tomatoes are harvested at the mature green stage and forced to ripen in transit or at their destination with ethylene gas. Ethylene ripening treatments, fluctuating storage temperatures, and physical damage all lead to a drastic reduction in postharvest fruit quality (Kader, 1986; Kader et al., 1977). To satisfy growing consumer demand for locally grown, fresh tomatoes during the off-season, greenhouse tomato growers in northern climates increasingly rely on supplemental lighting to compensate for the naturally low solar daily light integral (DLI), or the daily amount of photosynthetically active radiation (PAR) received by a plant, during winter months (Dorais et al., 1991; Korczynski et al., 2002). Greenhouse supplemental lighting is typically provided from overhead HPS (OH-HPS) lamps, emitting an orange-biased spectrum and producing large amounts of radiant waste heat. Some of the most efficient HPS lamps have an energy conversion efficiency of 1.70 $\mu\text{mol}\cdot\text{J}^{-1}$, which is commensurate with some of the most efficient LED arrays (1.66 $\mu\text{mol}\cdot\text{J}^{-1}$) presently available (Nelson and

Bugbee, 2014). However, the HPS fixtures most widely used by commercial growers have an electrical conversion efficiency of only 1.02 $\mu\text{mol}\cdot\text{J}^{-1}$. Because energy is the second largest indirect cost for greenhouse crop production (Frantz et al., 2010), there is a clear and present need for more efficient sources of supplemental lighting if high-quality produce is to be grown affordably in northern climates during the off-season.

Light-emitting diodes are becoming a viable alternative to OH-HPS supplementation because of their relatively high energy efficiency, low radiant heat, long life span, and ability to emit specific narrow wavebands of light (Morrow, 2008; Nelson and Bugbee, 2014). These attributes have enabled scientists to determine metabolic, morphological, and physiological plant responses to specific wavelengths of light. There is great interest in the potential to influence the phytochemical and flavor profile of various high-value crops including but not limited to arugula (*Eruca sativa*) (Mattson and Harwood, 2012), kale (*Brassica oleracea*) (Lefsrud et al., 2008), and lettuce (*Lactuca sativa*) (Li and Kubota, 2009; Lin et al., 2013; Samuoliene et al., 2012, 2013; Stutte et al., 2009; Zukauskas et al., 2011). Some studies with high-light-requiring crops such as cucumber (*Cucumis sativa*) and pepper (*Capsicum annum*) have been conducted to quantify crop yield when grown with IC-LEDs (Hao et al., 2012; Jokinen et al., 2012). However, little fruit quality-attribute work with LEDs has been done on a long duration, full grow-out of tomatoes.

Kowalczyk et al. (2012) compared tomatoes grown with OH-HPS supplemental lighting to those grown under overhead LED arrays and reported that tomatoes harvested from plants grown under either type of supplemental lighting were ranked sweeter and had a higher overall quality score compared with control fruits (grown only with ambient solar radiation). That study used overhead LED arrays that likely illuminated the upper portion of the high-wire crop canopy. Gomez et al. (2013) used vertical IC-LED towers that irradiated both foliage as well as developing fruit clusters throughout the canopy, showing that comparable yield can be achieved with IC-LED supplemental lighting using only a fraction the energy of OH-HPS supplemental lamps. With tomato fruit photosynthesis accounting for up to 15% of total photosynthate within the fruit (Hetherington et al., 1998), we hypothesized that incident light on tomato fruits from IC-LED supplemental lighting would alter fruit metabolism and the sensory quality of fruits. The objective of this study was to determine whether IC-LED supplemental lighting could affect perceived or measured quality attributes of greenhouse tomato fruits compared with OH-HPS or unsupplemented plants and determine how.

Materials and Methods

Plant material. Tomato varieties ‘Komeett’ (De Ruiter Seeds, Bergshenhoek,

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The Netherlands) (Expts. 1, 2, and 3), 'Rebelski' (De Ruiter Seeds) (Expt. 2), and 'Success' (De Ruiter Seeds) (Expt. 1) were grown hydroponically in a randomized block design using high-wire trellising in a glass-glazed greenhouse in West Lafayette, IN (40° N, 86° W). Expts. 1 and 3 were conducted under naturally decreasing DLI (summer to winter; 4 months in length), and Expt. 2 was conducted under naturally increasing DLI (winter to summer; 5 months in length), with supplemental lighting treatment locations rerandomized for each experiment. Daily fertigation used a commercial fertilizer (4.5N–14P–34K; CropKing, Lodi, OH) mix with irrigation intervals adjusted to maintain a 30% leaching fraction. Tomato plants were grown either with natural solar radiation only (control), natural solar radiation plus supplemental lighting from 600-W OH-HPS lamps (PL Lighting Systems, Beamsville, ON), or natural solar radiation plus supplemental light from IC-LED towers (ORBITEC, Madison, WI). The IC-LED towers emitted red (peak wavelength = 627 nm) and blue (peak wavelength = 450 nm) light with a 95:5 red:blue ratio. Global photosynthetic photon flux (*PPF*) of the IC-LED towers was adjusted equivalent to that of the OH-HPS treatment in the vertical profile below HPS lamps using a line quantum meter (QMSW-SS; Apogee Instruments, Inc., Logan, UT), correcting for yield photon flux with a spectroradiometer (EPP-2000; StellarNet Inc., Tampa, FL). Supplemental DLI was adjusted monthly based on latitudinal outdoor data (Korczynski et al., 2002) reduced by 50% to account for attenuation by greenhouse glass and infrastructure. Total DLI (solar + supplemental light) was therefore relatively constant throughout each experiment with a target total DLI of 25 mol·m⁻²·d⁻¹, which is adequate for tomato production (Dorais, 2003; Jones, 2008; Moe et al., 2006). Table 3 details the monthly supplemental DLIs used in these studies. Treatments were separated by white polyethylene curtains between rows that were deployed only during supplemental lighting periods, thereby allowing maximal solar radiation to reach all sections of the greenhouse while preventing light pollution across treatments. Plants were leaned and lowered to maintain constant plant height as well as harvested and pruned using practices standard in the industry. Data collected during the experimental period for greenhouse ambient DLI and greenhouse ambient temperature are presented in Figs. 1 and 2, respectively.

Physicochemical testing. Tomato fruits from ripening clusters were sorted based on ripeness stage. Samples were collected over 4 weeks and harvest time was determined to be nonsignificant. Stage 5 tomatoes (>60% of fruit is red) (USDA Tomato Ripeness Classification) were labeled with a two-digit identifier code corresponding to the provenance of the fruit (light treatment, block, and plant number), and allowed to ripen fully (Stage 6; >90% red) at room temperature (≈23 °C). After 2 d, tomatoes that had not ripened to Stage 6 were removed from bins to allow for homogeneity among sampled fruits.

Fig. 1. Ambient daily light integral (DLI) collected during the experimental period. Expt. 1 spanned from Aug. to Nov. 2012. Expt. 2 spanned from Jan. to May 2013. Expt. 3 spanned from Aug. to Nov. 2013.

Fig. 2. Greenhouse day and night ambient temperature collected during the experimental period. Expt. 1 spanned from Aug. to Nov. 2012. Expt. 2 spanned from Jan. to May 2013. Expt. 3 spanned from Aug. to Nov. 2013.

Fruits were analyzed for colorimetric attributes using a Chroma meter (CR-300; Konica Minolta, Ramsey, NJ) to confirm homogeneity as well as to quantify chromatic differences in fruits from each light treatment and are reported as L, a, b color spaces. Individual fruits were then homogenized for 30 s in

a blender (CPB 300 SmartPower; Cuisinart, Stamford, CT), and 50-mL aliquots of homogenate were immediately placed in a –20 °C freezer for future analysis. Frozen samples were thawed at room temperature, rehomogenized with a vortex mixer for 10 s and the homogenate strained through

Miracloth® (22- to 25- μ m pore size; EMD Millipore, Billerica, MA) to filter the tomato serum. Brix of the serum was determined using a handheld digital refractometer (PAL-1; Atago U.S.A., Bellevue, WA). EC and pH of the serum were determined by diluting 5 mL of serum in 50 mL of deionized water using a pH/EC meter (9813-6; Hanna Instruments, Woonsocket, RI). Citric acid equivalent content was later determined titrimetrically using 0.1 M sodium hydroxide solution (Sigma Aldrich, St. Louis, MO) until pH 8.1 (Lees, 1968).

Organoleptic sensory panels. Fruits were labeled, harvested, and allowed to fully ripen as described for physicochemical testing. Before each test, panelists were given a tutorial about the features of the survey. In single-blind studies, panelists were presented with six wedges of tomato fruit (approximately $\approx$ one-eighth of a fruit by volume) within individual cups labeled with the fruit's two-digit identifier code. Using 5-point objective (indicating magnitude) and hedonic (indicating preference) scales, panelists were asked to rate each tomato sample for color, aroma, texture/mouthfeel, acidity, sweetness, aftertaste, and overall approval. For the objective scale, values from 1 to 5 represented "very low," "low," "neutral," "moderately high," and "very high," respectively. For the hedonic scale, values from 1 to 5 represented "dislike extremely," "dislike moderately," "neutral," "like moderately," and "like extremely," respectively. The fields "color," "texture," "aftertaste," and "overall approval" were not used in the objective scale because the magnitude of these attributes was difficult for panelists to define, as determined by preliminary studies. Fresh water and plain crackers were provided to the panelists for clearing their palate between samples. All personnel were required to take research ethics training for human subject research through the Collaborative Institution Training Initiative Program before conducting the sensory panels. These methods were adapted from Massa et al. (2010).

Statistics. For physicochemical data, the GLM (SS3) procedure was used to decide pooling of error variances. Final analysis of variance (ANOVA) and least squares mean separation tests were performed with MIXED. Organoleptic sensory panel data were arcsin transformed for statistical processing and are presented in back-transformed units. Means separation tests were performed with the Tukey-Kramer procedure at $\alpha = 0.05$. Cultivar effects were found to be nonsignificant and different cultivars were pooled within each experiment. Expts. 1 and 3 were not pooled together due to different cultivar combinations and uncommon ANOVA models as a result. All statistical analyses were performed using SAS (Package 9.2; SAS Institute, Cary, NC).

Results

Expt. 1. Brix was not significantly affected by supplemental light quality during the first summer-to-winter experiment (Table 1).

Titrateable acidity displayed a similar trend of nonsignificance among treatments. pH differences, however, were found to be highly significant among lighting treatments, with control and IC-LED fruit extracts having a similar pH (3.969 and 3.934, respectively), and OH-HPS fruits having the lowest pH (3.825). However, EC was highly significant among treatments, with control fruits having the highest EC value (0.548 mS $\cdot$ cm $^{-1}$). Individual chromatic characteristics were unaffected by supplemental lighting treatments, except for the a:b ratio. No cultivar effect was observed for any physicochemical parameter measured in this study.

Expt. 2. During a subsequent winter-to-summer experiment, tomatoes supplemented by OH-HPS lamps or IC-LED towers had higher average Brix values (3.995 or 3.911, respectively) than control fruits (3.778) (Table 1). Titrateable acidity also was highly significant with IC-LED supplemented tomatoes having the highest average value (4.345), but not statistically different from OH-HPS (4.126). pH was not statistically different among treatments regardless of differences measured in titrateable acidity. EC was significantly different among treatments at $P \leq 0.05$ with IC-LED fruits having the highest value. The two cultivars responded similarly to the supplemental lighting treatments.

Expt. 3. In a second summer-to-winter experiment, Brix values were significantly higher in the OH-HPS treatment (3.795) compared with controls (3.588) and IC-LED (3.619). No other physicochemical attributes were statistically different during this experiment.

Organoleptic sensory panels. None of the measured attributes of tomato fruit quality were statistically different among treatments (Table 2). Generally, most aspects were above 3, indicating that these aspects were above neutral and left tasters with a positive impression. The exceptions were that "acidity" and "sweetness" fell below 3 on the objective scale for both Expts. 1 and 2. Fruits grown under IC-LED supplemental lighting tended to average higher than other light treatments in those categories, but the differences were not significant at $P \leq 0.05$. "Overall approval" of tomato fruits was found to be similarly above neutral among treatments in Expts. 1 and 2.

Discussion

Contrary to our hypothesis, fruit quality was largely unaffected by direct, IC supplemental lighting. Developing tomato fruits have been shown to be photosynthetically active (Carrara et al., 2001), and $\approx$ 15% of the photosynthate present in developing tomato fruits can be derived from fruit-localized photosynthesis (Hetherington et al., 1998). However, fruit-localized photosynthesis is likely more important for seed development than for central metabolic processes, as seeds are a strong sink for photosynthate (Lytovchenko

et al., 2011). Fruits expressing the SIGLK2 transcription factor (U/U), allowing for the formation of dark-green fruit shoulders via the accumulation of chloroplasts, have markedly elevated levels of starch and sugar (Powell et al., 2012). However, that transcription factor is defective in most contemporary tomato varieties due to a point mutation that occurred during early breeding efforts, so it is likely that direct irradiation of ripening fruits with *PAR* has no effect on sugar content in fruits from modern cultivars. In other high-value greenhouse-grown crops, such as cucumber, supplementing the inner canopy with *PAR* from HPS lamps in addition to OH-HPS lighting increased plant yield (15%) and fruit-skin chlorophyll concentration, but did not affect fruit dry matter significantly compared with OH-HPS controls that received the same amount of total light (Hovi-Pekkanen and Tahvonen, 2008). Regardless of supplemental light treatment or supplemental lighting per se, fruits from our experiments that had significantly different sugar concentrations did not elicit changes in perceived sweetness as made evident by our sensory studies.

In a study monitoring tomato fruit quality from two shade treatments (57% and 34% reduction in solar *PPF*) to nonshaded plants, sugar, total dry matter, and lycopene remained the same in fruits from all treatments, but titrateable acidity increased while β -carotene decreased in fruits from heavily shaded plants (Klaring and Krumbein, 2012). Although not statistically significant, titrateable acidity was lowest in fruits gathered from control plants, but only during experimental periods going from high to low solar DLI (e.g., Expts. 1 and 3). Therefore, the naturally low levels of available sunlight during the summer-to-winter period may have slowed the turnover of titrateable acids (e.g., citric acid) in control fruits compared with fruits developed with supplemental lighting as previously shown by Gautier et al. (2008). This trend was not noticeable during the winter-to-summer experimental period (Expt. 2), perhaps due to the reduced need for supplemental lighting because of naturally increasing solar DLI. Gautier et al. (2004) used photosensitive films placed over ripening tomato fruit clusters to determine effects of specific wavelengths of light on fruit quality. Blocking infrared radiation reduced ascorbate and sugar content, whereas blocking *PAR* reduced carotenoid content for greenhouse-grown tomatoes. Similar to our results, that study found that different wavelengths of light did not greatly affect sugar or acid content in fruits. Lu et al. (2012) found that supplemental light from a fluorescent bulb had a profound impact on tomato fruit Brix compared with unsupplemented controls. Vastly different conclusions in regard to the importance of supplemental IC light on tomato fruit quality might be explained by complex genetic $\times$ environmental interactions that are poorly understood.

Fruit pH was significantly higher in control and IC-LED lighted tomatoes in Expt. 1

Table 1. Least squares means of physicochemical metrics of tomato fruit quality as a function of supplemental lighting treatment.

	Brix	Titrateable acidity (g·L ⁻¹)	pH	EC (mS·cm ⁻¹)	L	a	b	a/b
Expt. 1								
Control (n = 30)	3.88 a	4.41 a	3.97 A	0.55 A	38.38 a	28.36 a	20.73 a	1.37 a
OH-HPS (n = 29)	3.70 a	4.07 a	3.83 B	0.49 B	38.58 a	26.65 a	21.38 a	1.25 b
IC-LED (n = 32)	3.84 a	4.24 a	3.93 A	0.52 B	38.70 a	27.87 a	21.01 a	1.33 ab
Expt. 2								
Control (n = 50)	3.78 b	3.94 B	4.04 a	0.53 b	— ^z	—	—	—
OH-HPS (n = 50)	4.00 a	4.13 AB	4.04 a	0.53 b	—	—	—	—
IC-LED (n = 50)	3.91 ab	4.35 A	4.05 a	0.56 a	—	—	—	—
Expt. 3								
Control (n = 20)	3.59 b	4.14 a	4.18 a	0.53 a	38.86 a	29.56 a	23.03 a	1.29 a
OH-HPS (n = 26)	3.80 a	3.90 a	4.19 a	0.51 a	39.77 a	29.15 a	22.27 a	1.31 a
IC-LED (n = 23)	3.62 b	3.94 a	4.18 a	0.52 a	39.33 a	29.89 a	23.19 a	1.29 a

^zData not recorded.OH-HPS = overhead high-pressure sodium; IC-LED = intracanopy light-emitting diode. Lower case and capital letters represented significance at $P \leq 0.05$ or 0.01, respectively. Significance determined within individual experiments. Expt. 1 spanned from Aug. to Nov. 2012. Expt. 2 spanned from Jan. to May 2013. Expt. 3 spanned from Aug. to Nov. 2013.

Table 2. Organoleptic sensory panel scores on of tomatoes from summer-to-winter and winter-to-summer experiments.

	Color (H)	Aroma (O H) ^z	Texture (H)	Acidity (O H)	Sweetness (O H)	Aftertaste (H)	Overall approval (H)
Expt. 1 (n = 32)							
Control	4.01 a	3.27 a 3.48 a	3.57 a	2.94 a 3.53 a	2.82 A 3.30 a	3.45 a	3.41 a
OH-HPS	3.96 a	2.83 a 3.43 a	3.15 a	2.74 a 3.36 a	2.77 A 3.10 a	3.30 a	3.35 a
IC-LED	4.11 a	3.24 a 3.49 a	3.37 a	3.09 a 3.52 a	2.81 A 3.84 a	3.34 a	3.49 a
Expt. 2 (n = 64)							
Control	4.34 a	3.00 a 3.70 a	3.52 a	2.80 a 3.48 a	2.78 a 3.30 a	3.35 a	3.57 a
OH-HPS	4.13 a	2.95 a 3.44 a	3.76 a	2.99 a 3.43 a	2.82 a 3.31 a	3.48 a	3.51 a
IC-LED	4.00 a	3.01 a 3.58 a	3.74 a	3.23 a 3.45 a	2.73 a 3.21 a	3.45 a	3.49 a

^z(O | H) indicates the 5-point objective-scale rating followed by the 5-point hedonic-scale rating.Ratings are presented as back-transformed means and were not significant at $P \leq 0.05$ and are indicated by similar Tukey letters. OH-HPS = overhead high-pressure sodium; IC-LED = intracanopy light-emitting diode. Expt. 1 spanned from Aug. to Nov. 2012. Expt. 2 spanned from Jan. to May 2013. Expt. 3 spanned from Aug. to Nov. 2013.

Table 3. Supplemental daily light integral (DLI) used in each experiment.

	Feb.	Mar.	Apr.	May	June	Sept.	Oct.	Nov.	Dec.
Expt. 1						10.0	13.8	16.5	16.5
Expt. 2	10.8 ^z	13.0	8.8	3.8	3.8				
Expt. 3						10.0	13.8	18.8	18.8

^zValues represent supplemental DLI in mol·m⁻²·d⁻¹ with a target total DLI of 25 mol·m⁻²·d⁻¹. Expt. 1 spanned from Aug. to Nov. 2012. Expt. 2 spanned from Jan. to June 2013. Expt. 3 spanned from Aug. to Nov. 2013.

(Table 1). However, that effect was of no relevance to perceived sensory quality as pH is not always associated with titrateable acidity, an estimate of perceived acidity (Boulton, 1980). Colorimetric data were collected to ensure uniformity of ripeness for harvested fruits selected for physicochemical and sensory analysis. Significance was found among treatments in Expt. 1 but not in Expt. 3. The a:b ratio, which has been correlated with lycopene content (Brandt et al., 2006; Helyes and Pek, 2006), was highest in the control treatment during Expt. 1. As light can affect carotenoid content (Dumas et al., 2003), direct quantification of carotenoids is of great interest for future studies to better understand the effects of different lighting treatments on the nutritional value of tomato fruits.

Lack of differences in flavor attributes of tomato fruits grown under different lighting treatments indicated that plants supplemented with red + blue IC-LEDs yielded fruits that were acceptable and comparable in quality to those receiving supplemental lighting from OH-HPS, the industry standard for greenhouse lighting. The fact that neither supplemental lighting source affected fruit

quality compared with unsupplemented controls suggests that supplemental lighting per se, at least with the particular spectra used, had a neutral effect with respect to fruit quality. Human taste is a complex sensation that involves much more than just perception of sugars and acids. Volatile organic compounds (VOCs) found in tomato fruits interplay with sugars and acids to create unique flavors and aromas (Buttery, 1993). Although fruits in this study were not perceived to be different in sensory studies, the possibility to modify greenhouse-grown tomatoes still exists using different light quality from IC-LED. Colquhoun et al. (2013) found that VOCs in tomato fruits could be modified by the individual use of red, blue, or far-red LEDs in a postharvest scenario. It is reasonable to infer that the same impacts could be made with tomatoes on the vine through IC-LED. However, tasters in our study were not able to discern among fruits from different light treatments, possibly indicating either that the intensity of light reaching the fruits during critical stages in ripening was not high enough to elicit these metabolic changes, or that the spectrum was not optimized for

altering the flavor of fruits. Because these experiments focused on supplemental lighting in the greenhouse environment, the effect of solar radiation may have overcome any potential differences that the supplemental lighting regimes may have had, particularly in the winter-to-summer experiment (Expt. 2). Moreover, the physicochemical parameters measured in this study may not be as strongly influenced by visible light as was hypothesized. Other qualities of light, such as ultraviolet-B (280 to 315 nm), may better serve as a catalyst of change in fruit quality. Still, plants supplemented with IC light from LEDs were able to produce the same yield as tomato plants supplemented with HPS lamps, but IC-LED fixtures used significantly less energy (Gomez et al., 2013; Gomez and Mitchell, 2014).

Conclusion

This study demonstrated that greenhouse tomato fruit quality was unaffected by both the type of supplemental lighting as well as supplemental lighting per se. Physicochemical measurements indicated only slight variation among fruits grown under different lighting regimes, and these findings were supported by nonsignificant differences in sensory attributes. As commercial growers begin to leverage LED technology for supplemental lighting of horticultural crops, the resulting quality of the final product is of utmost economic importance. Supplemental IC-LED lighting at the intensities and wavelengths used in this study did not negatively

affect greenhouse tomato fruit quality and demonstrates a potential alternative for OH-HPS supplementation. Enhancement of flavor attributes of greenhouse tomatoes awaits other environmental or genetic interventions to give them the perceived quality of fresh, garden-grown fruits.

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