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Effect of LED lighting on winter production of tomatoes in Iceland

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Abstract

Growers in Iceland have adopted intensive use of supplementary lighting to maintain year-round production. Lighting methods with high-pressure vapour sodium lights (HPS) and light emitting diodes (LED) are quested that increase yield and profit margin. Tomato transplants (*Lycopersicon esculentum* Mill. cv. Completo) received either HPS lights or LEDs and in continuous production were different LED treatments (Hybrid toplighting with or without LED interlighting) with 370 µmol/m²/s tested during the winter. Tomatoes that received LED lights in young plant production were earlier ripe than tomatoes that received HPS lights, but total yield, marketable yield and their number was independent of the light treatment. Used kWh's were better transferred into yield with LED interlighting than without. It is recommended to grow tomato transplants under HPS lights. After transplanting a lighting system without LED interlights is recommended.

1. Introduction

The extremely low natural light level is the major limiting factor for winter glasshouse production in Iceland. Therefore, supplementary lighting is essential for winter glasshouse production. Traditionally, lamps are mounted above the canopy (top lighting), which entails that lower leaves are receiving limited light. By LED interlighting is it possible to diminish the strong light gradient along the canopy and provide adequate illumination along the canopy (Bantis et al. 2018; Paponov et al. 2020). The benefits from interlighting in contrast to top lighting alone have been confirmed with different vegetable crops. According to Davis and Burns (2016), interlighting in tomatoes has proved highly successful and it was reported a significant increase in yield. Furthermore, interlighting increased first class yield of cucumbers along with increasing fruit quality and decreased unmarketable yield, both in weight and number (Hovi-Pekkanen and Tahvonen 2008).

However, to ensure a good harvest a high quality of the seedlings is necessary. Light experiments with seedlings of vegetable plants under LED and HPS lights are very limited in recent years and results indicate that: Leaf thickness of tomato plants increased by 12% when grown under LED lights with a ratio of 88:12 red:blue light compared to plants grown under HPS lights (Dueck et al. 2012a). Tomato seedlings that were grown under LED lights were more compact and had a lower plant height, shorter stem and lower leaf area (Bergstrand et al. 2016). Therefore, the question is, if these effects of LEDs in young plant production, will affect yield of greenhouse grown tomatoes in continuous production over the high winter (with low levels of natural light) in Iceland and which light treatment is economically recommended.

2. Data, Methods and Approach

Tomatoes (*Lycopersicon esculentum* Mill. cv. Completo from De Ruiter) were grown in the research greenhouse of the Agricultural University of Iceland (Hveragerði, South Iceland). Young plants received either HPS lights or LEDs. In the beginning of November 2020 348 transplants were planted with a plant density of 2.5 tops/m^2 in rockwool plugs. Tomatoes were grown in continuous production under different LED treatments with 370 µmol/m^2/s from 05:00 - 21:00. The plants were lighted either with Hybrid top lighting (33% HPS + 33% LED) together with LED interlighting (33%) or with only Hybrid top lighting (66% HPS + 33% LED). Therefore, in total four different light treatments were tested (Tab. 1). Green power LED (deep red / white) were used. The manufacturer indicates no detailed data about the light spectrum. The experiment ended in the middle of March 2021.

Tab. 1: Light treatments

Light treatment	Young plant production	Continuous production
HPS, Hybrid+LED	HPS	Hybrid top lighting (33% HPS + 33% LED) + LED interlighting (33%)
LED, Hybrid+LED	LED	Hybrid top lighting (33% HPS + 33% LED) + LED interlighting (33%)
HPS, Hybrid	HPS	Hybrid top lighting (66% HPS + 33% LED)
LED, Hybrid	LED	Hybrid top lighting (66% HPS + 33% LED)

The temperature was 20°C / 17°C (day / night) until 12.12.2020. Thereafter, the temperature was increased to 22°C / 20°C (day / night). 800 ppm CO_2 was applied. Plants received standard nutrition through drip irrigation. Each light treatment was grown in three beds, representing three repetitions. Eight plants (= two rockwool plugs) in each repetition and light treatment were measured. Fruits of these eight plants were regularly harvested and classified. Substrate temperature was weekly measured at noon in 1-2 cm depth by a portable thermometer (TP1110-HD2307.0 Temperature meter, Nieuwkoop, Aalsmeer, The Netherlands) and leaf temperature in the middle of the plant by a portable infrared contact thermometer (BEAM infrared thermometer, TFA Dostmann GmbH & Co. KG, Wertheim-Reicholzheim, Germany) at two plants of each repetition in each light treatment. The energy usage was registered. At the end of the growth period an economic calculation was carried out.

SAS Version 9.4 was used for statistical evaluations. The yield was subjected to one-way analyses of variance with the significance of the means tested with a Tukey/Kramer HSD-test at $p = 0.05$ for the comparison of the means between light treatments. A two factor analysis of variance with Tukey/Kramer HSD was applied to determine how the light treatment in young plant production and the light treatment in continuous production affect yield parameters and to determine whether or not there were interactions between the factors.

3. Results and Discussion

Transplants that received LEDs in young plant production were more compact than those that received HPS lights in young plant production (Stadler 2023). This was in accordance with results of Bergstrand et al. (2016) and Hogewoning et al. (2012) for tomato and cucumber seedlings.

Tomatoes that reveived LED lights in young plant production were about half a week earlier ripe than tomatoes that received HPS lights (data not shown). This might be caused by the higher leaf temperature of plants that received LEDs and not HPS lights in young plant production (Tab. 2) as results of the two-way ANOVA revealed (($F(1)=42.40$, $p < 0.0001$). However, no effect of the light source in young plant production on soil temperature was found (($F(1)=7.93$, $p = 0.0107$). In contrast, the light treatment in continuous production (“Hybrid+LED” or “Hybrid”) had no influence on leaf temperature (($F(1)=4.71$, $p = 0.0422$) and substrate temperature (($F(1)=3.10$, $p = 0.0938$). The higher leaf temperature might be related to different thickness of leaves between light sources and might have positively influenced development and leading to an earlier harvest compared to treatments that received HPS lights in young plant production. Indeed, Dueck et al. (2012a) reported that leaf thickness of tomato plants increased by 12% when grown under LED lights with a ratio of 88:12 red:blue light compared to plants grown under HPS lights.

Särkka et al. (2017) reported that cucumber leaf temperature was lower (4-5°C at the centre parts of leaf blades, 3-4°C at the top of the canopy) with only LED lights (top and interlighting) and there was a lower temperature difference between night and day compared to the other light treatments (HPS top and HPS interlights, HPS top and LED interlights). This resulted in reduced leaf appearance rate, flower initiation rate, increased fruits abortion rate, whereas stem elongation and leaf expansion was increased compared to full HPS (HPS top and HPS interlights) and Hybrid (HPS top and LED interlights) lighting. The lower temperature might have decreased fruit growth of cucumbers in the LED treatment through reduced cell growth and indirectly through sink strength. Indeed, also Stadler (2018) reported that development and harvest of strawberry plants under LEDs was delayed by two weeks compared to strawberries under HPS lights when temperature settings were the same. However, when temperature settings were adapted, strawberry plants under HPS lights showed a delayed growth that was one week behind the development of strawberries treated with LEDs and increased temperature (Stadler 2019). In fact, van Delm et al. (2016) concluded that the regulation of temperature and lighting strategy seems to be important for plant balance between earliness and total yield.

Tab. 2: Substrate and leaf temperature of tomato plants at different light treatments in young plant production and continuous production

Temperature (°C)	HPS, Hybrid+LED	LED, Hybrid+LED	HPS, Hybrid	LED, Hybrid
Substrate	21.7 ab	21.8 a	21.4 b	21.8 a
Leaf	20.3 b	20.7 a	20.3 b	20.5 a

Letters indicate significant differences (HSD, $p \leq 0.05$).

At the end of the harvest period there was a marketable yield of 12.6-14.8 kg/m^2 (Tab. 3). Total yield, marketable yield and their number was according to the two-way ANOVA independent of the light treatment in young plant production and continuous production as well as their interaction. Also, Stadler (2018, 2020) reported no yield differences between HPS and LED lights for strawberries and tomatoes. When considering the marketable tomato yield per cluster, treatments that received LEDs in young plant production had a lower value than plants that received HPS lights in young plant production despite of the earlier harvest. Average weight was significantly higher in the treatment “Hybrid” compared to “Hybrid+LED” (($F(1)=13.07$, $p = 0.0068$), whereas the treatment in young plant production (($F(1)=1.07$, $p = 0.3319$) as well as the interaction between the light treatment in young plant production and the light treatment in continuous production did not affect average weight (($F(1)=4.27$, $p = 0.0727$). No advantage with LED interlighting compared to only the Hybrid top lighting system was gained.

Tab. 3: Harvest parameters of tomatoes at different light treatments in young plant production and continuous production

Harvest parameter	HPS, Hybrid+LED	LED, Hybrid+LED	HPS, Hybrid	LED, Hybrid
Total yield (kg/m^2)	22.7 a	22.3 a	24.6 a	22.8 a
Marketable yield (kg/m^2)	13.7 a	12.6 a	14.8 a	12.8 a
Marketable fruits (no/m^2)	176 a	171 a	185 a	158 a
Average weight (g/fruit)	78 ab	74 b	80 a	81 a
Harvested clusters (no/m^2)	23	26	25	25
Marketable yield (kg/cluster)	0.60	0.48	0.60	0.51

Letters indicate significant differences (HSD, $p \leq 0.05$).

The slightly lower use of electricity by LEDs was compensated by a higher price of the lights. No additional costs for heating were added under LEDs due to the use of free geothermal energy for heating. With HPS lights in young plant production was the utilization of kWh's better transferred into yield compared to LEDs in young plant production (Tab. 4). Dueck et al. (2012a) reported that the production under LEDs was lower than under HPS, but LEDs saved 30 % of dehumidification and heat energy and 27 % of electricity relative to the crop grown with HPS lights. Särkka et al. (2017) mentioned that the electrical use efficiency (kg yield J^{-1}) increased when HPS light was replaced with LEDs in cucumbers, but the high capital cost is still an important aspect delaying the LED technology in horticultural lighting.

“Hybrid+LED” used about 21 % less energy than “Hybrid” (Tab. 4). Light related costs (electricity costs + investment into lights) were higher for “Hybrid” than for “Hybrid+LED”. Used kWh's were better transferred into yield with “Hybrid+LED” than with “Hybrid”. Also Dueck et al. (2012b) compared the effect of top lighting and interlighting with HPS and/or LEDs on the production of tomatoes. The amount of energy required per kg of harvested tomatoes was highest for the LED treatment and Hybrid system with LED top lighting. In cucumbers, LED interlighting increased light use efficiency, mainly by increasing light reaching the intercanopy, compared with HPS top lights (Hao et al. 2014). Also, Hovi-

Pekkanen and Tahvonen (2008) reported that interlighting (compared to top lighting) improved energy use efficiency in lighting of cucumbers.

Tab. 4: Economic numbers

Economic parameter	HPS, Hybrid+LED	LED, Hybrid+LED	HPS, Hybrid	LED, Hybrid
Energy use (kWh)	26,960	26,309	34,036	33,523
Electricity costs (ISK/m^2)	3,854	3,761	4,869	4,791
Investment into lights (ISK/m^2)	3,441	3,744	3,358	3,664
Energy use efficiency (kg/kWh)	0.025	0.024	0.022	0.019

Särkka et al. (2017) concluded that at the current stage of LED technology, the best lighting solution for high latitude winter growing appears to be HPS top lights combined with LED interlights. However, a solution for the near future could be a combination of LED and HPS as top lights to be able to maintain a suitable temperature, but reduce energy use. This is in accordance with Dueck et al. (2012a) who suggested that a combination of HPS and LEDs as top lighting is the most promising alternative for greenhouse grown tomatoes when taking into consideration different production parameters and costs for lighting and heating. These results comply with the optained results indicating rather to skip LEDs for interlighting, but suggesting LEDs in addition to HPS lights as top lights.

4. Conclusions

It can be advised to grow high wire transplants under HPS lights. However, after transplanting a system without LED interlighting seems to be recommended.

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