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DGG-Proceedings, Vol. 9, 2019, No. 4, p. 1-5.
DOI: 10.5288/dgg-pr-cs-2019

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DGG-Proceedings
Short Communications (peer reviewed, open access)
German Society of Horticultural Sciences (DGG)
www.dgg-online.org

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1. Introduction, Knowledge, Objectives

In Iceland, strawberries in commercial production are only grown in protected cultivation. Winter cultivation in greenhouses is only possible with additional lighting due to the extremely low natural solar radiation. It is common to use high-pressure vapour sodium (HPS) lamps, but thereby representing energy costs a large proportion of total production costs (*Stadler*, 2018). In addition, reduced subsidies are contributing to find ways to save energy. Energy costs could be reduced by choosing a light source that is saving energy. In this context, LEDs are coming into discussion (*Bantis* et al., 2018). However, experience to illuminate with LEDs are not yet available in Iceland. Therefore, it was tested, if it is (1) possible to grow strawberries in winter in Iceland under LEDs and (2) how the yield of strawberries is influenced by the light source and (3) if this is economically feasible.

2. Material and Methods

Strawberries (*Fragaria* x *ananassa* cv. Sonata and cv. Magnum) were grown in the research greenhouse of the Agricultural University of Iceland (Hveragerði, South Iceland). Each 500 heavy tray plants of both Sonata and Magnum were planted on 07.12.2017. The experiment ended on 05.04.2018.

Strawberries were grown in hanging gutters with a plant density of 12 plants/m^2 (4 plants / 5 l pot). The plants were lighted either with HPS lamps (277 µmol/m^2/s) or with LED lights (279 µmol/m^2/s, Green power LED (deep red / white); the manufacturer indicates no detailed data about the light spectrum). Light was turned on from 07.00 to 23.00. The temperature was 16 °C / 8 °C (day / night) and 800 ppm CO_2 was applied. Plants received standard nutrition through drip irrigation. Each variety was grown in six beds, representing six repetitions. Per repetition were four plants (= one pot) per variety measured: One unpollinated flower per pot and treatment was weekly marked and these flowers were daily observed until their pollination and their harvesting date was recorded. The number of open flowers and fruits per plant was weekly counted at one pot. Fruits of these four plants were regularly harvested and classified. The energy usage was registered. At the end of the growth period the profit margin was calculated.

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 $p = 0.05$.

3. Results

It took 1-2 days from flowering to pollination. An increased number of flowers / fruits per plant was observed for Sonata, although this was only statistically significant under LEDs. Sonata had around 55 flowers / fruits, while Magnum had around 45 flowers / fruits (Fig. 1). After the maximum was reached, the amount decreased due to the start of the harvest. The development of the flowers and fruits was delayed by two weeks under LED. Fruits ripened two weeks earlier under HPS lights and the harvest was also two weeks earlier finished. In addition, Magnum was earlier ripe. Strawberries were ripe after 41 days (Magnum, Sonata) under HPS lights and after 45 / 47 days (Magnum / Sonata) under LEDs.

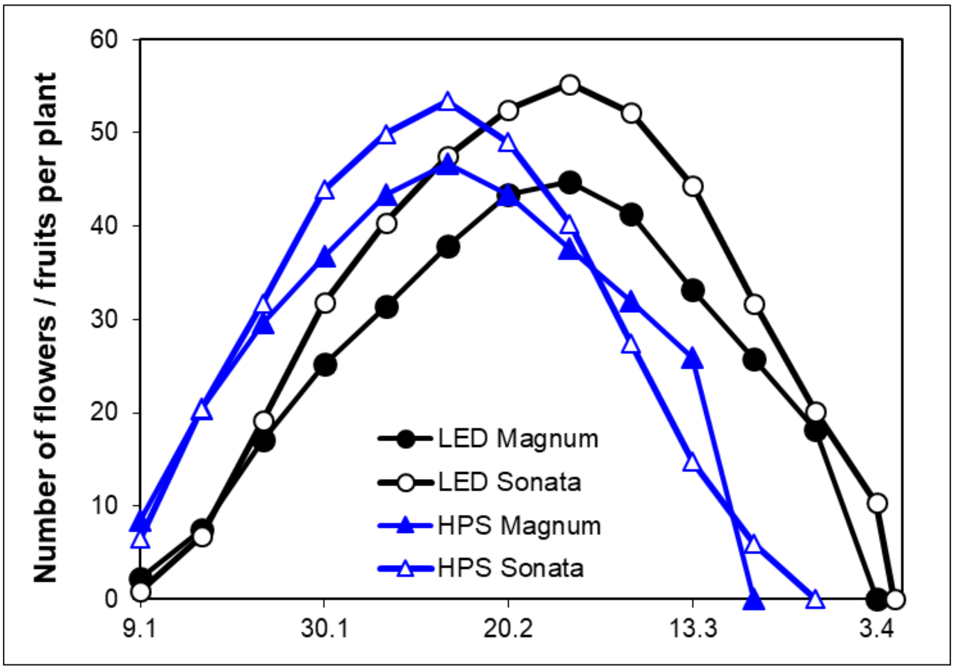

Fig. 1: Open flowers / fruits per plant with different light sources in 2018

Sonata reached under LEDs 590 g/plant and 610 g/plant under HPS, but Magnum reached under LEDs 530 g/plant and 520 g/plant under HPS (Fig. 2). Differences were not statistically different between light sources. However, the yield of Sonata was about 10 % higher compared to Magnum. The lower yield of Magnum was attributed to a lower number of marketable fruits (Tab. 1) due to a significantly higher percentage of unshaped fruits (Tab. 2). Marketable yield was about 90 % of total yield. Yield differences between varieties developed at the middle of the harvest period (Fig. 2). With progressive harvest decreased the average weight from 20 g/fruit to about 10 g/fruit. Neither between light sources nor between varieties were observed significant differences in the weight of the fruits (Fig. 2).

Additional heating of the HPS lights caused a higher day temperature in the HPS treatment (17,1 °C) compared to the LED treatment (16,6 °C). In addition, the soil temperature and the leaf temperature were under HPS lights significantly higher than under LEDs (Tab. 3).

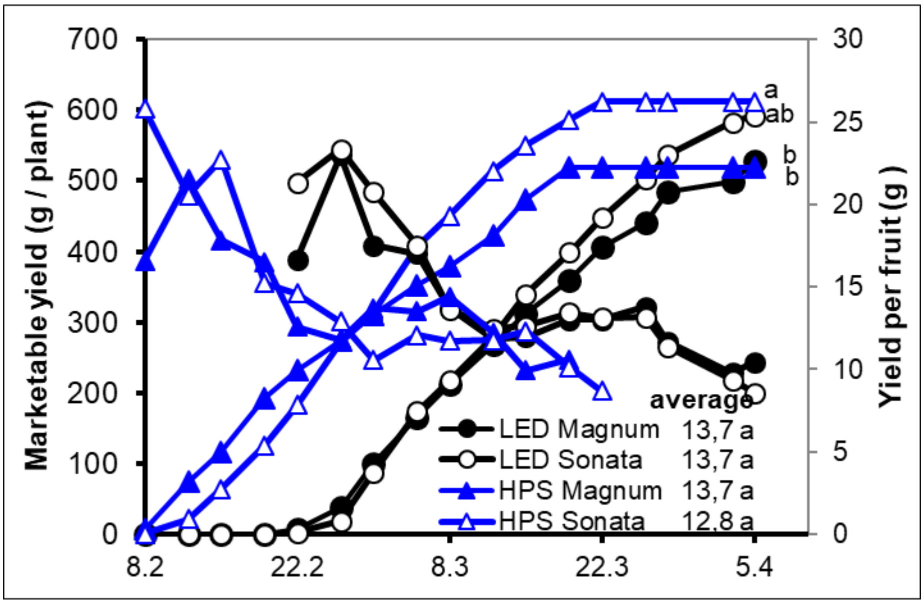

Fig. 2: Accumulated marketable yield and fruit weight with different light sources. Letters indicate significant differences at the end of the experiment (HSD, p≤0.05)

Tab. 1: Number of harvested fruits with different light sources. Letters indicate significant differences at the end of the experiment (HSD, p≤0.05)

	Marketable yield (no. fruits / plant)	
Treatment	**extra class**	**1st class**
LED Magnum	13 a	25 b
LED Sonata	14 a	29 ab
HPS Magnum	14 a	24 b
HPS Sonata	15 a	33 a

Tab. 2: Proportion of marketable and unmarketable yield with different light intensities. Letters indicate significant differences at the end of the experiment (HSD, p≤0.05)

	Marketable yield (%)			Unmarketable yield (%)		
Treatment	**extra class**	**1st class**	**too small**	**moldy**	**unshaped**	**green**
LED Magnum	46 a	42 ab	2 b	0 a	8 a	2 a
LED Sonata	49 a	44 ab	4 a	0 a	1 b	2 a
HPS Magnum	48 a	39 a	2 b	0 a	7 a	3 a
HPS Sonata	46 a	49 a	3 ab	0 a	1 b	2 a

Tab. 3: Leaf and soil temperature with different light sources. Letters indicate significant differences (HSD, $p \leq 0.05$)

	Temperature (°C)	
Treatment	**Soil**	**Leaf**
LED Magnum	15,0 c	14,1 b
LED Sonata	14,9 c	14,3 b
HPS Magnum	15,7 b	17,0 a
HPS Sonata	16,2 a	17,2 a

Using LEDs was associated with nearly 45 % lower daily usage of kWh's, resulting in lower electricity expenses, but higher investment costs for the LEDs. With the use of LEDs instead of HPS lights increased the profit margin by 1.200 ISK/m^2 for Magnum and by 500 ISK/m^2 for Sonata. Growing Sonata instead of Magnum increased yield under HPS by 1,1 kg/m^2 and profit margin by 2.300 ISK/m^2 (1 € ≈ 135 ISK), under LEDs by 0,8 kg/m^2 and 1.600 ISK/m^2 (data not shown).

4. Discussion

The effect of two light sources was tested on two varieties of strawberries. It was shown, that winter production of strawberries was possible under LEDs. However, the development of flowers and fruits was delayed by two weeks compared to HPS lights. Hence, the harvest under LEDs started two weeks later. Consequently, the harvest under HPS lights was finished two weeks earlier than the harvest under LED lights, where the ripening process took nearly one week longer. Additional heating by HPS lights caused a 0,4 °C higher day temperature compared to LEDs. In addition, the soil temperature was about 1 °C and the leaf temperature nearly 3 °C higher in the HPS treatment. This temperature advantage could have positively influenced the development of the plants and might be the reason for the earlier ripening. Also, *Hernández* & *Kubota* (2015) attributed the 28 % greater shoot dry mass of cucumbers, the 28-32 % higher shoot fresh weight and the 9-12 % higher leaf number under HPS lights compared to the LED treatments (blue LED, red LED) to the higher canopy air temperature. Indeed, *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.

However, the accumulated yield of strawberries was only delayed under LEDs, but the yield amount was independent of the light source. This was contrary to *Särkka* et al. (2017), where the lower temperature under LED lights (top and interlighting) compared to full HPS (HPS top and HPS interlights) might have decreased fruit growth of cucumbers in the LED treatment through reduced cell growth and indirectly through sink strength. But it has also to be taken into account that solar irradiation increased at the end of the presented experiment and thus, possibly benefitting the LED treatment due to two weeks longer growing period compared to the HPS treatment. Among that, the selection of the variety is important. Sonata seem to be better suited under artificial lighting than Magnum.

Using LEDs was associated with 45 % lower daily usage of kWh's, resulting in lower expenses for the electricity compared to HPS lights. But the lower use of electricity 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. The use of LEDs resulted for both varieties in a higher profit margin than the use of HPS lights. The profit margin increased by 1.200 ISK/m^2 for Magnum and by 500 ISK/m^2 for Sonata. Also, *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.

So far, limited information is available comparing HPS with LED lighting in terms of plant growth and development (*Hernández* & *Kubota*, 2015). Reported results are controversial, first because of different plant species and cultivars and second due to various experimental conditions. Therefore, it is concluded by different authors (*Bantis* et al., 2018; *Hernández* & *Kubota*, 2015; *Singh* et al., 2015), that more detailed scientific studies are necessary to understand the effect of different spectra using LEDs on plant physiology and to investigate the responses to supplemental light quality of economically important greenhouse crops and validate the appropriate and ideal wavelength combinations for important plant species.

5. Conclusions

From an economic viewpoint it is recommended to use the variety Sonata to be able to increase yield and profit margin. Before LEDs can be advised in practice, more scientific studies are needed with different temperature settings to compensate the additional heating by the HPS lights and the delayed growth and harvest. Therefore, so far, a replacement of the HPS lamps by LEDs is not recommended.

6. Literature

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