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1. Introduction, Knowledge, Objectives

Strawberries in commercial production are only grown in protected cultivation in Iceland. So far, the harvest period of Icelandic strawberries is from May to October and therefore, there is no supply of Icelandic strawberries in winter and spring. However, there is also a demand on strawberries in those months with low levels of natural light and thus foreign strawberries are imported. 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 in Iceland. It was tested, if it is (1) possible to grow strawberries in winter in Iceland and (2) how the yield of strawberries is influenced by the light intensity and (3) if this is economically feasible.

2. Material and Methods

Two experiments with strawberries (*Fragaria* x *ananassa* cv. Sonata and cv. Elsanta) were conducted in the research greenhouse of the Agricultural University of Iceland (Hveragerði, South Iceland). Thousand heavy tray plants of Elsanta were planted on 24.08.2015 in the first experiment (A) that ended on 23.11.2015. Each 500 heavy tray plants of both Elsanta and Sonata were planted on 28.01.2016 in the second experiment (B) that ended on 30.05.2016.

Strawberries were grown with a plant density of 12 plants/m^2 (4 plants / 5 l pot). The plants were lighted with high-pressure vapour sodium lamps (HPS, Osram Plantastar 600 W lamps). Light was turned on from 03.00 to 19.00. The lamps were automatically turned off when incoming illuminance was above the desired set-point. Two different light intensities were tested, 100 W/m^2 and 150 W/m^2 (installed light intensity). 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. From each of these repetitions 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 for this one pot was weekly counted. Fruits of these four plants were regularly harvested and classified. 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. Although not statistically significant, a tendency towards increased number of flowers / fruits per plant was observed in experiment A and B at the higher light intensity (150 W/m^2). Elsanta had 35 flowers / fruits at the higher light intensity and 30 flowers / fruits at the lower light intensity in experiment A. The amount of the flowers / fruits was higher in experiment B. Both varieties reached about 70 flowers / fruits at the higher light intensity, but 65 for Sonata and 60 for Elsanta at the lower light intensity (Fig. 1). After the achievement of the maximum the amount decreased due to the start of the harvest.

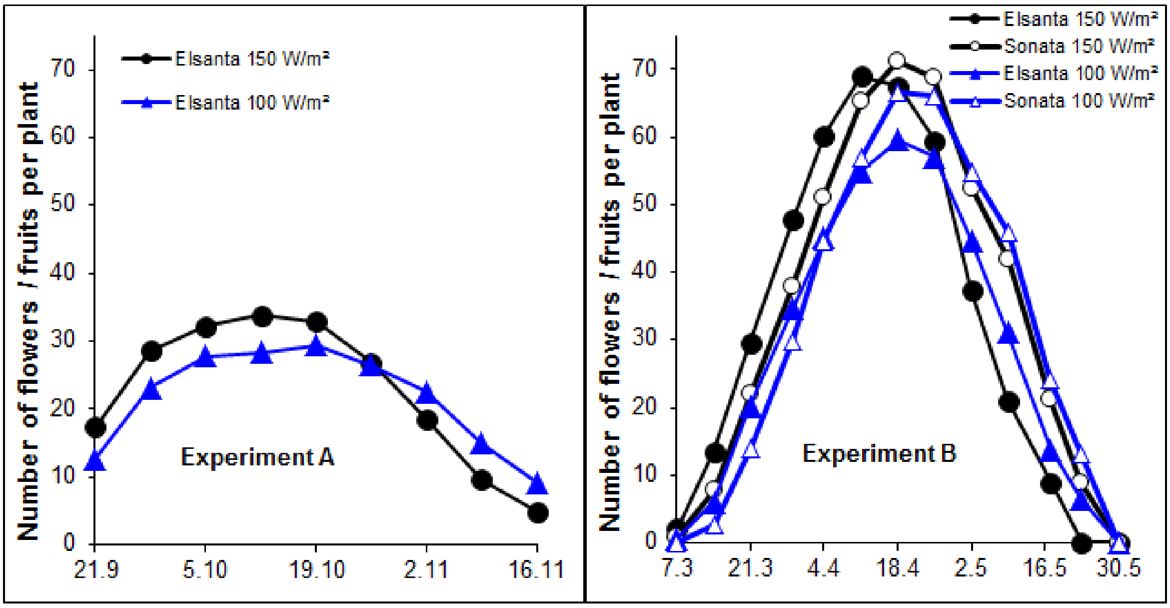

Fig. 1: Open flowers / fruits per plant in experiment A and B with different light intensities in 2015/2016

The strawberries were ripe after 41 days (average value) at the higher light intensity and after 43 days at the lower light intensity in experiment A. Elsanta was after 42 days and Sonata after 46 days ripe at 150 W/m^2 and Elsanta after 44 days and Sonata after 46 days at 100 W/m^2 in experiment B. The first fruits were some days earlier ripe at the higher light intensity compared to 100 W/m^2. In addition, Elsanta was earlier ripe. However, the plants of Elsanta were more developed at planting than the plants of Sonata.

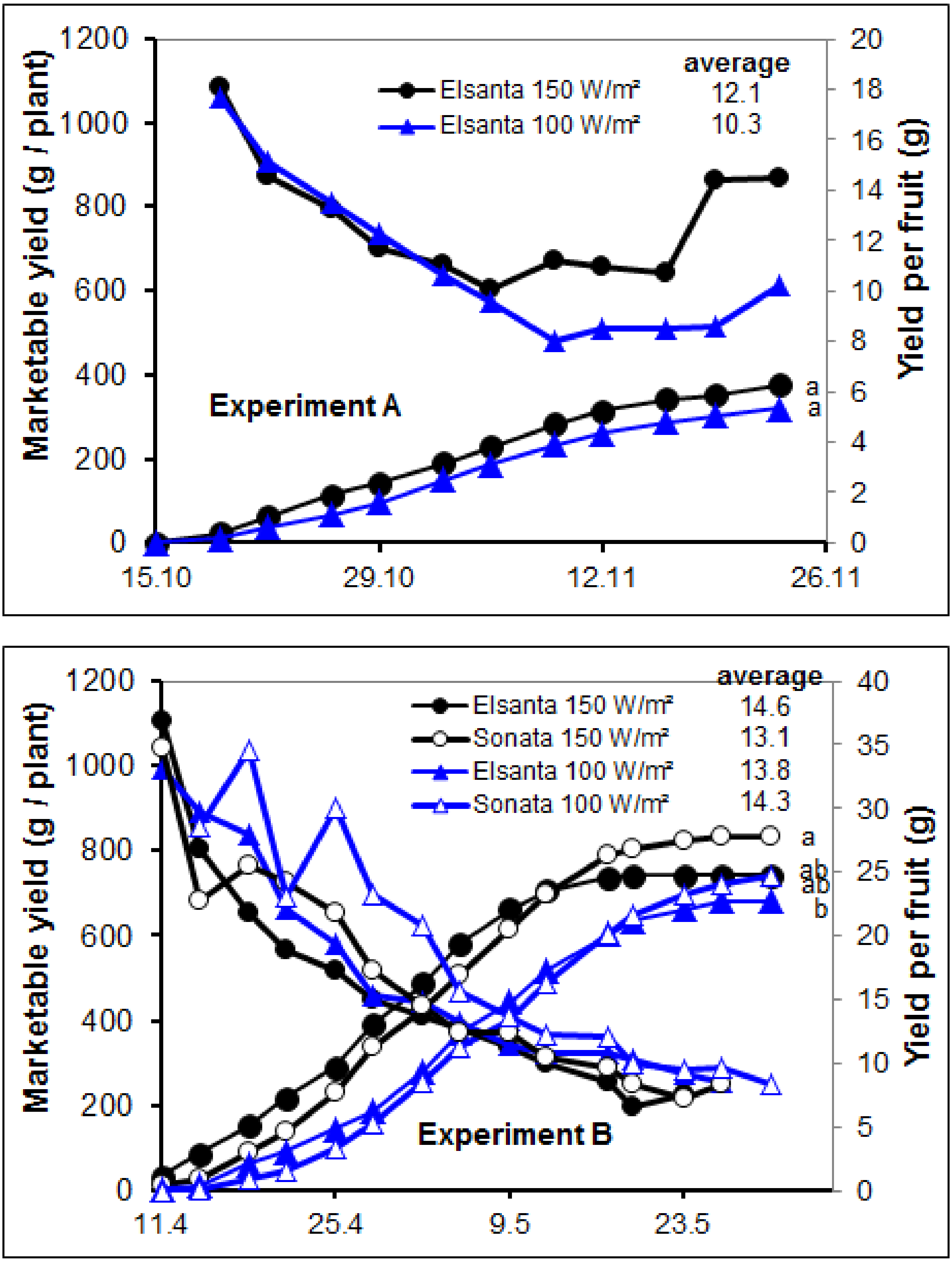

Fig. 2: Accumulated marketable yield and fruit weight at different light intensities. Letters indicate significant differences at the end of the experiment (HSD, p≤0.05)

Tab. 1: Number of harvested fruits at different light intensities. Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0.05$)

	Marketable yield (no. fruits / plant)			
	Experiment A		Experiment B	
Treatment	extra class	1. class	extra class	1. class
Elsanta 150 W/m^2	24 a	7 a	21 a	30 b
Sonata 150 W/m^2			20 a	40 a
Elsanta 100 W/m^2	22 a	10 a	17 a	35 ab
Sonata 100 W/m^2			19 a	33 ab

The marketable yield of Elsanta was 380 g/plant at 150 W/m^2 and 320 g/plant at 100 W/m^2 in experiment A. Elsanta reached 740 g/plant and Sonata 830 g/plant at 150 W/m^2 and Elsanta 680 g/plant and Sonata 740 g/plant at 100 W/m^2 in experiment B (Fig. 2). Differences were not statistically different, neither between light intensities nor between varieties. However, the yield of Sonata was about 10 % higher compared to Elsanta.

The trend of a higher yield at the higher light intensity compared to the lower light intensity was attributed to a tendentially higher number of harvested fruits (Tab. 1), while the average weight was not affected (Fig. 2).

Using a higher light intensity is associated with higher expenses for the electricity (data not shown). Thus, it is necessary that the higher use of electricity is paying off by obtaining a higher yield. An increase of the light intensity from 100 W/m^2 to 150 W/m^2 resulted in a yield increase of 0.7 kg/m^2 for Elsanta and this was reflected in an 800-900 ISK/m^2 increase of profit margin. For Sonata resulted an increase of 50 W/m^2 in 1.1 kg/m^2 more yield and 1,600 ISK/m^2 more profit margin. At the lower light intensity resulted the use of Sonata in 0.7 kg/m^2 more yield and 1,500 ISK/m^2 more profit margin compared to the use of Elsanta. At the higher light intensity gave Sonata 1.1 kg/m^2 more yield and 2,300 ISK/m^2 more profit margin than Elsanta.

4. Discussion

The drastic difference in marketable yield of Elsanta between experiment A (less than 400 g/plant) and experiment B (around 700 g/plant) was attributed to the condition of the plants at planting that decided about a low or high yield and contributed therefore considerably to a success of the harvest.

The number of flowers of Elsanta and Sonata was increased at the higher light intensity, which tends to result in the possibility to enhance strawberry productivity by distributing a higher amount of light intensity. *Marcelis* et al. (2006) reported the general rule, that 1 % increase of light intensity results in a yield increase of 0.7-1.0 % for fruit vegetables and 0.8-1.0 % for soil grown vegetables. No values were indicated for berries. The calculated values in the present experiment were 0.2-0.6 % for Elsanta and 0.2-0.3 % for Sonata and were with that much lower than the above mentioned ones for vegetables.

The reason for the trend of a higher yield at the higher light intensity was a tendentially increased number of harvested fruits. In addition, for Elsanta were the marketable fruits at the higher light intensity 0.8-1.8 g heavier than at the lower light intensity. In contrast, for Sonata were 0.5 g heavier fruits found at the lower light intensity, but tendentially more harvested fruits at the higher light intensity. Also, for fruit vegetables attributed *Dorais* et al. (1991) the increased yield with a higher light intensity to more, rather than heavier fruits.

In addition, was the higher light intensity accompanied with a slightly higher air, soil and leaf temperature and might also have been contributed to a yield increase. *Van Delm* et al. (2016) reported that the total yield of strawberries in Belgium decreased with lower light intensities or reduced operation hours and concluded that the regulation of temperature and lighting strategy seems to be important for plant balance between earliness and total yield.

Among that, the selection of the variety is important. *Van Delm* et al. (2016) mentioned that Elsanta was susceptible to malformation due to forcing. Especially HPS lighting (83 W/m^2) increased the percentage of misshaped fruits compared to unlighted strawberries. They concluded that Sonata seem to be better suited for forcing by lighting (and temperature) than Elsanta which was in accordance with the presented experiment.

5. Conclusions

From an economic viewpoint it is recommended to use a higher light intensity as well as the variety Sonata to be able to increase yield and profit margin. A further increase of yield and profit margin of strawberries in greenhouse production might be possible with a higher plant density. *Paranjpe* et al. (2008) found that early and total marketable yield increased linearly with increasing plant densities (8.8, 9.5, 10.4, 11.4, 17.6, 19.1, 20.8, 22.9 plants/m^2) without adversely affecting mean fruit size.

6. Literature

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