Rit LbhÍ nr. 103

„Áhrif LED lýsingar á vöxt, uppskeru og gæði gróðurhúsajarðarberja að vetri“

FINAL REPORT

Christina Stadler

LANDBÚNAÐARHÁSKÓLI ÍSLANDS

SAMBAND GARÐYRKJUBÆNDA

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Final report of the research project

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Abbreviations

DM	dry matter yield
DS	dry substance
E.C.	electrical conductivity
HPS	high-pressure vapour sodium lamps
kWh	kilo Watt hour
LED	light-emitting diodes
N	nitrogen
pH	potential of hydrogen
ppm	parts per million
W	Watt
Wh	Watt hours

Other abbreviations are explained in the text.

1 SUMMARY

In Iceland, winter production of greenhouse crops is totally dependent on supplementary lighting and has the potential to extend seasonal limits and replace imports during the winter months. Adequate guidelines for winterproduction of strawberries are not yet in place and need to be developed. The objective of this study was to test if the light source is affecting growth, yield and quality over the winter of junebearers and to evaluate the profit margin.

A strawberry experiment with junebearers (*Fragaria x ananassa* cv. Sonata and cv. Magnum) was conducted from the beginning of December 2017 to the beginning of April 2018 in the experimental greenhouse of the Agricultural University of Iceland at Reykir. Strawberries were grown in 5 l pots in six replicates with 12 plants/m^2 under high-pressure vapour sodium lamps (HPS, 180 W/m^2, 277 µmol/m^2/s) or under LED lights (279 µmol/m^2/s) for a maximum of 16 hours light. The day temperature was 16 °C and the night temperature 8 °C, CO_2 800 ppm. Strawberries received standard nutrition through drip irrigation. The effect of the light source was tested and the profit margin was calculated.

When it was not getting a bit bright outside were bumblebees still pollinating flowers in the HPS treatment, but not in the LED treatment. It took 1-2 days from flowering to pollination. The fruits were ripe in 40 / 41 days (Magnum / Sonata) under HPS lights and in 45 / 47 days (Magnum / Sonata) under LED lights. Sonata had about 10 more flowers than Magnum. For Sonata were 1 % of the total flowers unpollinated. For Magnum were 15 % unpollinated flowers or later rejected flowers counted under LED lights and 27 % under HPS lights. The development of the flowers and berries was delayed by 1,5-2 weeks under LED lights and therefore, gave the plants under HPS lights two weeks earlier ripe berries and harvest was also finished two weeks earlier than the harvest under LEDs.

The light source did not affect the weight of marketable yield. Sonata had with 580 / 590 g/plant under LED and 540 / 610 g/plant under HPS lights a tendentially or significantly higher marketable yield than Magnum with 400 / 530 g/plant under LED and 440 / 520 g/plant under HPS lights. The reason for the more than 10 % lower marketable yield of Magnum compared to Sonata was attributed to a lower number of marketable fruits due to a significantly higher percentage of unshaped fruits.

Differences between varieties developed at the middle of the harvest period. Marketable yield was about 90 % of total yield.

No differences in the sugar content between light sources were measured. Magnum had most of the time a significantly higher sugar content than Sonata. In the tasting experiment were higher grades given for the firmness under LED lights for both varieties and Sonata fruits seem to be evaluated juicier and Magnum fruits firmer. The use of Sonata increased the yield by 1,1 kg/m^2 and the profit margin by 2.300 ISK/m^2 under HPS lights, respectively by 0,8 kg/m^2 and 1.600 ISK/m^2 under LEDs.

Despite that chamber settings were set the same between treatments, were recorded differences: The CO_2 amount was a bit higher in the LED chamber due to more open windows in the HPS chamber. Air temperature was in average 0,4 °C higher under HPS lights due to a higher day temperature caused by additional heading by the HPS lamps. Under HPS lights was the soil temperature about 1 °C higher and the leaf temperature nearly 3 °C higher compared to the LED treatment. This temperature advantage could have positively influenced growth and yield of the plants under HPS lights. However, it has also to be taken into account, that solar irradiation increased at the end of the experiment and thus, possibly the LED treatment benefited from this due to the two weeks longer growing period compared to the HPS treatment.

Using LED lights was associated with nearly 45 % lower daily usage of kWh's, resulting in lower expenses for the electricity but higher investment costs compared to HPS lights. With the use of LEDs increased the profit margin by 1.200 ISK/m^2 for Magnum and by 500 ISK/m^2 for Sonata for one growing circle. A higher tariff did not change profit margin. Also, the position of the greenhouse (urban, rural) did nearly not influence profit margin. However, there was a small advantage for the urban area. Taking three years of growing strawberries into account was resulting in a profit margin that was similar between light sources. Possible recommendations for saving costs other than lowering the electricity costs are discussed.

Before LEDs can be adviced 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. In addition, solutions for a successful pollination during the time when no solar light is entering the greenhouse must be found to ensure a satisfactory yield with LED lighting. Therefore, so far a replacement of the HPS lamps by LEDs is not recommended.

YFIRLIT

Vetrarræktun í gróðurhúsum á Íslandi er algjörlega háð aukalýsingu. Viðbótarlýsing getur því lengt uppskerutímann og komið í stað innflutnings að vetri til. Fullnægjandi leiðbeiningar vegna vetrarræktunar á jarðarberjum eru ekki til staðar og þarfnast frekari þróunar. Markmiðið var að prófa hvort ljósgjafi hefði áhrif á vöxt, uppskeru og gæði yfir hávetur á junebearers og hvort það væri hagkvæmt.

Gerð var jarðarberja tilraun með junebearers (*Fragaria x ananassa* cv. Sonata og cv. Magnum) frá byrjun desember 2017 og fram í byrjun apríl 2018 í tilraunagróðurhúsi Landbúnaðarháskóla Íslands að Reykjum. Jarðarber voru ræktuð í 5 l pottum í sex endurtekningum með 12 plöntum/m^2 undir topplýsingu frá háþrýsti-natríumlömpum (HPS, 180 W/m^2, 277 µmol/m^2/s) eða undir LED ljósi (279 µmol/m^2/s) að hámarki í 16 klst. Daghiti var 16 °C og næturhiti 8 °C, CO_2 800 ppm. Jarðarberin fengu næringu með dropavökvun. Áhrif ljósgjafa var prófuð og framlegð reiknuð út.

Þegar það naut ekki smá dagsbirtu voru býflugur ennþá að frjóvga blóm í HPS meðferð, en ekki í LED meðferð. Það tók 1-2 daga frá blómgun til frjóvgunar. Ávextir voru þroskaðir á 40 / 41 degi (Magnum / Sonata) undir HPS ljósi og á 45 / 47 dögum (Magnum / Sonata) undir LED ljósi. Sonata var með fleiri blóm borið saman við Magnum. Að auki voru 1 % af heildarblómum ófrjóvguð. Hins vegar var hlutfall hjá Magnum 15 % ófrjóvgað eða blómin blómstruðu og visnuðu síðan undir LED ljósum og 27 % undir HPS ljósum. Þróun blómanna og berjanna var um 1,5-2 víkum seinni með LED ljósum og því byrjaði meðferð undir HPS ljósum tveimur vikum áður að gefa þroskuð ber og uppskeran var einnig búin tveimur vikum fyrr.

Ljósgjafinn hafði ekki áhrif á þyngd markaðshæfrar uppskeru. Sonata var með 580 / 590 g / plöntur undir LED ljósi og 540 / 610 g / plöntur undir HPS ljósum markaðhæfrar uppskeru en Magnum með 400 / 530 g / plöntur undir LED ljósi og 440 / 520 g / plöntur undir HPS ljósum. Ástæðan fyrir meira en 10 % lægri markaðshæfrar uppskeru af Magnum borið saman við Sonata voru færri jarðarber vegna tölfræðilega marktækt hærra hlutfalls af illa löguðum jarðarberjum. Mismunur milli yrkja myndaðist á miðju uppskeru tímabilinu. Hlutfall uppskerunnar sem hægt var að selja var um 90 %.

Enginn munur var á sykurinnihaldi milli ljósgjafa, en sykurinnihaldið var yfirleitt meira hjá Magnum en hjá Sonata. Þessi munur fannst ekki í bragðprófun. Einkun fyrir þéttleika var hærri undir LED ljósi fyrir bæði yrkin og Sonata var með meiri safi og

Magnum með meiri þéttleika. Ræktun af Sonata í staðin fyrir Magnum jók uppskeru um 1,1 kg/m^2 og framlegð um 2.300 ISK/m^2 undir HPS ljósi og um 0,8 kg/m^2 og 1.600 ISK/m^2 undir LED.

Þrátt fyrir eins stillingar milli meðferða, var skráður munur: CO_2 magnið var svolítið hærra í LED klefa vegna þess að gluggarnir í HPS klefa voru að opnast meira. Lofthitastigið var að meðaltali 0,4 °C hærra í HPS klefanum vegna hærri dagshita út af viðbótarhiti frá HPS lömpum. Í HPS klefanum var jarðvegshiti um 1 °C hærri og laufhiti næstum því 3 °C hærri samanborið við LED klefann. Það getur líka haft jákvæð áhrif á vöxt plantna og uppskeru. Hins vegar þarf einnig að taka tillit til þess að sólarinngeislun jókst í lok tilraunarinnar og því gæti LED meðferð hafði hagnast á þessu vegna um tveggja vikna lengra vaxtartímabils miðað við HPS meðferðina.

Með notkun LED ljóss var næstum 45 % minni dagleg notkun á kWh, sem leiddi til minni útgjalda fyrir raforku miðað við HPS ljós, en hærri fjárfestingarkostnaður af LED. Þegar LED ljós var notaður, þá jókst framlegð um 1.200 ISK/m^2 fyrir Magnum og um 500 ISK/m^2 fyrir Sonata yfir einn vaxtarhring. Hærri rafmagnsgjaldskrá breytir framlegð næstum ekkert. Það skiptir nánast ekki máli hvort gróðurhús er staðsett í þéttbýli eða dreifbýli, framlegð er svipuð, en þó aðeins betri í þéttbýli. Möguleikar til að minnka kostnað, aðrir en að lækka rafmagnskostnað eru taldir upp í umræðunum í þessari skýrslu.

Áður en hægt er að ráðleggja að nota LED, er þörf á fleiri vísindarannsóknum með mismunandi hitastillingar til að bæta viðbótarhitun sem varð með HPS ljósunum við LED klefann til að ekki sé seinkun á vexti og uppskeru þar. Að auki þarf að finna lausnir fyrir vel heppnað frjóvgun á þeim tíma þegar ekkert sólarljós kemur inn í gróðurhúsið til að tryggja líka árangurríka uppskeru með LED lýsingu. Þess vegna er ekki mælt með því að skipta HPS lampa út fyrir LED að svo stöddu.

2 INTRODUCTION

The extremely low natural light level is the major limiting factor for winter greenhouse production in Iceland and other northern regions. Therefore, supplementary lighting is essential to maintain year-round production. This could replace imports from lower latitudes during the winter months and make domestic vegetables and fruits even more valuable for the consumer market.

Árni Magnús Hannesson from Fluðir is the pioneer in growing strawberries in Iceland. He has started with the production in the year 1985. Eiríkur Ágústsson and Olga Lind Guðmundsdóttir started to grow strawberries at Silfurtún in the year 2002 and in 2011 more growers joined producing strawberries. 2018 were seven strawberrry growers counted.

The possibilities for strawberry production are based on growing under vegetation covers for the market in June-August or cultivate strawberries in heated greenhouses with preferably supplementary lighting. The harvest period was so far from May to October and therefore, Icelandic strawberries are not available in winter and spring. However, a demand exists because relative cheap strawberries are imported and the Icelandic producers can hardly compete with the price of imported strawberries.

Since several years it is tradition to grow strawberries in heated greenhouses in the Netherlands and Belgium (e.g. *van Delm* et al., 2016). Also, the Norwegians are experimenting with greenhouse cultivation of strawberries during winter (e.g. *Verheul* et al., 2007). The question is whether this can also be pursued in Iceland. It is difficult to cultivate strawberries on high latitudes like in Iceland, because there are short days and little daylight from middle of September to middle of April and the low natural light level is the main limiting factor for a production in winter in greenhouses. Therefore, supplemental lighting is necessary to maintain an equal harvest over the year and this could make imports from lower latitudes unnecessary. Vegetables are grown during winter with supplemental lighting and the question is whether it is possible to extend the growing season of strawberries in the same way. Therefore, it should be considered if it is possible to use supplemental lighting when active radiation (PAR) falls below the critical value in production of strawberries.

Strawberry production in the greenhouse is based on producing strawberries at times where cheap strawberries are not available. "Sonata" and "Elsanta" are the most common strawberry varieties abroad and also in Iceland. These varieties are junebearers that produce one harvest in June or early spring. Under lighting abroad is also the junebearer “Magnum” grown. This variety is giving bigger berries than the two before mentioned varieties and has been tested in Iceland the first time in the year 2017 by one grower.

The positive influence of artificial lighting on plant growth, yield and quality of tomatoes (*Demers* et al., 1998a), cucumbers (*Hao* & *Papadopoulos*, 1999) and sweet pepper (*Demers* et al., 1998b) has been well studied. It is often assumed that an increment in light intensity results in the same yield increase. Indeed, yield of sweet pepper in the experimental greenhouse of the Agricultural University of Iceland at Reykir increased with light intensity (*Stadler* et al., 2010). However, with tomatoes, a higher light intensity resulted not (*Stadler*, 2012) or in only a slightly higher yield (*Stadler*, 2013). *Van Delm* et al. (2016) reported that the total yield of strawberries in Belgium decreased with lower light intensities. In the research greenhouse of the Agricultural University of Iceland were two different light intensities tested and at the beginning of the harvest were strawberries at the higher light intensity (150 W/m^2) some days earlier ripe than at 100 W/m^2. The higher light intensity had a positive effect on marketable yield. The yield was about 15 % more due to a higher number of “extra class” strawberries. The unmarketable yield seemed to be lower at the higher light intensity (*Stadler*, 2016a; *Stadler* 2016b). However, these results apply to the junebearers Sonata and Elsanta, whereas for Magnum is not yet knowledge available.

Supplemental lighting that is normally used in greenhouses has no or only a small amount of UV-B radiation. High pressure sodium (HPS) lamps are the most commonly used type of light source in greenhouse production due to their appropriate light spectrum for photosynthesis and their high efficiency. The spectral output of HPS lamps is primarily in the region between 550 nm and 650 nm and is deficient in the IV and blue region (*Krizek* et al., 1998). However, HPS lights suffer from restricted controllability and dimming range limitations (*Pinho* et al., 2012).

Light-emitting diodes (LED) have been proposed as a possible light source for plant production systems and have attracted considerable interest in recent years with their advantages of reduced size and minimum heating plus a longer theoretical lifespan as compared to high intensity discharge light sources such as HPS lamps (*Bula* et al., 1991). These lamps are a radiation source with improved electrical efficiency (*Bula* et al., 1991), in addition to the possibility to control the light spectrum and the light intensity which is a good option to increase the impact on growth and plant development. Several plant species have been successfully cultured under LEDs (e.g. *Philips*, 2017; *Philips*, 2015; *Tamulaitis* et al., 2005; *Schuerger* et al., 1997; *Brown* et al., 1995; *Hoenecke* et al., 1992). However, with HPS was achieved a significantly higher fresh yield of salad in comparison to LEDs. But, two times more kWh was necessary with only HPS lights in comparision with only LEDs. The only use of HPS lights resulted in the highest yield, while the yield with only LEDs was about ¼ less (*Stadler,* 2015).

But, before LEDs are put into practice on a larger scale, more knowledge must be acquired on effects of LED lighting on crops (*Dueck* et al., 2012). In addition to the yield is also the quality of the harvest important. Research in the Netherlands has shown that with LED lights was it possible to increase the taste (*Hanenberg* et al., 2016). Experience of growing strawberries under LEDs in Iceland is not available and therefore, the effect of light on yield over the high winter (with low levels of natural light) need to be tested under Icelandic conditons. There is already knowledge available about growing the variety “Sonata” during the winter under HPS lights and therefore, this variety will be compared to one other promising variety, Magnum.

Incorporating lighting into a production strategy is an economic decision involving added costs versus potential returns. Therefore, the question arises whether these factors are leading to an appropriate yield of strawberries.

The objective of this study was to test if (1) the light source is affecting growth, yield and quality of different strawberry varieties, if (2) this parameter is converted efficiently into yield, and if (3) the profit margin can be improved by the chose of the light source and variety. This study should enable to strengthen the knowledge on the best method of growing strawberries and give strawberry growers advice how to improve their production by modifying the efficiency of strawberry production.

3 MATERIALS AND METHODS

3.1 Greenhouse experiment

A strawberry experiment with two different varieties of junebearers (*Fragaria x ananassa)* cv. Sonata and cv. Magnum and different light sources (see chapter "3.2 Treatments") was conducted at the Agricultural University of Iceland at Reykir during winter 2017/2018.

Four heavy tray plants of Sonata respectively Magnum were planted on 07.12.2017 in 5 l pots filled with moist strawberry substrate in two chambers with different light sources.

Fig. 1: Experimental design of cabinets.

The strawberry pots were placed in rows in six 134 cm high beds (Fig. 1) with 8 cm between pots and 93 cm between beds. Beds were divided into two parts and the different varieties put out in a zick zack system. One bed had 16 pots with eight pots from each variety. Six replicates, one replicate in each bed consisting of one pot (4 plants for Sonata / Magnum) acted as subplots for measurements. The plant density was 12 plants/m^2. The temperature was set on 16 °C during day and 8 °C during night. Ventilation started at 20 °C. It was heated up with 1,5-2 °C per hour. The aim was to reach 16 °C at one hour after day starts. At the end of the day was the temperature dropped without delay. The underheating started heating up two hours before lights were turned on and reached 35 °C during the day and was turned off one hour before night.

Carbon dioxide was provided (800 ppm CO_2 (from week three until the end) with no ventilation and 500 ppm CO_2 with ventilation). A misting system was installed. Humidity was set to 75 % to be able to reach 70 % during the whole experiment.

Bumblebees were used for pollination. Paraat was sprayed four days after planting. It was started three weeks after planting to spray Loker once a week (see details in appendix). Once was sprayed with Prev-Magnum ^{tm} (Multi-purpose adjuvant boosted with magnesium oxide) and once with Topaz ® for the preventative control of powdery mildew. Plant protection was managed by beneficial organisms. Aphiscout (mix of parasitic wasps), Thripor-L (*Orius laevigatus*) was used (see details in appendix).

Strawberry plants got fertilizer according to Tab. 1.

Tab. 1: Used fertilizer mixture for strawberries.

	Stem solution A (100 l)			**Stem solution B (100 l)**									**Relation**
Fertilizer (amount in kg) (amount in l) * (amount in g) **	Calciumnitrate	Iron 6%* DTPA *	Iron 6% EDDHA **	Potassium sulfate	Magnesium sulfate	Monopotassium phosphate	Potassium nitrate	Mangansulfat 32,5 % Mn **	Borax 11,3 % B **	Koparsulfat 24 % Cu **	Zinksulfat 23 % Zn **	Natriummolybdat 40 % Mo **	
Planting – 10 white fruits / plant (growth)	8,4	0,2	50	1,3	3,6	1,7	2,9	51	14	3	21	1,5	1:100
10 white fruits / plant – harvest end (fruit development)	7,3 (without NH_4^+)	0,25	50	1,3	3,6	1,7	7,3	51	14	3	21	1,5	1:100

Plants were irrigated through drip irrigation (1 tube per bucket). The watering was set up that the plants could root well down, which means no runoff after planting and a low amount of runoff in the first 2-3 weeks. At the growing stage was the irrigation arranged to 10-20 % runoff on sunny days and 0-5 % on cloudy days with an E.C in the drip of 1,5-1,7. At flowering and carrying green fruits was the runoff supposed to be 25-30 % on sunny days and 10-15 % on cloudy days with lowering the E.C. from 1,7 to 1,5 one week before harvest. The E.C. of the input and runoff water is supposed to be adjusted that their sum was 3,2-3,3 during growth and flowering and 3,0-3,1 during harvest. 100 ml/drip was irrigated. In general was the rule that the first drip in the morning should not give runoff. The first watering was at 9.00 and the last at 21.00 with E.C. 1,6 and pH 5,8. The irrigation interval was variable in accordance to the runoff.

3.2 Treatments

Strawberries were grown from 07.12.2017-05.04.2018 in two chambers with different light sources:

1. HPS top lighting (Philips bulbs, 600 W) 180 W/m^2, 277 µmol/m^2/s, **HPS**
2. LED top lighting (GreenPower LED, Philips), 279 µmol/m^2/s µmol, **LED**

Lamps for top lighting were mounted horizontally over the canopy. Directly after planting was the lighting from 07.00-15.00 and increased by one hour per day until 16 hours (07.00-23.00) were reached. Half of the lamps went on at 07.00 and the other half at 07.30. Half of the lamps went off at 23.00 and the other half at 23.30. The lamps were automatically turned off when incoming illuminance was above the desired set-point. The lamps were distributed in the way that strawberries got the most equal light distribution, on average, 277 µmol/m^2/s in the HPS chamber and 279 µmol/m^2/s in the LED chamber (Tab. 2). In addition, white plastic on the surrounding walls helped to get a higher light level at the edges of the growing area.

Tab. 2: Light distribution in the chambers.

	HPS (µmol/m²/s)				LED (µmol/m²/s)			
repetition	**door**	**middle**	**glas**	**average**	**door**	**middle**	**glas**	**average**
1	244	290	310	**281**	274	291	257	**280**
2	272	276	291	**280**	276	295	270	**281**
3	282	295	292	**290**	275	298	267	**279**
4	270	274	257	**267**	274	290	272	**280**
5	262	281	276	**273**	278	292	273	**280**
6	273	286	250	**270**	279	294	266	**274**
average	**267**	**284**	**279**	**<u>277</u>**	**276**	**293**	**268**	**<u>279</u>**

In addition, six flowering lamps (Philips GreenPower, deep red / white / far red) were set up in the LED chamber in the same hight as the LED lights. When 1,5-2 leaves were visible, it was started to turn on the flowering lamps during the time, when the LED lights were turned off. The desired growth was one cm/day. Because this value was not reached, the flowering lamps were turned on for 24 hours. The flowering lamps were turned off when leaves were 18-20 cm. However, the growth was then less than 1,0-1,5 cm / day and clusters were short, and therefore, the flowering lamps were turned on again until the beginning of the harvest.

3.3 Measurements, sampling and analyses

Soil temperature and leaf temperature was measured once a week. The amount of fertilization water (input and runoff) was measured every day.

To be able to determine plant development, the number of leaves, the number of clusters and the number of open flowers was counted each week. This gave information regarding the total amount of flowers per plant and the number of flowers per cluster.

During the growth period were runners regularly taken away and the number per plant was registered. During the harvest period were berries regularly collected (2 times per week) in the subplots. Total fresh yield, number of fruits, fruit category (extra-class (> 25 mm), 1. class (18 mm) and not marketable fruits (too little fruits (< 18 mm), damaged fruits, misshaped fruits, moldy fruits) were determined. At the end of the harvest period was on each plant the number of immature fruits (green) counted. The marketable yield of the whole chamber was also measured.

In the LED chamber were LED glasses used for picking to be able to distinguish if berries were ripe or not.

The interior quality of the berries was determined. A brix meter (Pocket Refractometer PAL-1, ATAGO, Tokyo, Japan) was used to measure sugar content of the strawberries during the growth period. From the same harvest, the flavour of fresh fruits was examined in a tasting experiment with untrained assessors. Also, subsamples of the fruits were dried at 105 °C for 24 h to measure dry matter yield.

Energy use efficiency (total cumulative yield in weight per kWh) and costs for lighting per kg yield were calculated for economic evaluation and the profit margin was determined.

3.4 Statistical analyses

SAS Version 9.4 was used for statistical evaluations. The results were subjected to one-way analyses of variance with the significance of the means tested with a Tukey/Kramer HSD-test at $p \leq 0,05$.

4 RESULTS

4.1 Environmental conditions for growing

4.1.1 Solar irradiation

Solar irradiation was allowed to come into the greenhouse. Therefore, incoming solar irradiation was affecting plant development and was regularly measured. The natural light level was low during the whole growing period. From December to the beginning of February were less than 1 kWh/m^2 reached. After that increased the incoming solar irradiation up to 5 kWh/m^2 at the end of the experiment (Fig. 2).

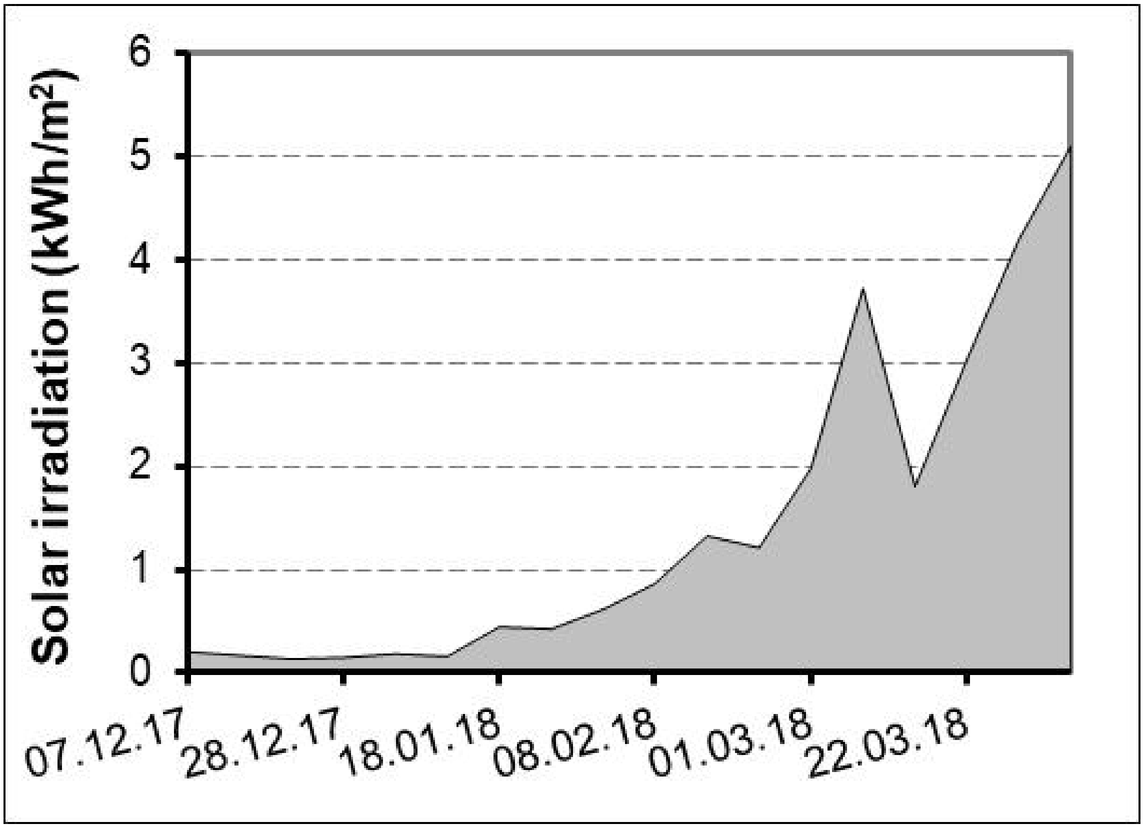


Fig. 2: Time course of solar irradiation.
Solar irradiation was measured every day and values for one week were cumulated.

4.1.2 Chamber settings

The settings in the chambers were regularly recorded. Table 3 shows the weekly average of the CO_2 amount and the average air and floor temperature as well as the average day and night temperature.

The mean CO_2 amount was in average a bit higher in the LED treatment due to nearly 50 % more often open windows in the HPS chamber. The CO_2 amount was in the LED chamber higher in the first three weeks of the growing period, while later in the growing period no differences between light sources were observed when week 8, 15 and 16 were excluded. In week 12 was the CO_2 amount higher in the HPS treatment, while in week 13 was it the other way round.

The air temperature was in average 0,4 °C higher in the HPS chamber. This was due to a higher day temperature in the HPS chamber because of the HPS lamps generate high radiant heat. This difference between chambers was much smaller during the night.

The floor temperature was comparable between light sources during the day. However, during the night was the temperature higher in the HPS chamber than in the LED chamber.

Tab. 3: Chamber settings.

Week	CO_2 (ppm)		Air (day / night) (°C)		Floor day / night (°C)	
	HPS	LED	HPS	LED	HPS	LED
1	497	527	13,0 (15,9 / 11,1)	12,5 (15,1 / 10,4)	34,8 / 23,5	34,9 / 21,3
2	460	487	16,4 (18,0 / 11,5)	15,2 (16,7 / 11,3)	34,8 / 28,0	34,9 / 26,2
3	433	470	15,0 (16,6 / 10,8)	14,5 (16,0 / 10,4)	34,8 / 20,9	34,9 / 17,3
4	727	723	14,9 (16,3 / 10,5)	14,2 (15,4 / 10,1)	34,8 / 19,9	34,9 / 17,2
5	712	724	16,2 (17,3 / 12,2)	15,5 (16,6 / 11,8)	34,8 / 21,9	34,9 / 18,9
6	728	741	16,0 (17,2 / 11,9)	15,4 (16,6 / 11,3)	34,8 / 21,8	34,9 / 18,8
7	540	527	15,7 (16,9 / 11,3)	15,0 (16,1 / 11,4)	34,8 / 21,7	34,9 / 19,2
8	649	736	15,9 (17,2 / 11,3)	15,5 (16,7 / 11,3)	34,8 / 21,5	34,9 / 19,1
9	696	729	15,9 (17,2 / 11,4)	15,5 (16,8 / 11,3)	34,8 / 21,5	34,9 / 19,1
10	744	757	15,5 (16,8 / 10,8)	15,0 (16,3 / 10,8)	34,8 / 21,3	34,9 / 18,5
11	682	713	16,0 (17,3 / 11,5)	15,6 (16,8 / 11,3)	34,8 / 21,6	34,9 / 18,9
12	717	681	16,5 (17,7 / 12,6)	16,1 (17,3 / 12,2)	34,8 / 22,7	34,9 / 19,9
13	678	735	15,7 (17,1 / 10,6)	15,4 (16,7 / 10,9)	34,8 / 21,8	34,9 / 18,9
14	710	722	15,5 (16,9 / 11,0)	15,2 (16,6 / 10,9)	34,8 / 21,3	34,9 / 18,5
15	578	636	16,6 (17,9 / 12,3)	16,3 (17,5 / 12,0)	34,8 / 20,5	34,9 / 18,4
16		637		16,0 (17,3 / 11,5)		34,9 / 17,8
17		645		15,9 (17,3 / 11,2)		35,1 / 17,7
Ø	**637**	**659**	**15,6 (17,1 / 11,4)**	**15,2 (16,6 / 11,2)**	**34,8 / 22,0**	**34,9 / 19,2**

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation at 10.00 (except on 15.02 was measured at 12.00) and fluctuated between 14-19 °C. Soil temperature was most of the time significantly higher in the HPS chamber compared to the LED chamber. In average amounted the difference about 1 °C. While in the LED chamber no differences between varieties were observed, was the temperature in the pots with Magnum tendentially and sometimes during the latter part of the growing period significantly higher than with Sonata (Fig. 3).

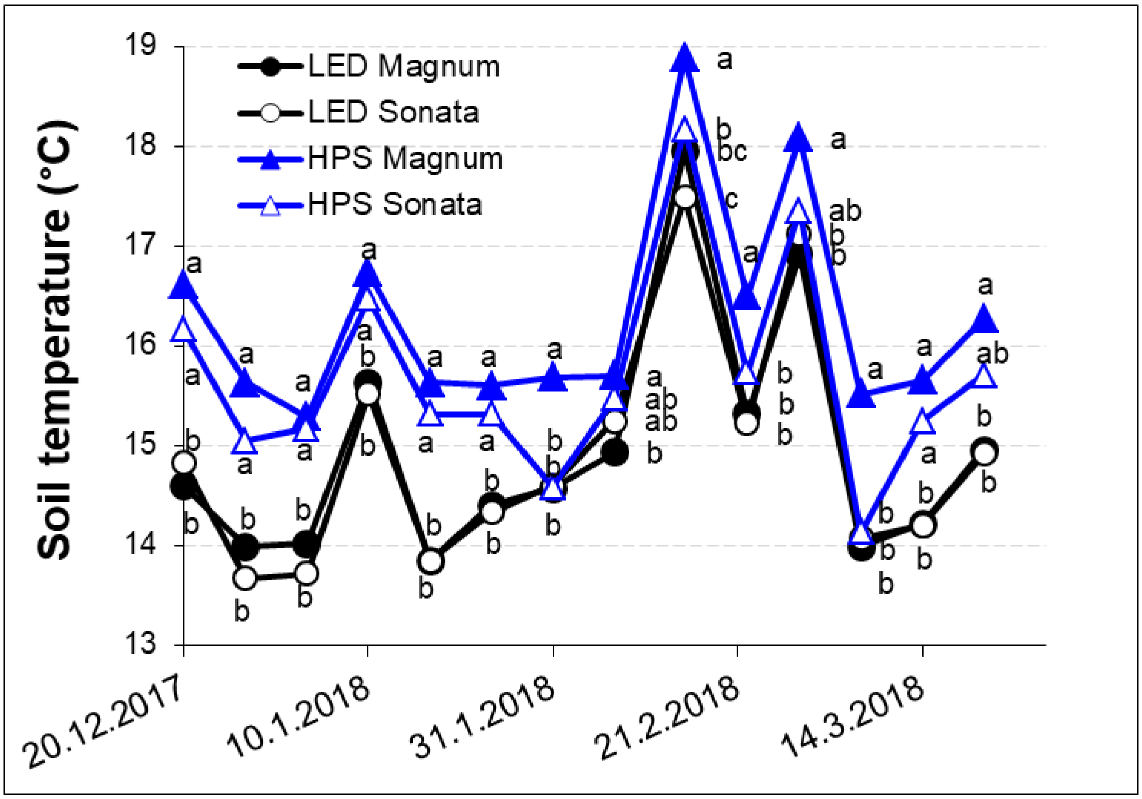


Fig. 3: Soil temperature.

Letters indicate significant differences during the growing period (HSD, p ≤ 0,05).

4.1.4 Leaf temperature

Leaf temperature was measured weekly at low solar radiation at 10.00 (except on 15.02 was measured at 12.00). Leaf temperature fluctuated between 12-20 °C. Leaf temperature was most of the time higher in the HPS chamber compared to the LED chamber. In average was the leaf temperature nearly 3 °C higher in the HPS chamber. Differences between varieties were not observed (Fig. 4).

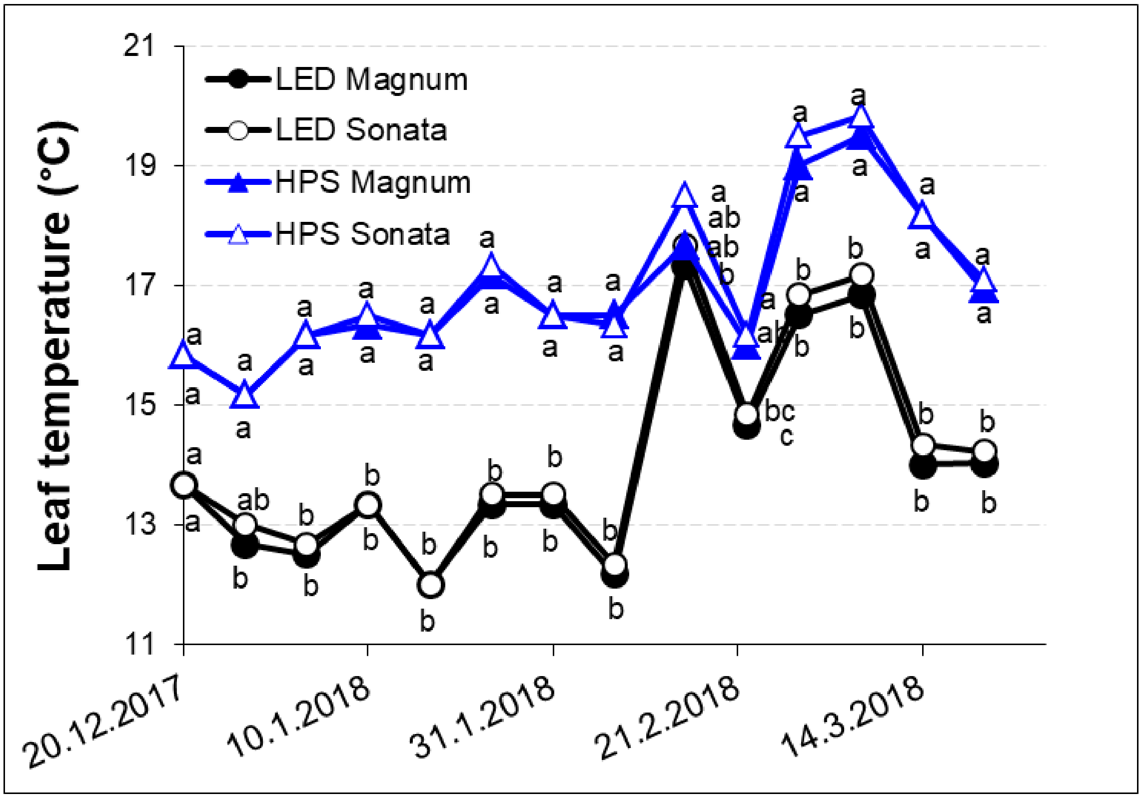


Fig. 4: Leaf temperature.

Letters indicate significant differences during the growing period (HSD, $p \leq 0,05$).

4.1.5 Irrigation of strawberries

The amount of applied water increased with longer growth of the strawberries from about 100 ml/plant to about 400 ml/plant (Fig. 5). The plants in the LED chamber were watered with a lower amount of water than the HPS chamber. Even though, was the growing media more wet in the LED treatment. More water was applied to Magnum compared to Sonata.

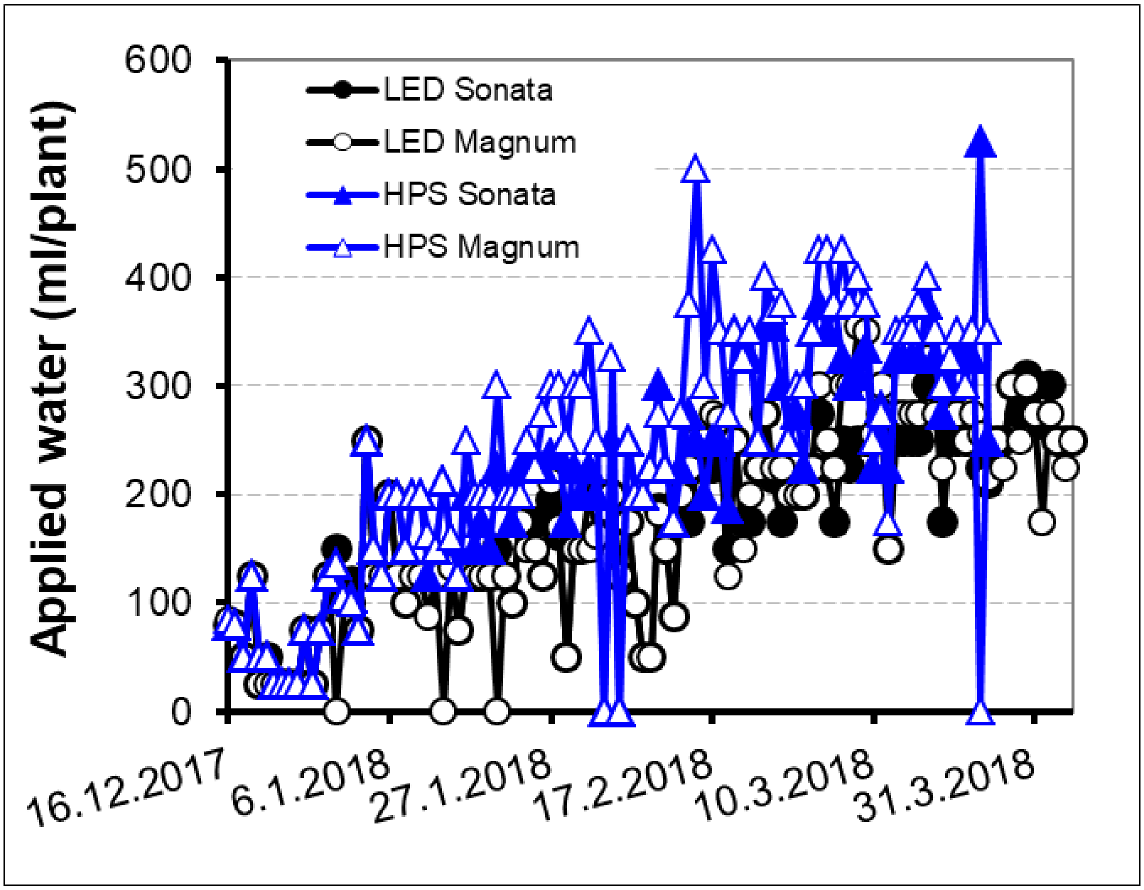


Fig. 5: **Daily applied water.**

E.C. and pH of irrigation water was fluctuating much (Fig. 6). The E.C. of applied water ranged most of the time between 1,2-2,0 and the pH between 4,0-7,0. The E.C. of runoff stayed most of the time between 0,8-2,4 and the pH between 5,5-8,5.

At the beginning of the growing period was the irrigation adjusted to no runoff due to the rooting down of the roots. After that was the amount of runoff increased. The amount of runoff from applied irrigation fluctuated very much and varied most of the time between 10-50 % runoff. In average had Sonata a higher runoff than Magnum (Fig. 7).

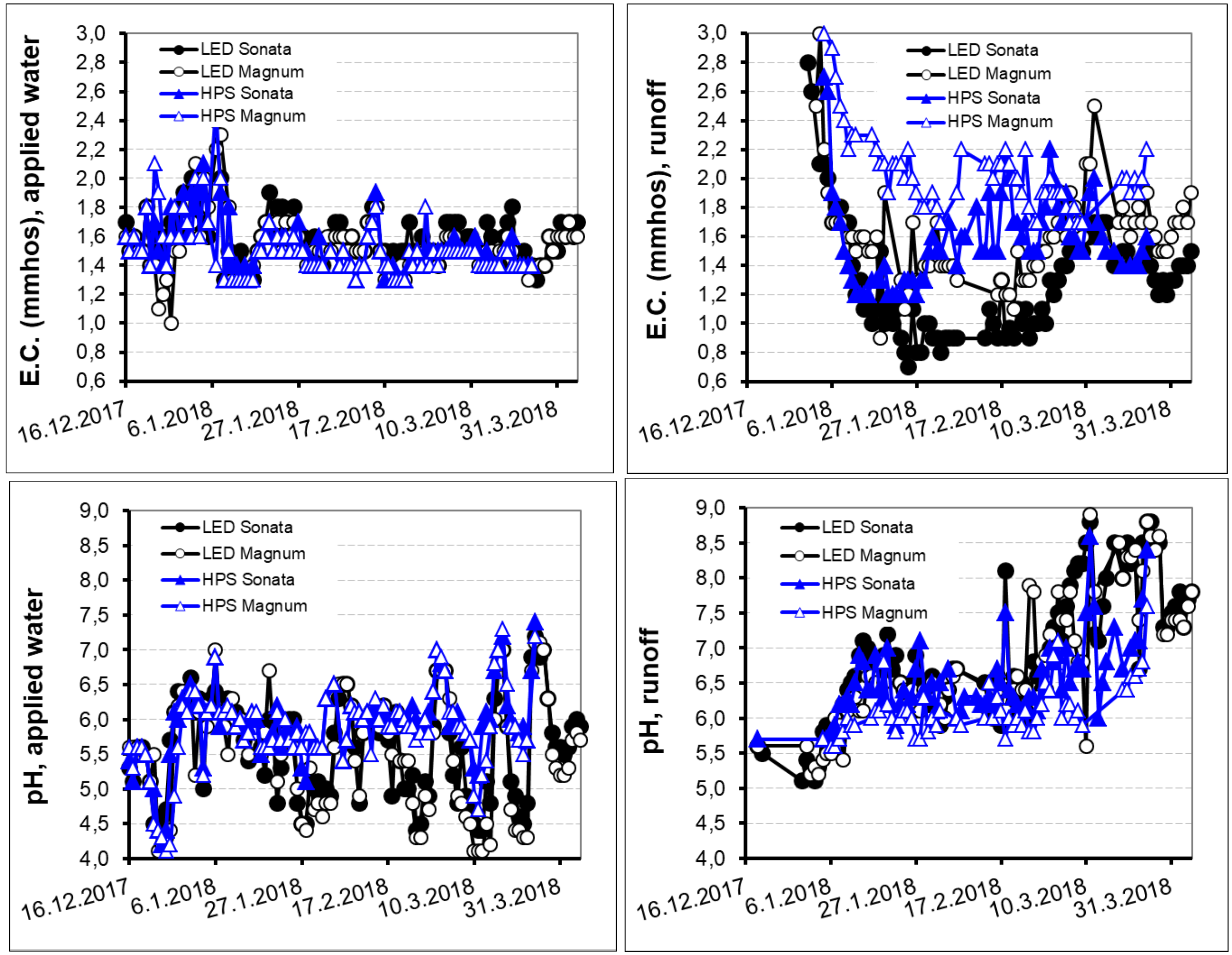


Fig. 6: E.C. and pH of irrigation water and runoff.

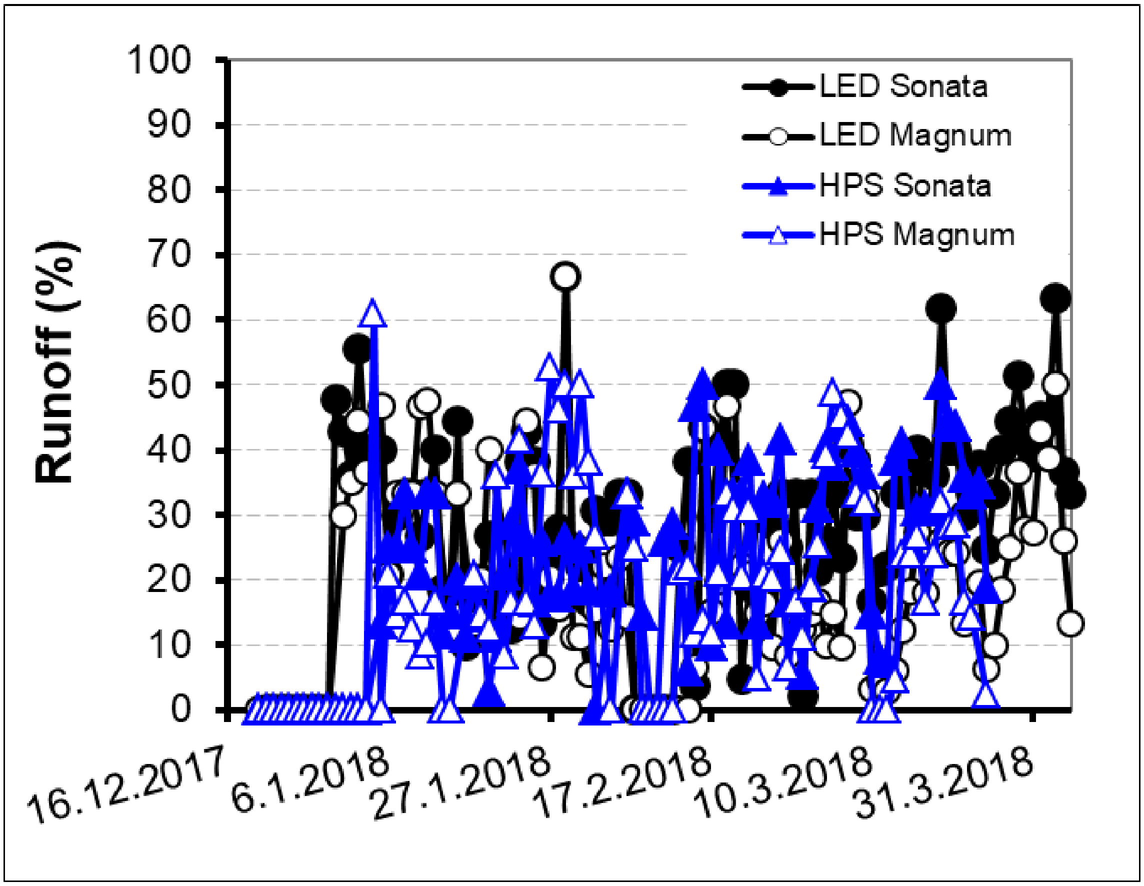


Fig. 7: Proportion of amount of runoff from applied irrigation water.

4.2 Development of strawberries

4.2.1 Plant diseases

Some strawberry plants of Sonata were infected with phytopthora (*Phytopthora cactorum*). Infected plants were removed. Symptoms started to appear about one month after planting. However, the amount of Sonata plants with phytopthora was low and amounted 2 % in the HPS chamber and 1 % in the LED chamber. Magnum was not infected with phytopthora.

4.2.2 Number of leaves

The number of leaves increased for Sonata from 14 to 26 and for Magnum from 16 to 30 (Fig. 8). No significant differences in the number of leaves between light sources and between varieties were found. However, the leaves in the HPS chamber started earlier to grow after planting. In addition, the leaves were also taller in the HPS chamber. Under both light sources had Magnum taller leaves than Sonata (data not shown).

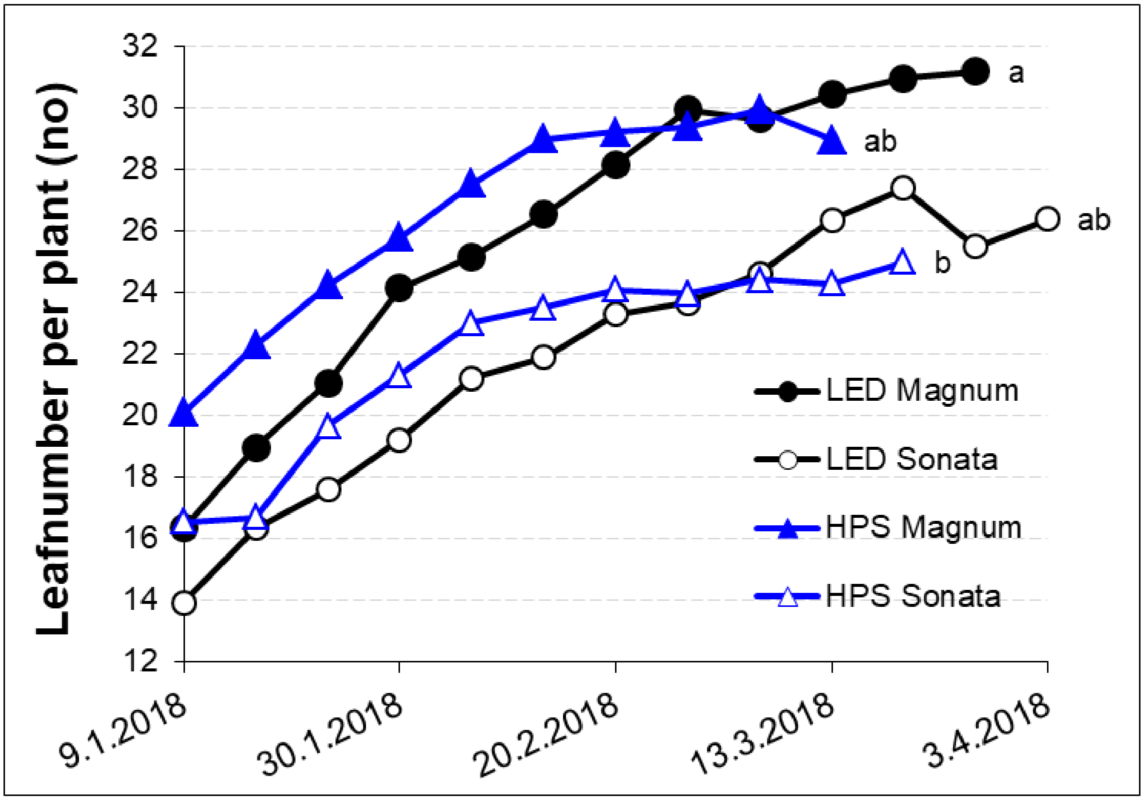


Fig. 8: Number of leaves at strawberry plants.

Letters indicate significant differences at the end of the each growing period (HSD, $p \leq 0,05$).

4.2.3 Number of runners

Strawberry plants of the variety Magnum had more than six runners per plant while Sonata had about four runners per plant. The light source was not influencing the number of runners (Fig. 9).

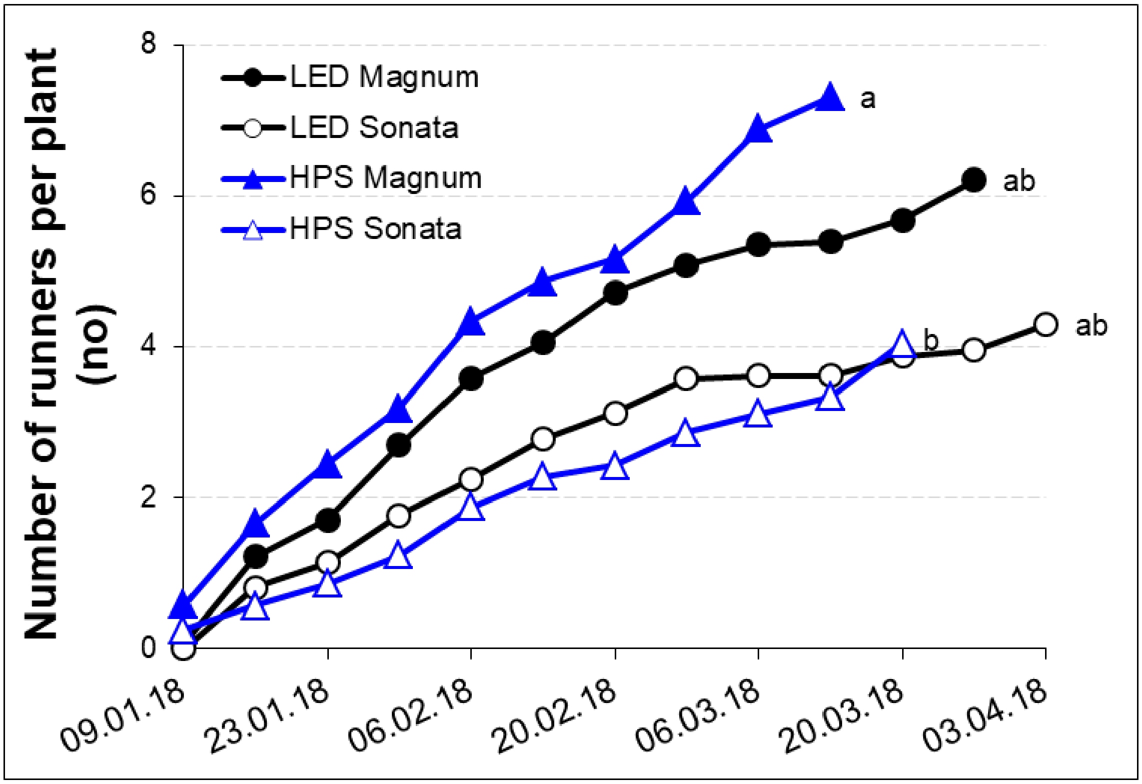


Fig. 9: Number of runners at strawberry plants.

Letters indicate significant differences at the end of each growing period (HSD, $p \leq 0,05$).

4.2.4 Number of clusters

The number of clusters with flowers and / or fruits increased until the beginning of the harvest and decreased after that when all fruits from a cluster were harvested. The development (increasing and decreasing) of plants in the LED chamber was a bit behind of the plants in the HPS chamber (Fig. 10).

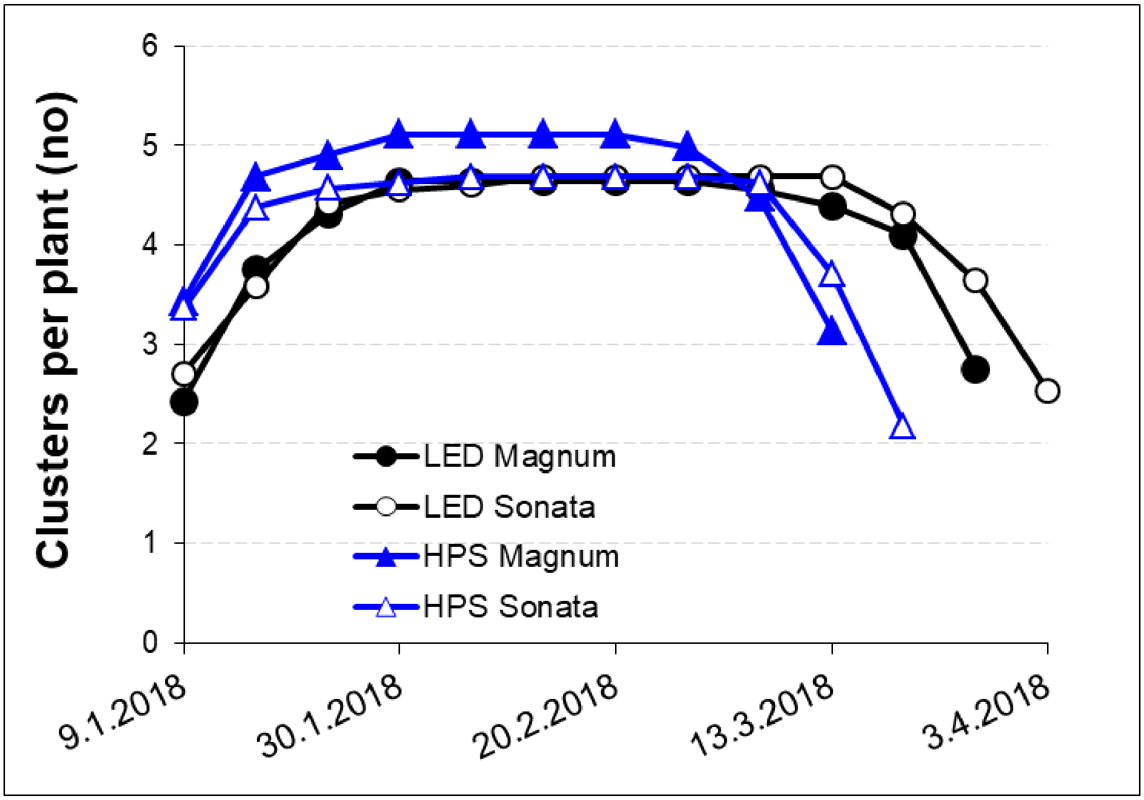


Fig. 10: Number of clusters at strawberry plants.

4.2.5 Open flowers / fruits per cluster

The number of open flowers / fruits per cluster reached about 12 for Sonata and 9 for Magnum (Fig. 11). After that, the number decreased naturally due to harvested fruits. The peak was delayed at the LED treatment compared to the HPS treatment (Fig. 11).

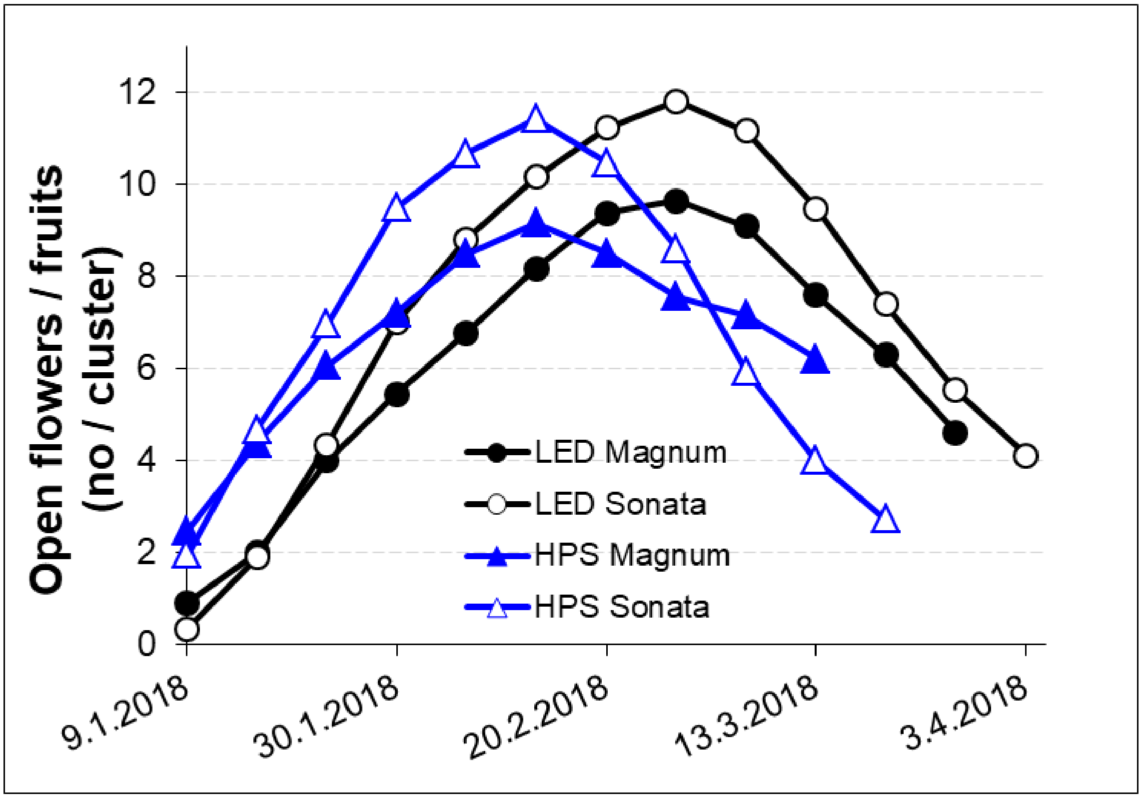


Fig. 11: Number of flowers / fruits per cluster.

4.2.6 Open flowers / fruits per plant

The number of open flowers / fruits of the Sonata plant reached about 55, while the Magnum plant reached about 45 before harvest started (Fig. 12). Thereafter, this number decreased naturally due to harvested fruits. The open flowers appeared earlier in the HPS chamber than in the LED chamber, where the development was 1,5-2 weeks behind plants from the HPS chamber. However, the number of the flowers / fruits was not different between chambers, except the before mentioned delay in the LED chamber (Fig. 12).

However, the total number of flowers of Magnum consisted of a high amount of unpollinated flowers and later rejected flowers, 15 % under LEDs and 27 % under HPS lights (Fig. 13). This was not observed for Sonata, where the percentage of unpollinated flowers was 1 %.

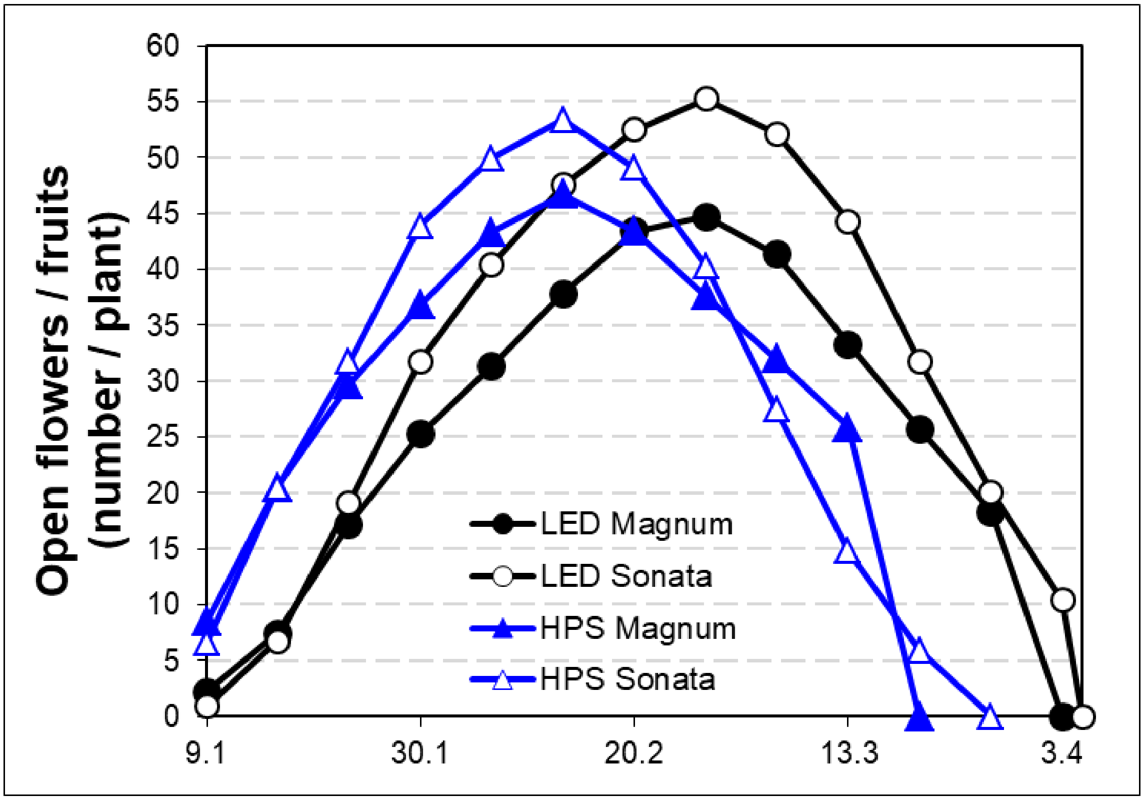


Fig. 12: Open flowers / fruits per plant.

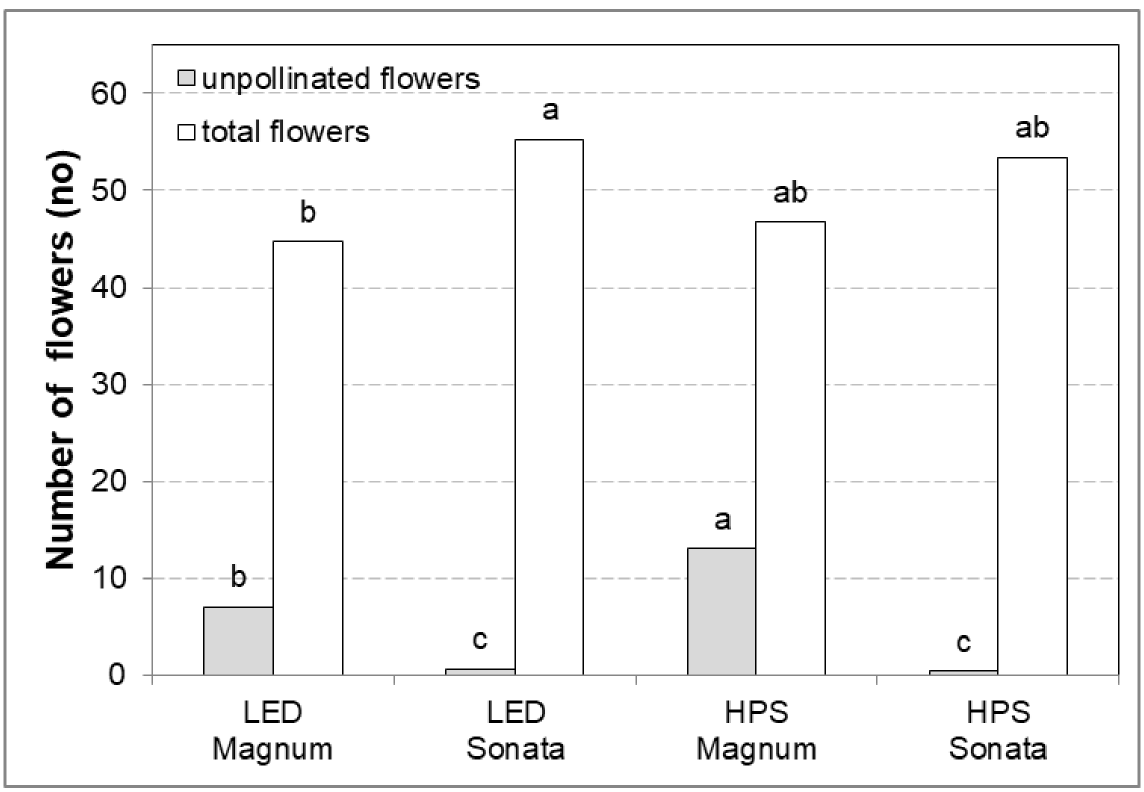


Fig. 13: Number of total flowers and unpollinated flowers.

Letters indicate significant differences at the end of each growing period (HSD, $p \leq 0,05$).

4.3 Yield

4.3.1 Total yield of strawberries

The yield of strawberries included all harvested red fruits during the growth period. The fruits were classified in extra-class (> 25 mm), 1. class (18 mm) and not marketable fruits (too little fruits (< 18 mm), misshaped fruits, moldy fruits and green fruits at the end of the harvest period).

Cumulative total yield of strawberries ranged between 0,46-0,65 g/plant (Fig. 14). For the experimental plants was a significantly higher yield of Sonata measured under LED lights, whereas for Magnum was the yield tendentially higher under HPS lights (Fig. 14a). However, this difference was not observed for the plants, where only the yield was measured (Fig. 14b). There seem to be a small advantage in the total yield for Sonata compared to Magnum.

4.3.2 Marketable yield of strawberries

At the end of the harvest period amounted yield of strawberries 0,40-0,61 g/plant (Fig. 15a, Fig. 15b). The light source had no influence on marketable yield of the plants where only the yield was measured (Fig. 15b). However, the marketable yield of the measurement plants was for Sonata significantly higher under LEDs, whereas for Magnum was no significant difference regarding light sources observed (Fig. 15a). But, it took two more weeks to get ripe fruits in the LED chamber compared to the HPS chamber. Also, the harvest in the HPS treatment ended two weeks before the LED treatment.

Regarding the variety, was the marketable yield of Sonata (580 / 590 g/plant under LED, 540 / 610 g/plant under HPS) tendentially respectively significantly higher than the marketable yield of Magnum (400 / 530 g/plant under LED, 440 / 520 g/plant under HPS). The marketable yield of Magnum was 69 % (LED) / 88 % (HPS) (Fig. 15a) and 89 % (LED) / 85 % (HPS) (Fig. 15b) of the marketable yield of Sonata. Magnum was about half a week earlier ripe than Sonata. Differences between varieties developed at the middle of the harvest period with an advantage of Sonata. The last berries of Magnum were harvested half a week earlier than the berries of Sonata.

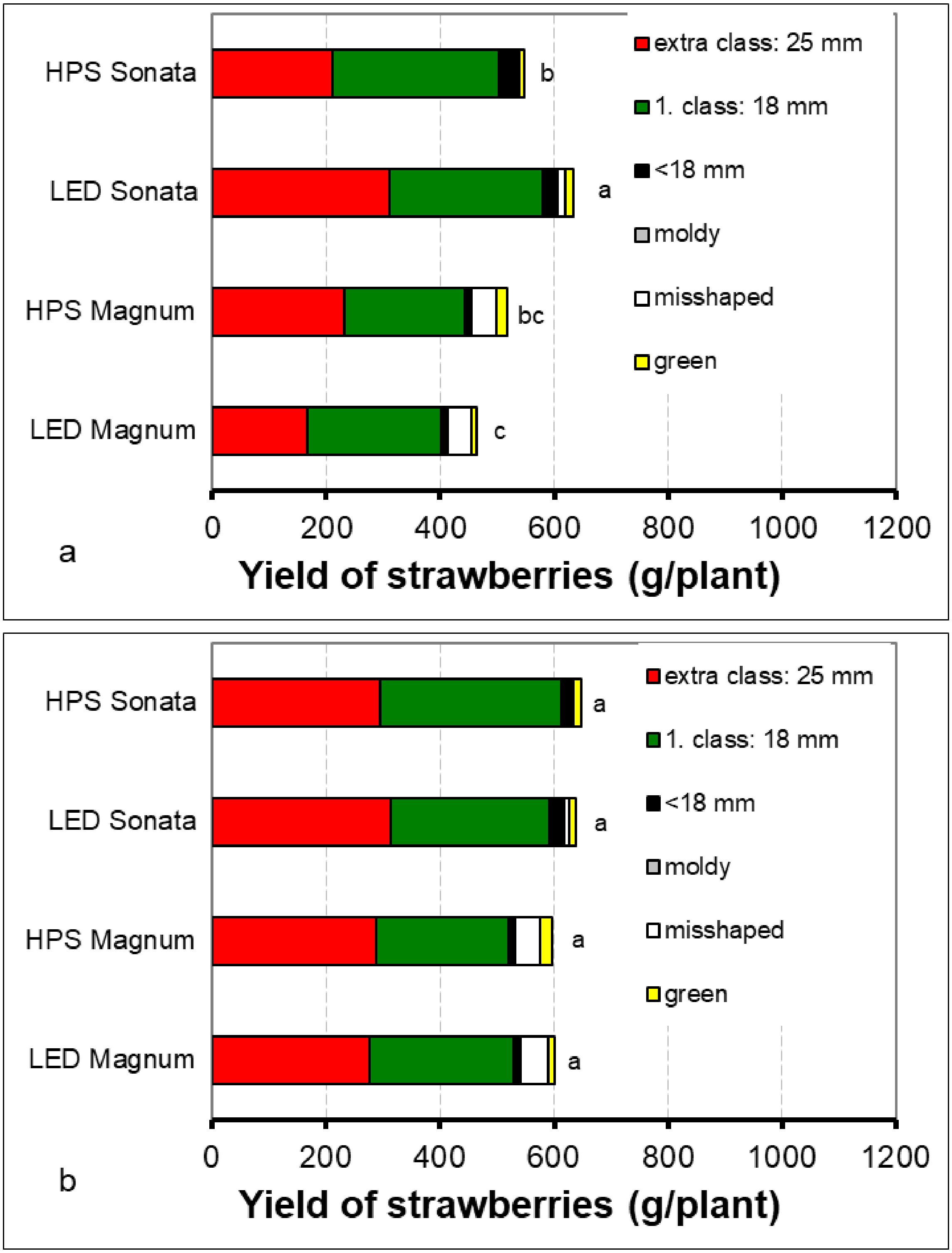


Fig. 14: Cumulative total yield of strawberries.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0{,}05$).

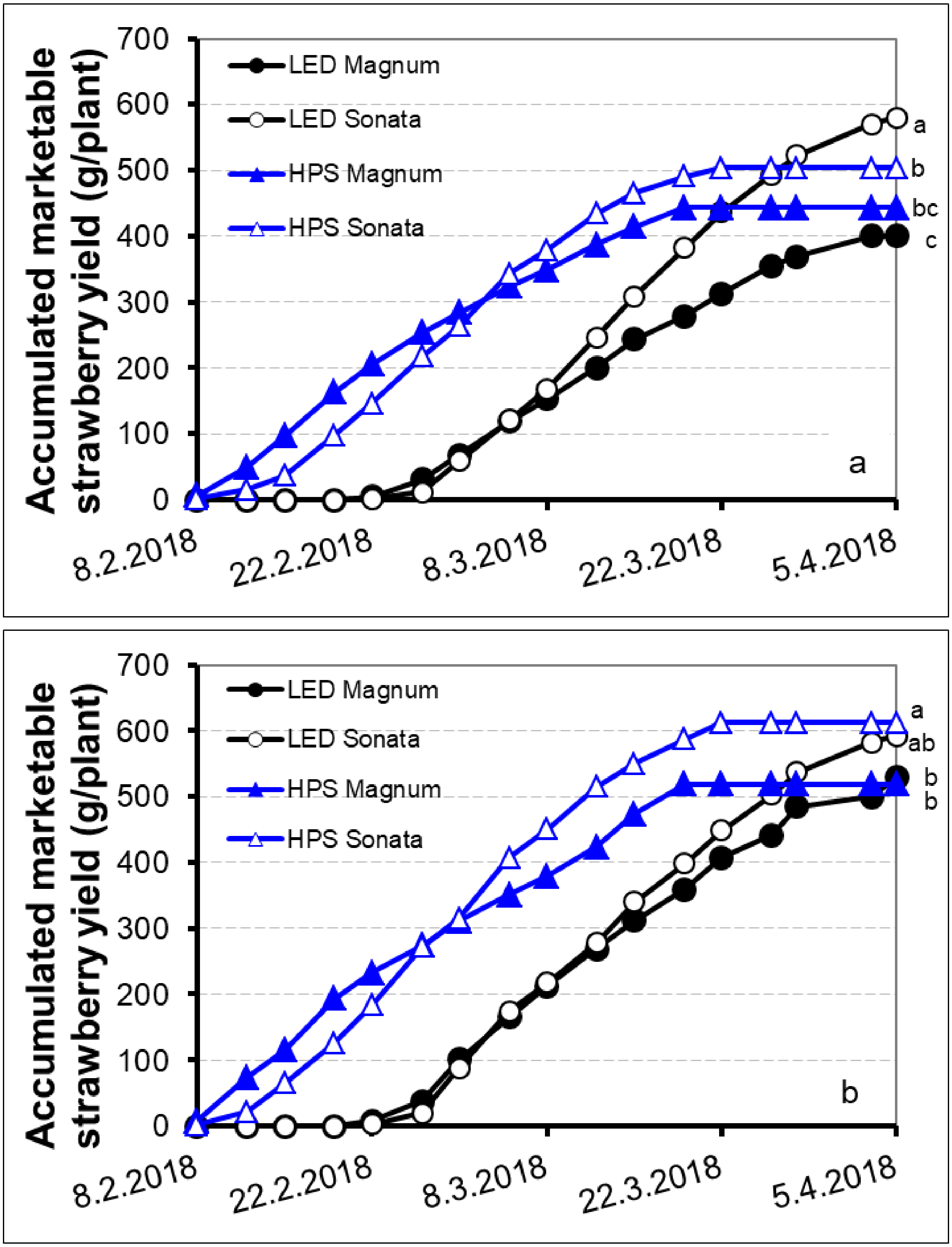


Fig. 15: Time course of accumulated marketable yield of strawberries.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

Letters indicate significant differences at the end of the experiment (HSD, $p \leq 0,05$).

Also, the marketable yield of the whole chamber was measured. A higher marketable yield was reached with Sonata (LED: 570 g/plant, HPS: 550 g/plant) compared to Magnum (LED: 460 g/plant, HPS: 510 g/plant) (Fig. 16). Regarding light sources, for Magnum was an advantage of the HPS treatment compared to the LED treatment reached, while for Sonata were no differences between light sources calculated.

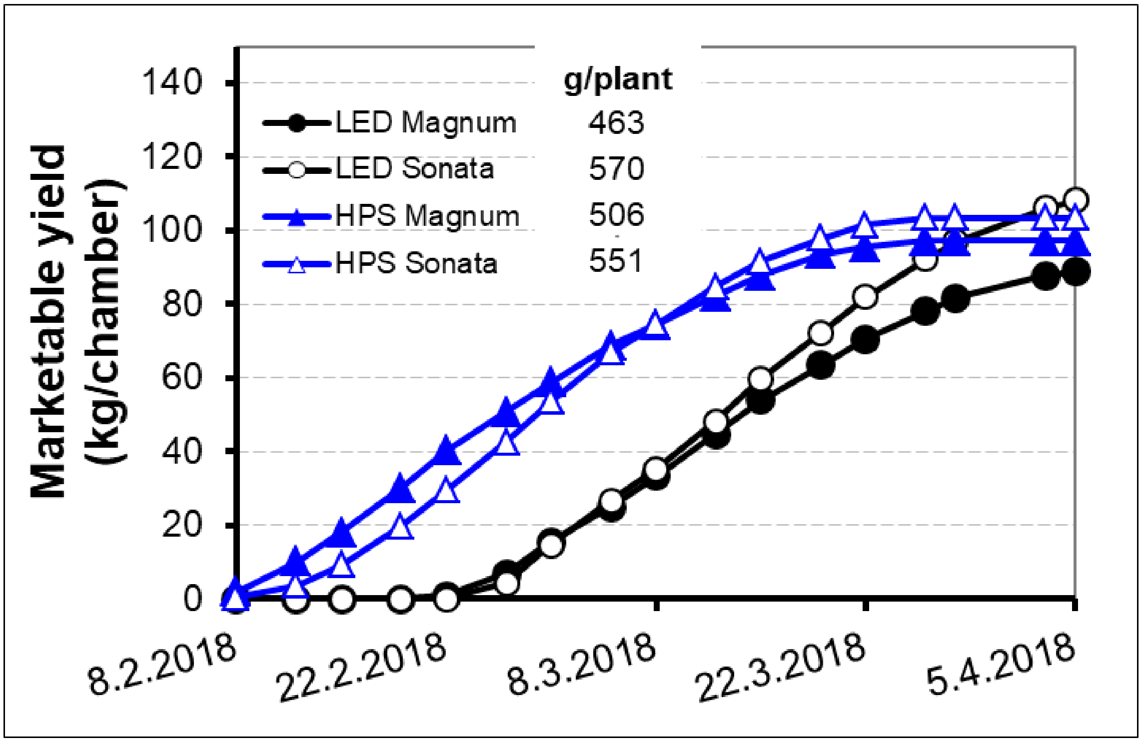
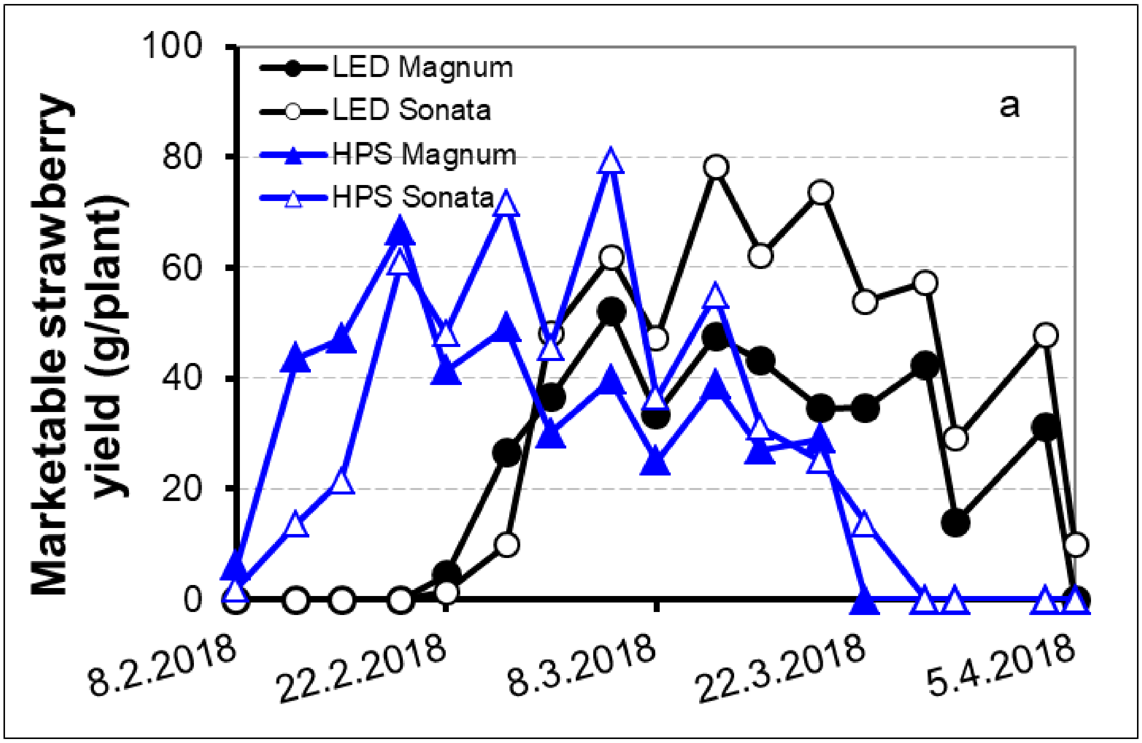


Fig. 16: Time course of accumulated marketable yield of strawberries for the whole chamber.

Fruits in the HPS chamber started earlier to ripe, resulting in a higher first yield, whereas later the marketable yield increase decreased. In the LED treatment gave the plants later than the HPS treatment marketable ripe berries. The marketable yield on each harvest day was nearly always higher for Sonata (Fig. 17).



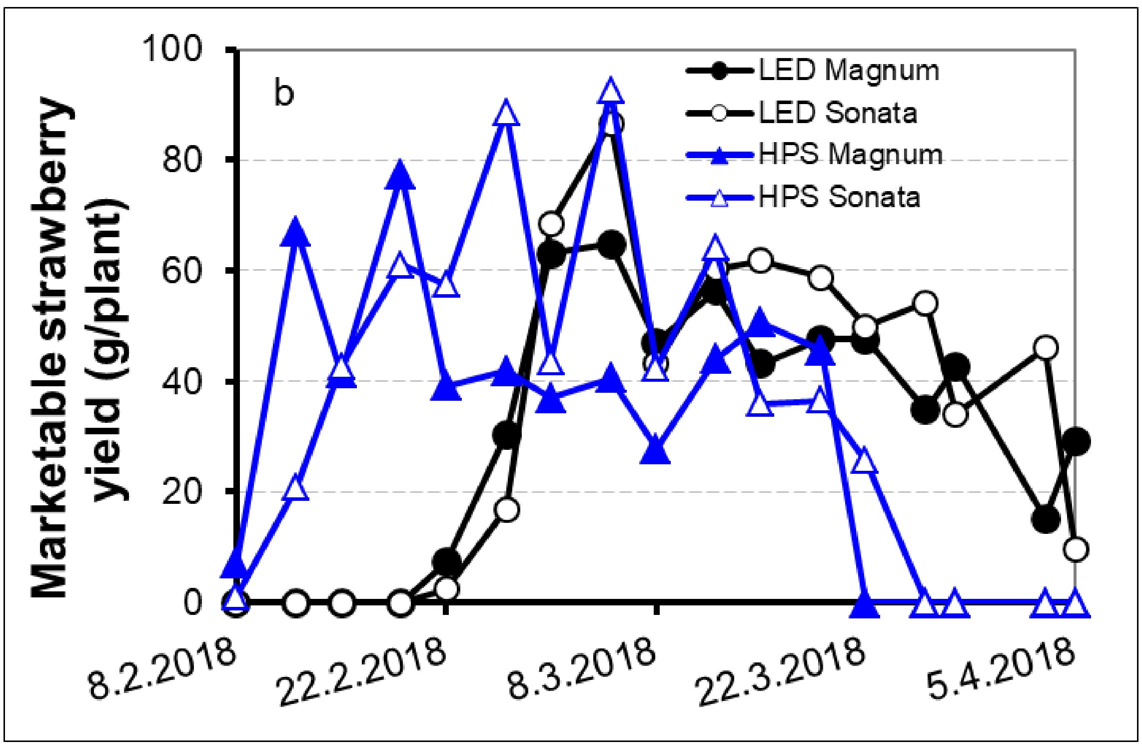


Fig. 17: Time course of marketable yield.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

There were no differences in the number of extra class fruits, neither between light sources nor between varieties when the significant higher number of extra class fruits with the variety Sonata under LED lights compared to HPS lights and the significant higher number of extra class fruits of Sonata compared to Magnum under LED lights was excluded (Tab. 4). For "class I + II" were no significant differences between light sources counted. In contrast, Sonata had a significant (under HPS lights) / respectively tendentially (under LED lights) higher number of first and second class fruits. However, when the sum of the marketable fuits was observed, was mostly a significant higher number of fruits for Sonata examined, whereas no differences between light sources were found.

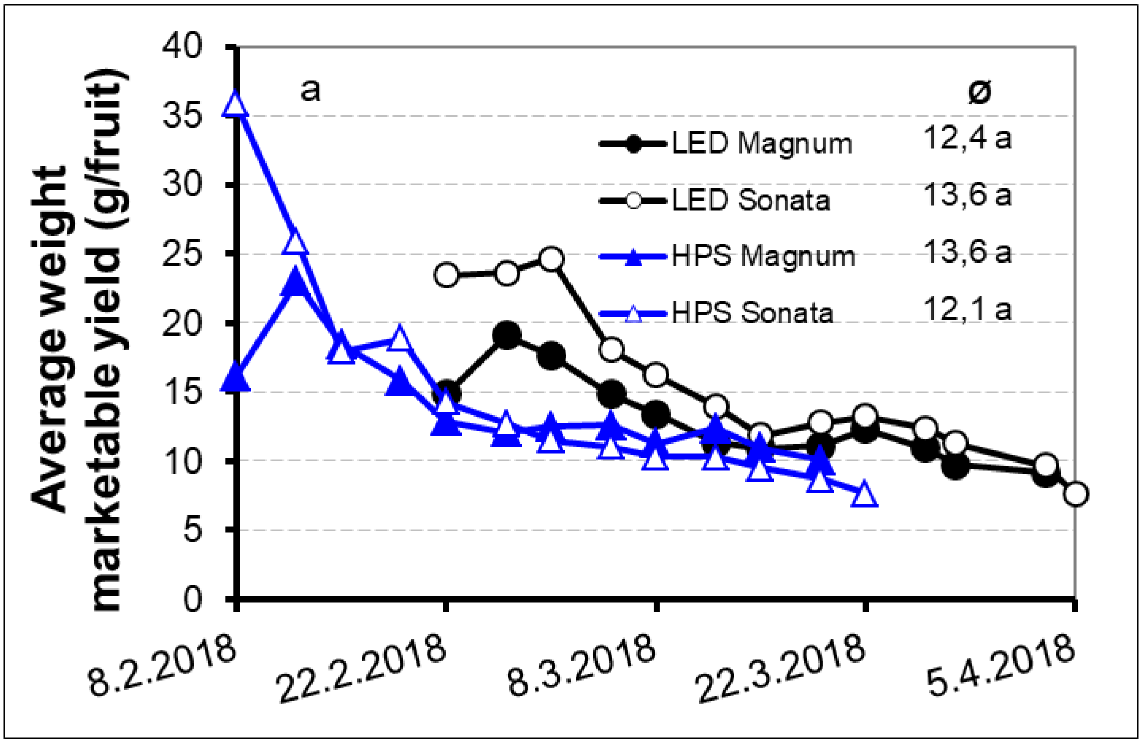
Tab. 4: Cumulative total number of marketable fruits.

Treatment	Number of marketable fruits		
	extra class (no/plant)	class I + II (no/plant)	total (extra class + class I + II) (no/plant)
HPS Sonata	10 b	32 a	42 a
LED Sonata	14 a	28 ab	43 a
HPS Magnum	11 ab	22 c	33 b
LED Magnum	8 b	24 bc	33 b
HPS Sonata *	15 a	33 a	48 a
LED Sonata *	14 a	29 ab	44 ab
HPS Magnum *	14 a	24 b	38 b
LED Magnum *	13 a	25 b	39 b

* for the plants, where only the yield was measured

Letters indicate significant differences (HSD, $p \leq 0{,}05$).

Average fruit size of marketable fruits decreased from 15-35 g to around 10 g during the harvest period (Fig. 18a, 18b). No significant differences between light sources and between varieties were observed in the average weight of the marketable fruits. However, Sonata had a tendentially higher average weight of 1 g under LED lights (Fig. 18a, 18b), whereas this effect was not observed with Magnum (Fig. 18b), respectively was it the other way round for the experimental plants (Fig. 18a). But, as stated before, were these differences not statistically significant.



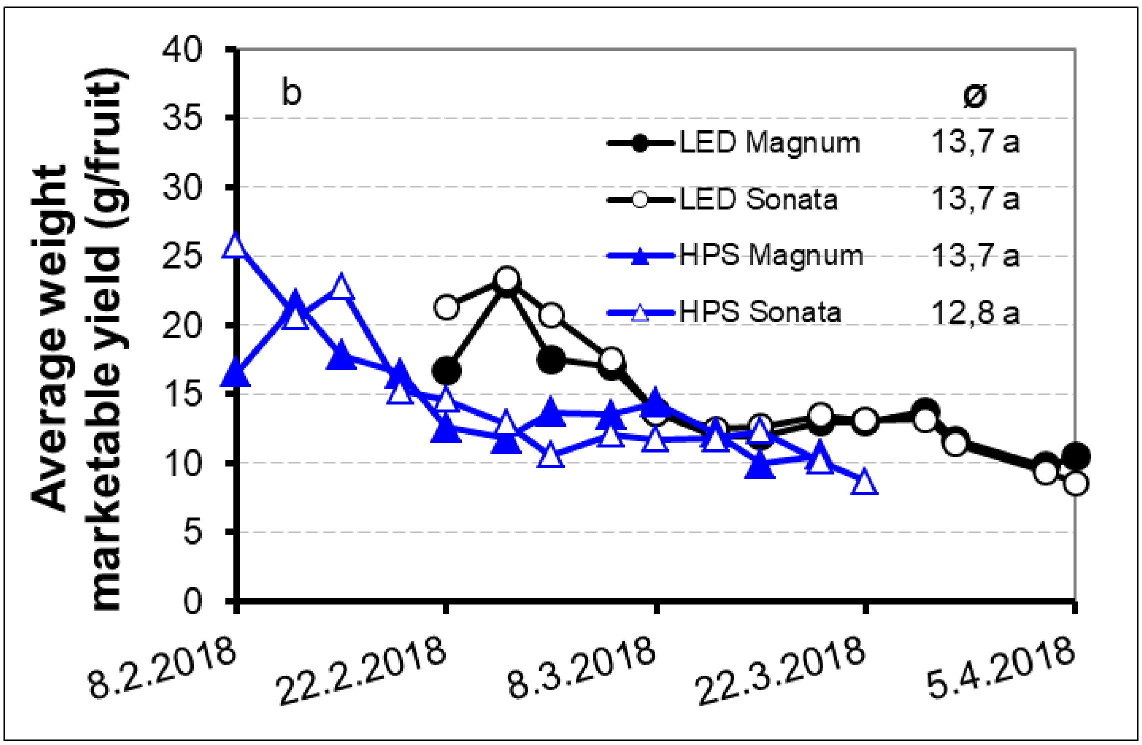


Fig. 18: Average weight of strawberries.
"a" is the average weight of the measurement plants, "b" the yield of the plants, where only the yield was measured.

To observe the success of flowering until harvest, flowers were marked and followed from pollination until harvest. Flowers were within 1-2 days pollinated (data not shown). Under HPS lights needed fruits of Sonata and Magnum fewer days to ripe than under LED lights. LEDs increased the number of days to get ripe fruits by five days. Number of days from pollination to harvest of Sonata was 33-46 days (average: 41 days) under HPS lights and 41-56 (average: 47 days) under LED lights and for Magnum 31-49 (average: 40 days) under HPS lights and 39-55 (average: 45 days) under LED lights (Fig. 19). The variety seems to have no influence on the number of days. No relationship was found between the number of days from pollination to harvest and the weight of the fruit.

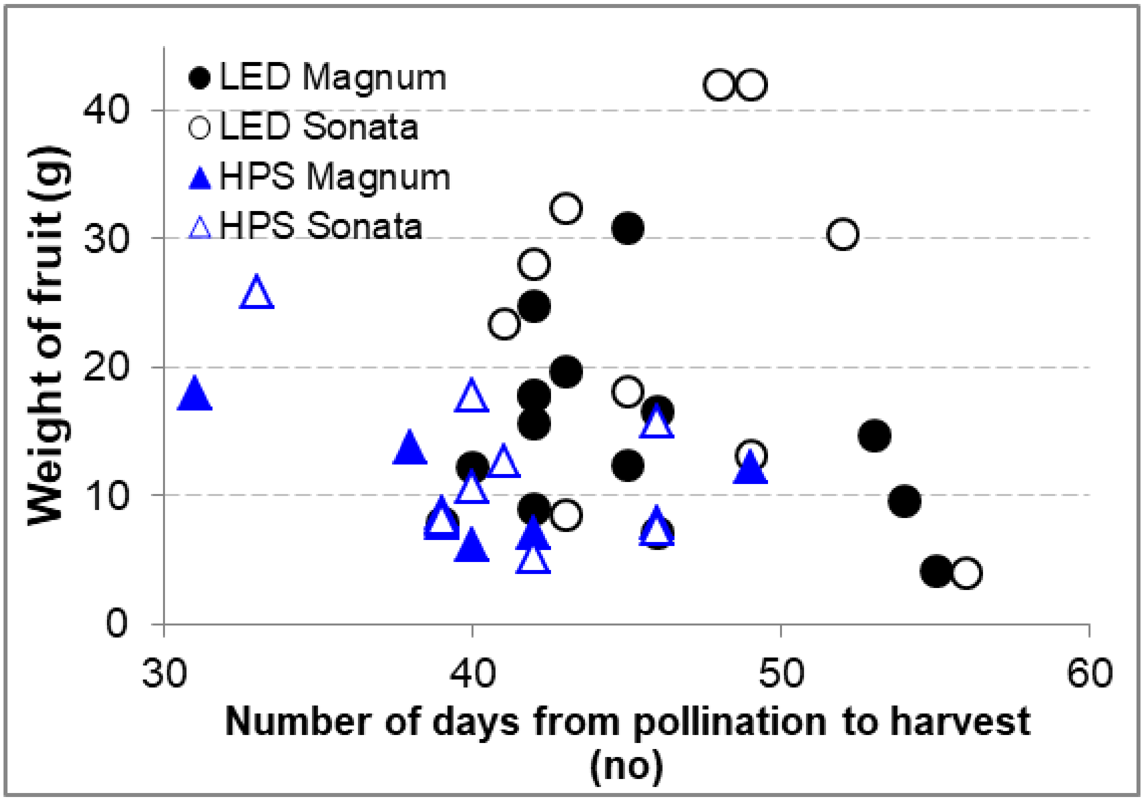


Fig. 19: Number of days from pollination to harvest and weight of the harvested fruit.

In the middle of the harvest of Sonata were most ripe fruits per week counted compared to the beginning (first two weeks) and the end of the harvest period (last two weeks). Around 10 fruits were weekly harvested when harvest reached its maximum (Fig. 20a). In contrast, for Magnum was the harvest more even during the harvest period and weekly were around six fruits harvested (Fig. 20b).

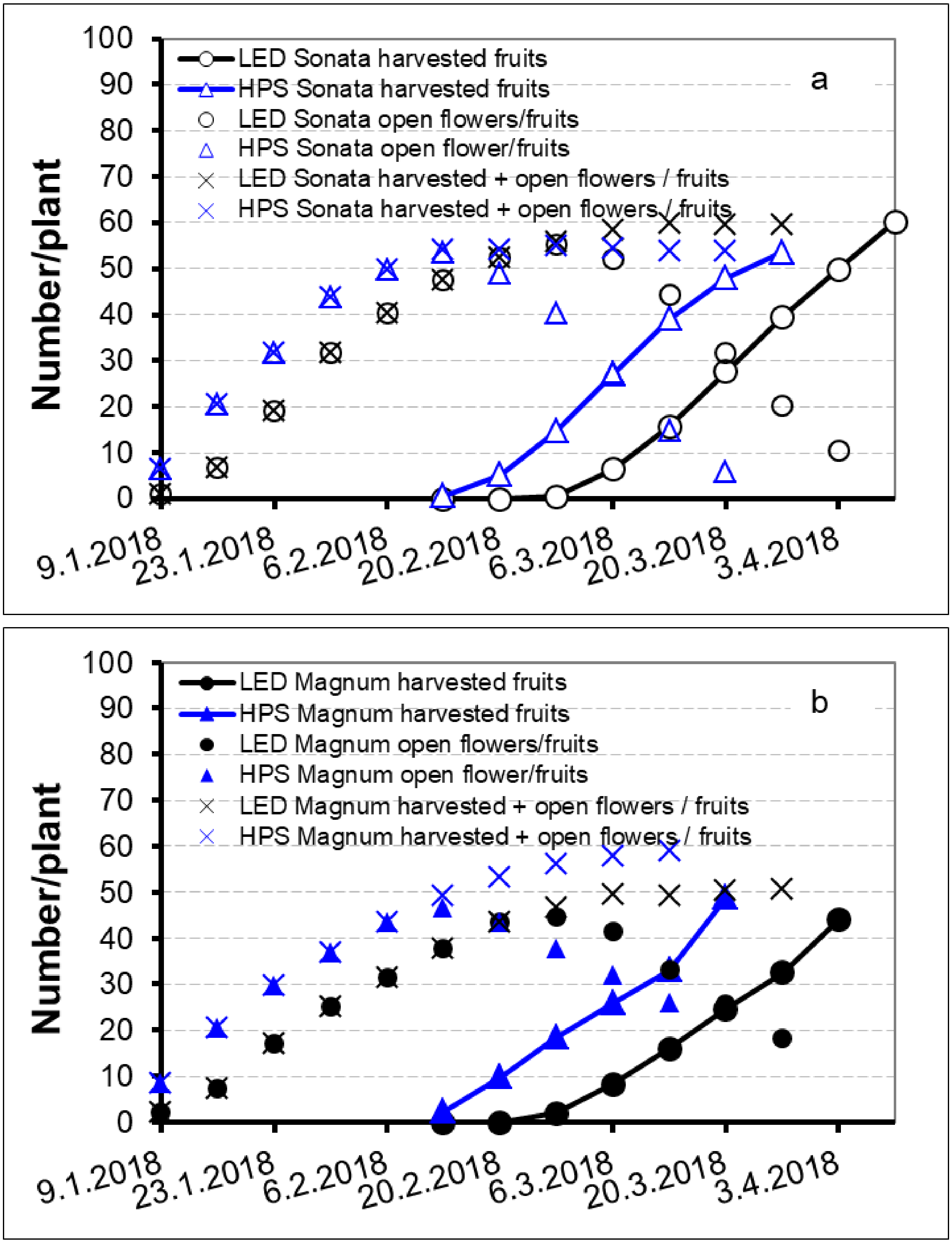


Fig. 20: Development of open flowers / fruits, harvested fruits and their sum during the growth of the strawberries.

Naturally, with the beginning of the harvest decreased the number of open flowers and fruits. The number of “harvested and open flowers / fruits” is the sum of the harvested fruits and the number of open flowers / fruits that was registered at weekly measurements. This number was about 50-60 flowers / fruits for both varieties.

4.3.3 Outer quality of yield

Marketable yield was about 90 % (Tab. 5). Sonata had a higher amount of marketable fruits than Magnum. There seem to be no difference between light sources in the proportion of marketable and unmarketable yield. Sonata seem to have a significantly respectively a tendentially higher proportion of too little fruits. In contrast, significantly more misshaped fruits were counted for Magnum.

Tab. 5: Proportion of marketable and unmarketable yield.

Treatment	Marketable yield (%)		Unmarketable yield (%)			
	extra class > 25 mm	1. class > 18 mm	too little weight	moldy	mis-shaped	green
HPS Sonata	38 a	54 a	5 a	0 a	1 b	2 a
LED Sonata	49 a	43 b	4 ab	0 a	2 b	2 a
HPS Magnum	44 a	41 b	2 c	0 a	9 a	3 a
LED Magnum	36 a	50 ab	3 bc	0 a	9 a	2 a
HPS Sonata *	46 a	49 a	3 ab	0 a	1 b	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
LED Magnum *	46 a	42 ab	2 b	0 a	8 a	2 a

* for the plants, where only the yield was measured

Letters indicate significant differences at the end of the experiment (HSD, p ≤ 0,05).

4.3.4 Interior quality of yield

4.3.4.1 Sugar content

Sugar content of strawberries was measured at three times during the harvest period. Due to differences in the ripening, different sample dates between treatments had to be taken. Magnum had with values of 10-11°BRIX a higher sugar content than Sonata with values of 8-9°BRIX. There were no differences between light sources measured. It seems that the sugar content increased at the end of the harvest period (Fig. 21).

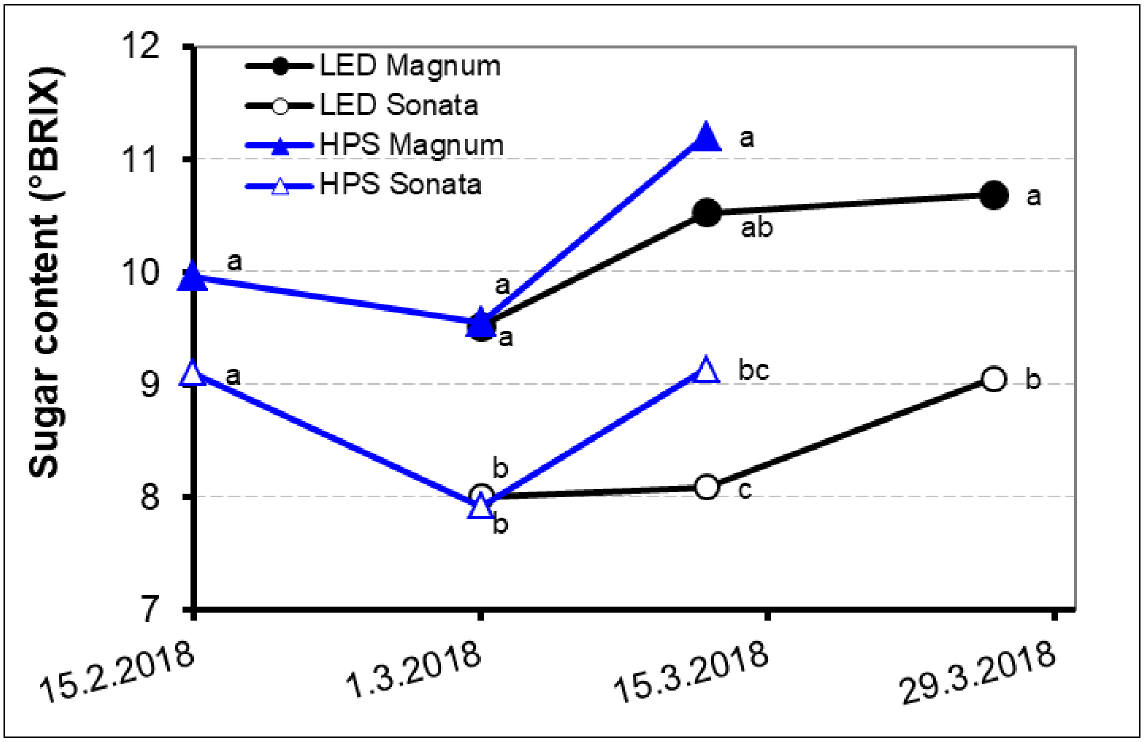


Fig. 21: Sugar content of strawberries.

Letters indicate significant differences (HSD, $p \leq 0,05$).

4.3.4.2 Taste of strawberries

The taste of strawberries, subdivided into sweetness, flavour, juiciness and firmness was tested by untrained assessors on 02.03.2018. The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. It seems that the light source did not influence the sweetness, flavour and juiciness of strawberries, while the firmness seems to be higher under LED lights. It seems that Sonata was evaluated with more juiciness while Magnum was evaluated with more firmness (Fig. 22).

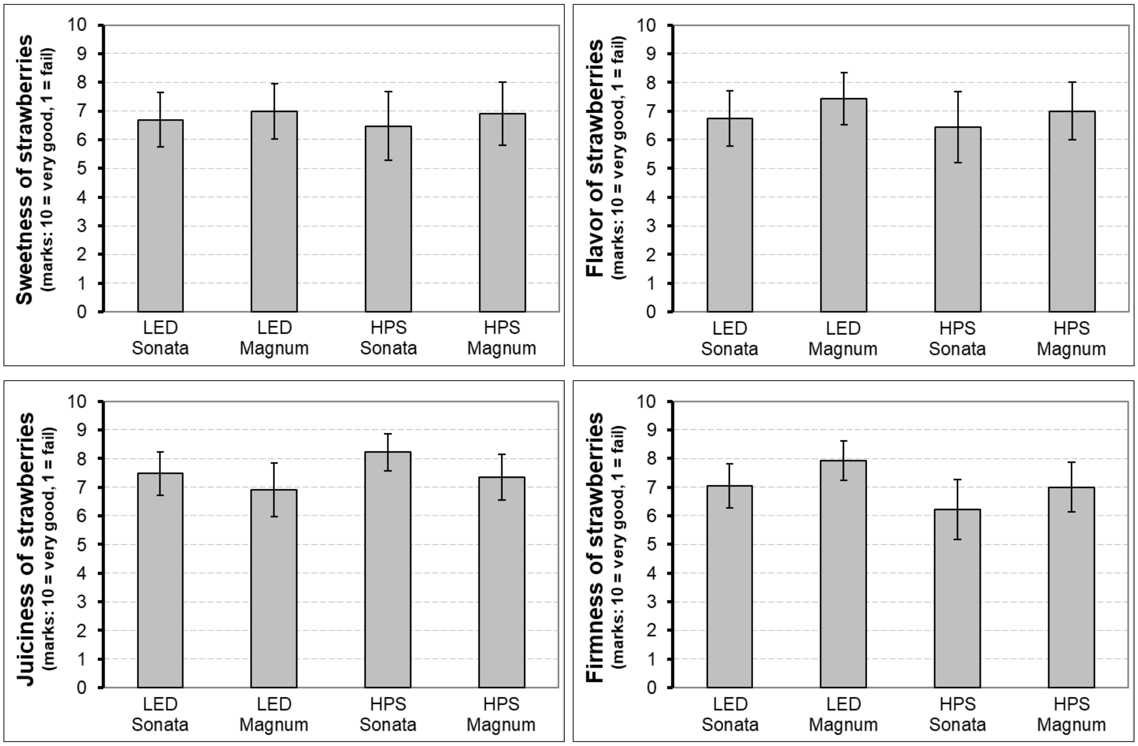


Fig. 22: Sweetness, flavour, juiciness and firmness of strawberries.

4.3.4.3 Dry substance of fruits

Dry substance (DS) of strawberries was measured on the same dates as the sugar content. Magnum had a significantly higher dry substance than Sonata. Between the light sources were no differences found. It seems that the dry substance increased during the harvest period from about 8 to 9 % for Sonata and from 9 to 11 % for Magnum (Fig. 23).

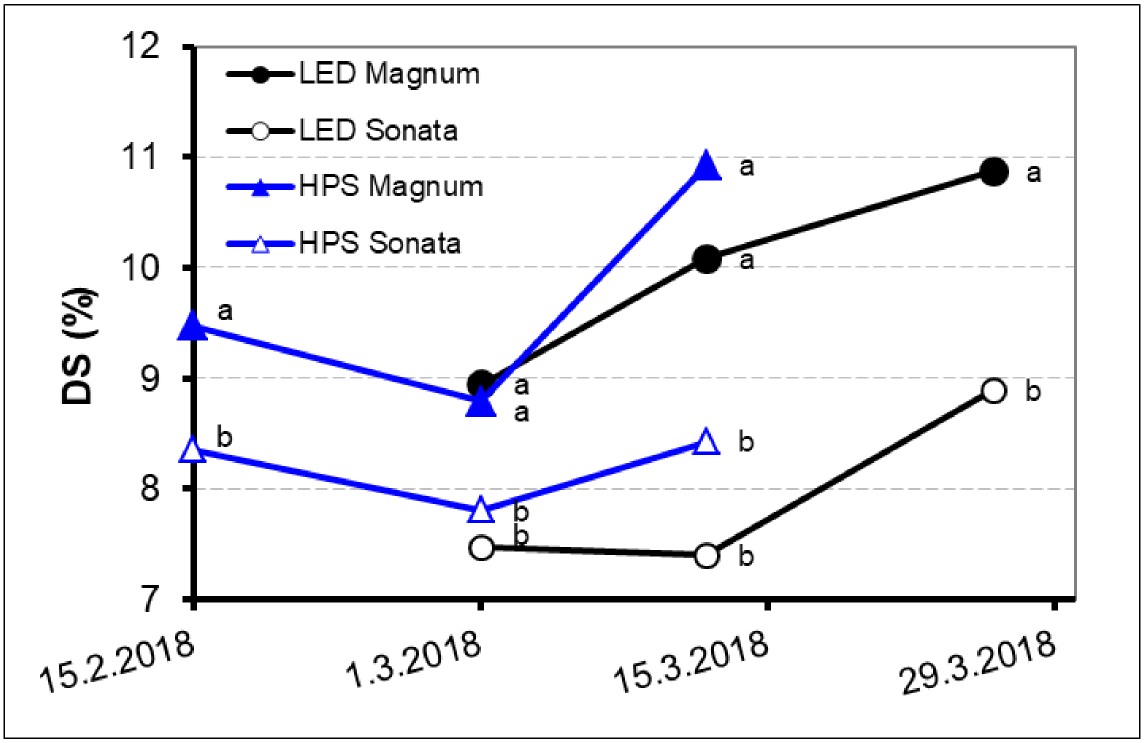


Fig. 23: Dry substance of strawberries.

4.3.4.4 Relationship between dry substance and sugar content of fruits

There was a relationship between dry substance and sugar content of fruits (Fig. 24).

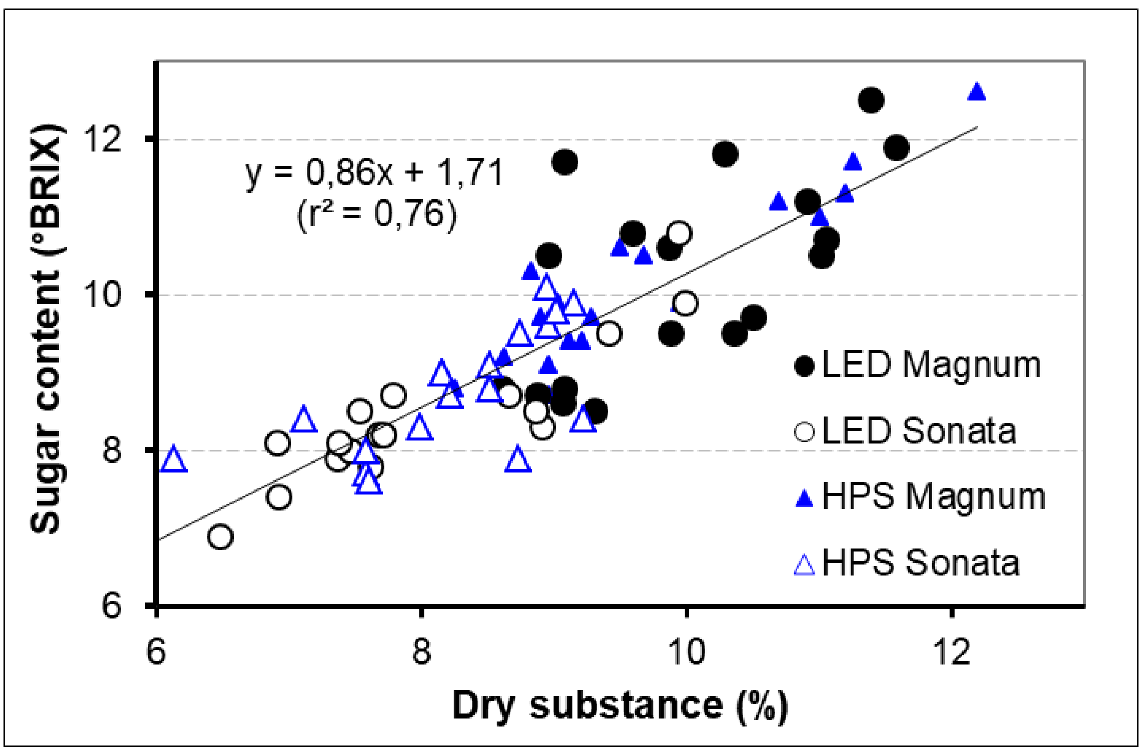


Fig. 24: Relationship between dry substance and sugar content of fruits.

A higher dry substance was involved with a higher sugar content. Sonata had a lower dry substance and a lower sugar content than Magnum.

4.4 Economics

4.4.1 Lighting hours

The number of lighting hours is contributing to high annual costs and needs therefore special consideration to consider decreasing lighting costs per kg marketable yield. The total hours of lighting during the growth period of strawberries were both simulated and measured with dataloggers.

The HPS chamber had a daily usage of 189 kWh (Fig. 25), while the LED chamber had with 106 kWh nearly 45 % less than the HPS chamber.

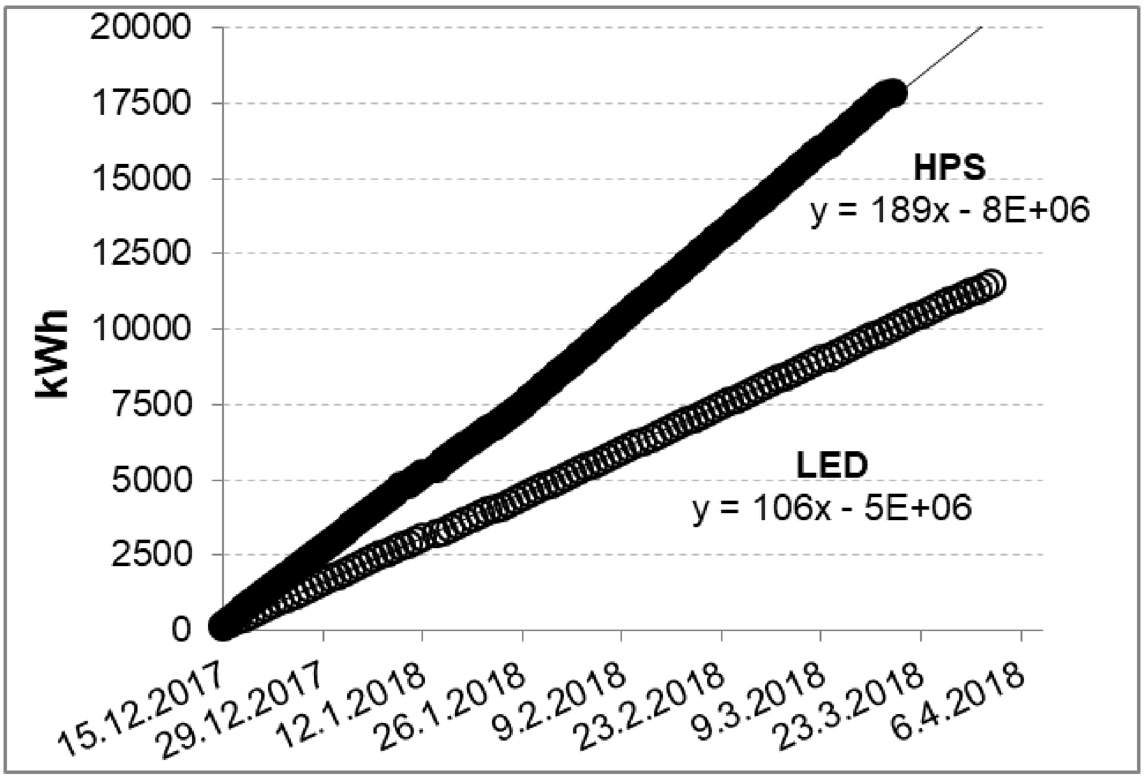


Fig. 25: Used kWh in the different chambers.

The simulated value was calculated according to the lighting hours written down. However, there it was not adjusted for automatic turn off, when incoming solar radiation was above a set-point (Tab. 6). Therefore, the simulated value was higher.

The measured lighting hours were higher for the LED chamber, because the harvest was finished two weeks later than the HPS chamber.

For calculation of the power, different electric consumptions were made, because the actual consumption is higher than the nominal value of the bulb: one was based on the power of the lamps (nominal Watts, 0 % more power consumption), one with 6 % more power consumption and one for 10 % more power consumption. The power was higher for the measured values than for the simulated ones.

Tab. 6: Lighting hours, power and energy in the cabinets.

Treatment	Hours	Power	Energy	Energy/m²
	h	W	kWh	kWh/m²
HPS Sonata				
Measured values	1.512	259	19.601	392
Simulated values				
0 % more power consumption (nominal)	1.673	180	15.058	301
6 % more power consumption	1.673	191	15.962	319
10 % more power consumption	1.673	198	16.564	331
LED Sonata				
Measured values	1.638	136	11.170	223
Simulated values				
0 % more power consumption (nominal)	1.960	117	11.464	229
6 % more power consumption	1.960	124	12.152	243
10 % more power consumption	1.960	129	12.611	252
HPS Magnum				
Measured values	1.465	259	18.993	380
Simulated values				
0 % more power consumption (nominal)	1.623	180	14.609	292
6 % more power consumption	1.623	191	15.485	310
10 % more power consumption	1.623	198	16.070	321
LED Magnum				
Measured values	1.613	136	11.002	220
Simulated values				
0 % more power consumption (nominal)	1.932	117	11.302	226
6 % more power consumption	1.932	124	11.980	240
10 % more power consumption	1.932	129	12.432	249

4.4.2 Energy prices

Since the application of the electricity law 65/2003 in 2005, the cost for electricity has been split between the monopolist access to utilities, transmission and distribution and the competitive part, the electricity itself. Most growers are, due to their location, mandatory customers of RARIK, the distribution system operator (DSO) for most of Iceland except in the Southwest and Westfjords (*Eggertsson*, 2009).

RARIK offers basically three types of tariffs:

a) energy tariffs, for smaller customers, that only pay fixed price per kWh,
b) “time dependent” tariffs (tímaháður taxti, Orkutaxti TT000) with high prices during the day (09.00-20.00) at working days (Monday to Friday) but much lower during the night and weekends and summer, and
c) demand based tariffs (afltaxti AT000), for larger users, who pay according to the maximum power demand.

In the report, only afltaxti is used as the two other types of tariffs are not economic. Since 2009, RARIK has offered special high voltage tariffs (“VA410” and “VA430”) for large users, that must either be located close to substation of the transmission system operator (TSO) or able to pay considerable upfront fee for the connection.

Costs for distribution are divided into an annual fee and costs for the consumption based on used energy (kWh) and maximum power demand (kW) respectively the costs at special times of usage. The annual fee is pretty low for “VA210” and “VA230” when subdivided to the growing area and is therefore not included into the calculation. However, the annual fee for “VA410” and “VA430” is much higher. Growers in an urban area in “RARIK areas” can choose between different tariffs. In the report only the possibly most used tariffs “VA210” and “VA410” in urban areas and “VA230” and “VA430” in rural areas are considered.

The government subsidises the distribution cost of growers that comply to certain criteria’s. Currently 64,8 % (before 87 %) and 69,2 % (before 92 %) of variable cost of distribution for urban and rural areas respectively. This amount can be expected to change in the future.

Based on this percentage of subsidy and the lighting hours (Tab. 6), for the cabinets the energy costs per m^2 during the time of the experiment for the growers were calculated (Tab. 7).

The energy costs per kWh are for distribution after subsides 1,74-2,03 ISK/kWh for „VA210“ and 1,50-1,79 for „VA230“, 2,95-3,33 ISK/kWh for „VA410“ and 2,10-2,32 ISK/kWh for „VA430“. The energy costs for sale are for „Afltaxti“ 6,01-6,74 ISK/kWh and for „Orkutaxti“ 6,01-8,34 ISK/kWh.

Cost of electricity was lower for the calculated values (Tab. 7). In general, tariffs for large users rendered lower cost. Costs of electricity for the LED treatment were slightly lower than for the HPS chamber, however, differences between tariffs were bigger.

Tab. 7a: Costs for consumption of energy for distribution and sale of energy for lighting with HPS lights.

	Costs for consumption							
	Energy ISK/kWh				Energy costs with subsidy per m^2 ISK/m^2			
Treatment	HPS Sonata		HPS Magnum		HPS Sonata		HPS Magnum	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					64,8 % subsidy from the state			
VA210	2,00	1,76	2,03	1,79	782	531 563 584	772	524 555 576
VA410	1,76	1,53	1,79	1,55	688	460 487 506	681	454 481 499
RARIK Rural					69,2 % subsidy from the state			
VA230	3,28	2,99	3,33	3,02	1.287	899 953 989	1265	883 936 971
VA430	2,32	2,12	2,35	2,15	910	639 677 703	894	627 664 689
SALE								
Afltaxti	6,65	6,07	6,74	6,14		1.829		1.794
Orkutaxti	8,38	7,34	8,45	7,44	2.607	1.939	2.560	1.902
						2.012		1.974

Comments: The first number for the calculated value is with 0 % more power consumption, the second value with 6 % more power consumption and the last value with 10 % more power consumption.

Prices are from January 2018.

Tab. 7b: Costs for consumption of energy for distribution and sale of energy for lighting with LEDs.

Treatment	Costs for consumption: Energy ISK/kWh				Energy costs with subsidy per m^2 ISK/m^2			
	LED Sonata		LED Magnum		LED Sonata		LED Magnum	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					64,8 % subsidy from the state			
VA210						398		396
	1,91	1,74	1,93	1,75	427	422	424	419
						438		435
VA410						344		342
	1,67	1,50	1,69	1,51	373	365	371	362
						378		376
RARIK Rural					69,2 % subsidy from the state			
VA230						677		671
	3,17	2,95	3,19	2,97	709	717	702	711
						744		738
VA430						481		477
	2,25	2,10	2,26	2,11	502	510	497	505
						529		524
SALE								
Afltaxti	6,43	6,01	6,47	6,04		1.377		1.365
Orkutaxti	8,28	6,88	8,34	6,92	1.437	1.460	1.424	1.446
						1.515		1.501

Comments: The first number for the calculated value is with 0 % more power consumption, the second value with 6 % more power consumption and the last value with 10 % more power consumption.

Prices are from January 2018.

4.4.3 Costs of electricity in relation to yield

Costs of electricity in relation to yield for wintergrown strawberries were calculated (Tab. 8). While for the distribution several tariffs were possible, for the sale only the cheapest tariff was considered. The yield of the plants, where only the yield (and no other measurements were done) was used for the calculation, because it seems that the yield was decreased when plants and clusters were touched very often due to measurements.

The costs of electricity per kg yield decreased by nearly 45 % (Sonata: 43 %, Magnum: 44 %) when LEDs were used instead of HPS lights. The selection of the variety did not influence the costs of electricity (Tab. 8).

Tab. 8: Variable costs of electricity in relation to yield.

	Variable costs of electricity per kg yield ISK/kg							
Treatment	HPS Sonata		LED Sonata		HPS Magnum		LED Magnum	
Yield kg/m²	7,3		7,1		6,2		6,3	
	real	calculated	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)								
VA210	3.389	2.360 2.502 2.596	1.864	1.775 1.882 1.953	3.332	2.318 2.457 2.550	1.848	1.760 1.866 1.936
VA410	3.295	2.289 2.426 2.517	1.810	1.721 1.824 1.893	3.241	2.248 2.383 2.473	1.795	1.706 1.809 1.877
Rural area (Distribution + Sale)								
VA230	3.894	2.728 2.892 3.001	2.146	2.054 2.177 2.259	3.825	2.677 2.838 2.945	2.127	2.035 2.157 2.239
VA430	3.517	2.468 2.616 2.714	1.939	1.858 1.970 2.044	3.454	2.421 2.566 2.663	1.922	1.841 1.952 2.025

4.4.4 Profit margin

The profit margin is a parameter for the economy of growing a crop. It is calculated by substracting the variable costs from the revenues. The revenues itself, is the product of the price of the sale of the berries and kg yield. For each kg of strawberries, growers are getting about 2.600 ISK from Sölufélag garðyrkjumanna (SfG). Therefore, the revenues increased with more yield (Fig. 26). With the choose of the variety Sonata increased the revenue slightly compared to Magnum. The light source had no influence on the revenue.

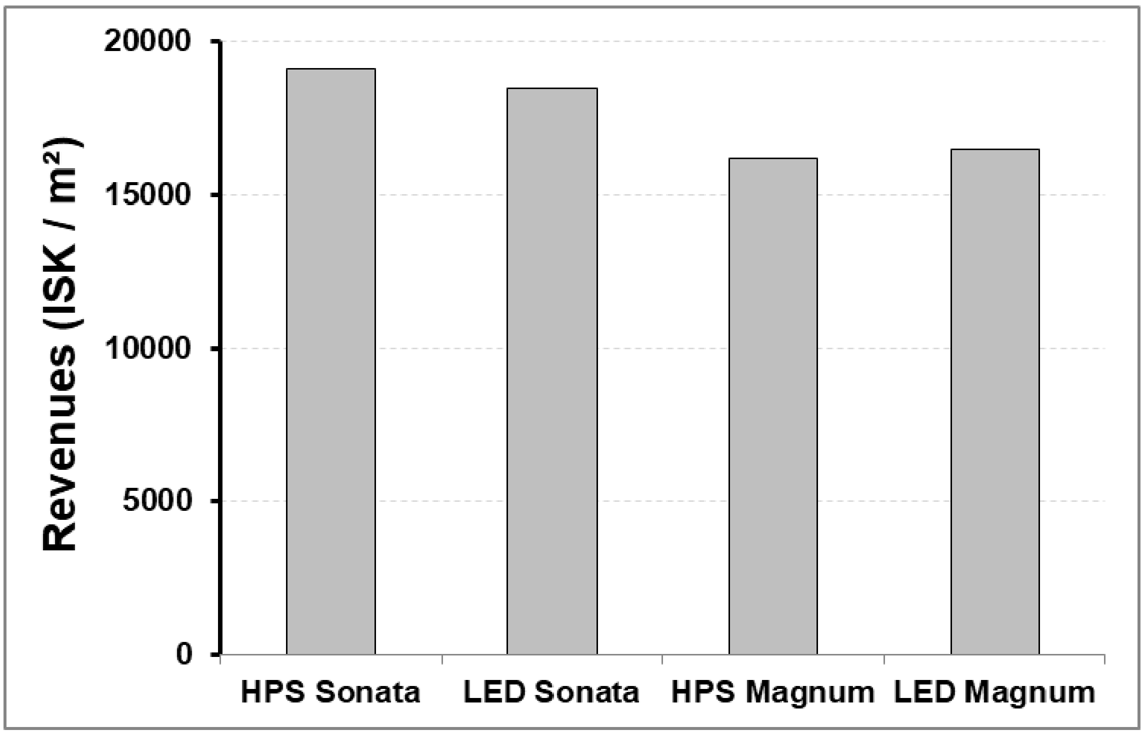


Fig. 26: Revenues at different treatments.

When considering the results of previous chapter, one must keep in mind that there are other cost drivers in growing strawberries than electricity alone (Tab. 7). Among others, this are e.g. the costs for the plant itself (≈ 1.200 ISK/m^2), soil (≈ 300 ISK/m^2), gutters and other material (≈ 50 ISK/m^2), costs for plant protection (≈ 300 ISK/m^2) and beneficial organism (≈ 250 ISK/m^2), plant nutrition (≈ 100 ISK/m^2), CO_2 transport (≈ 150 ISK/m^2), liquid CO_2 (≈ 1.000 ISK/m^2), the rent of the tank (≈ 150 ISK/m^2), the rent of the green box (≈ 150 ISK/m^2), material for packing (≈ 350 ISK/m^2) and transport costs from SfG (≈ 100 ISK/m^2) (Fig. 27).

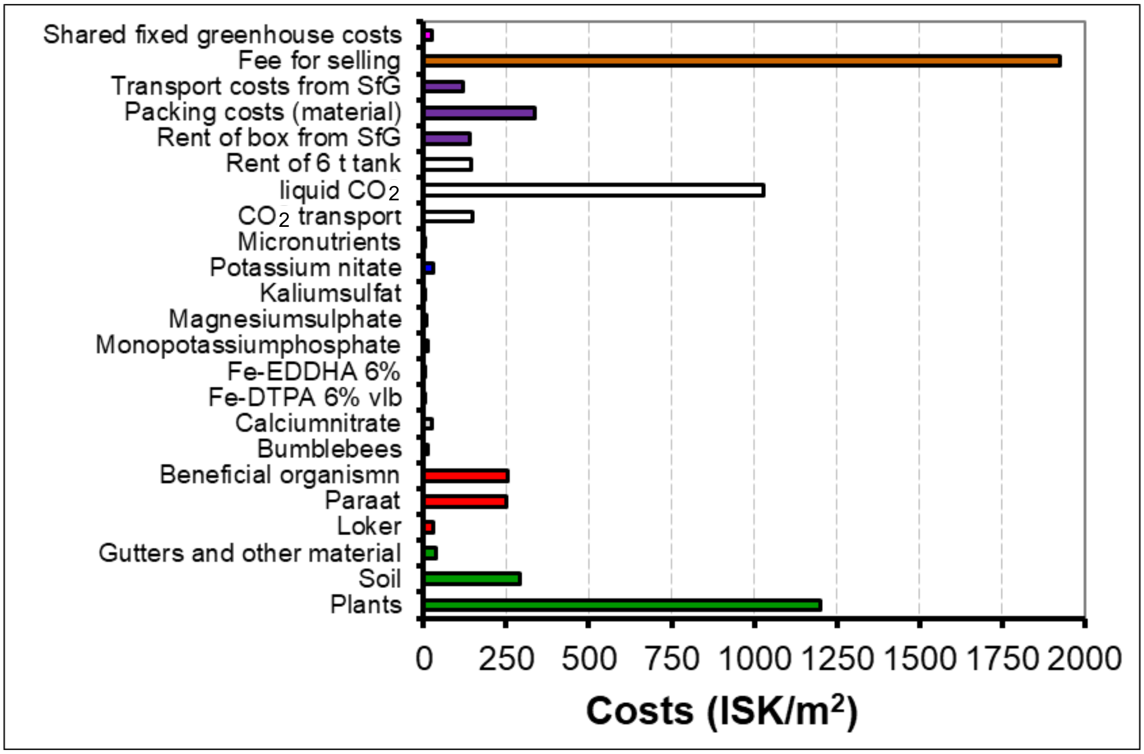


Fig. 27: Variable and fixed costs (without lighting and labour costs).

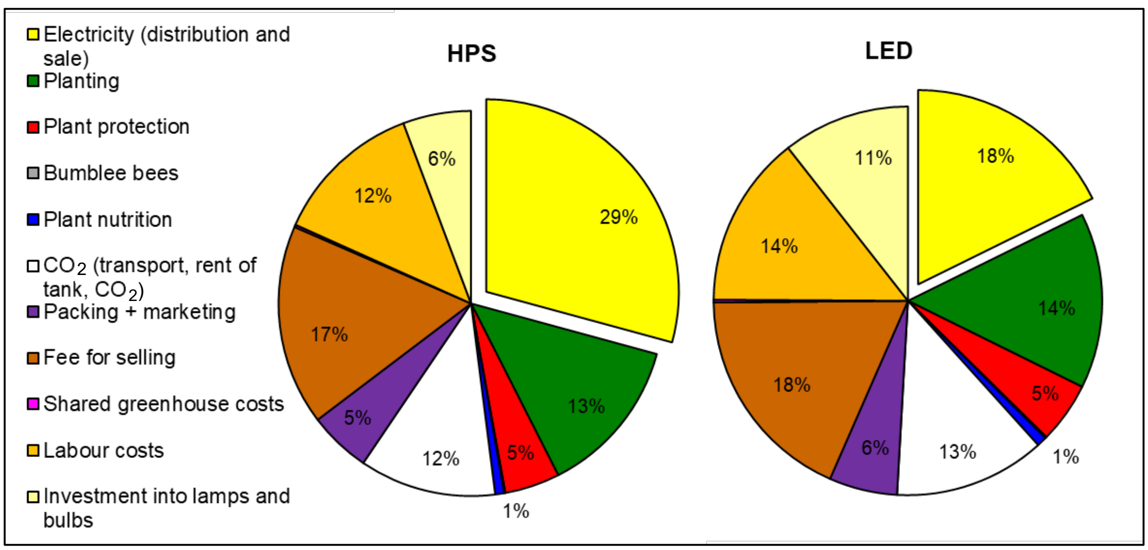


Fig. 28: Division of variable and fixed costs.

However, in Fig. 27 four of the biggest cost drivers are not included and these are the investment in lamps and bulbs, electricity, labour costs and the fee for SfG for selling the strawberries. These costs are also included in Fig. 28 and it is obvious, that especially the fee for selling the strawberries, the electricity as well as the labour costs are contributing much to the variable and fixed costs beside the costs for planting and CO_2 costs. The proportion of the variable and fixed costs is mainly the same for the HPS treatment and the LED treatment, except that for the LED treatment is the proportion of electricity about 10 % lower, whereas the proportion of the investment into lamps and bulbs is about 5 % higher compared to the proportion of the HPS chamber.

A detailed composition of the variable costs at each treatment is shown in Tab. 9.

The profit margin was dependent on the treatment and was between 4.500-8.000 ISK/m^2 (Fig. 29). The profit margin was higher for Sonata (7.000-9.000 ISK/m^2) than for Magnum (4.500-6.500 ISK/m^2). The profit margin was higher when LEDs were used instead of HPS lights. That means the choose of LEDs instead of HPS lights roose the profit margin by 500 ISK/m^2 for Sonata and by 1.200 ISK/m^2 for Magnum. However, it has to be taken into account that the profit margin depends much on the actual price of the LEDs. Also, the choose of Sonata instead of Magnum increased the profit margin by 2.300 ISK/m^2 when HPS lights were used and by 1.600 ISK/m^2 when LED lights were used.

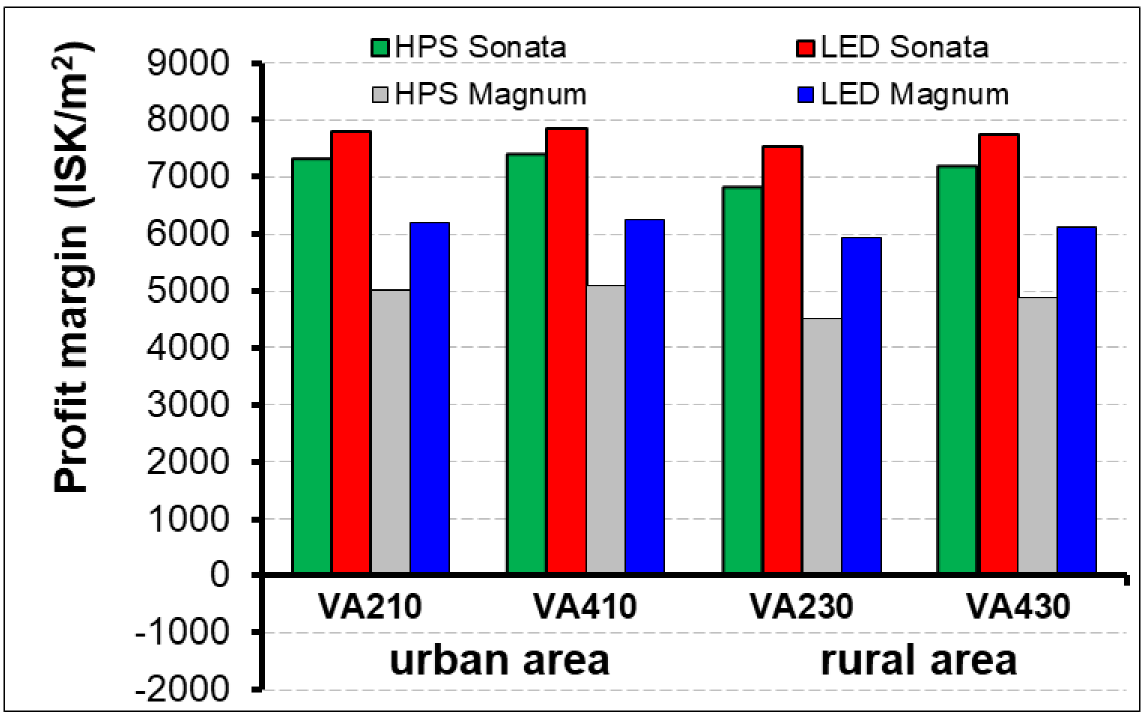


Fig. 29: Profit margin in relation to tariff and treatment.

Tab. 9: Profit margin of strawberries at different light treatments (urban area, VA210).

Treatment	HPS Sonata	LED Sonata	HPS Magnum	LED Magnum
Marketable yield kg/m²	7,3	7,1	6,2	6,3
Sales				
SfG (ISK/kg) [1]	2.600	2.600	2.600	2.600
Revenues (ISK/m²)	**19.103**	**18.475**	**16.201**	**16.497**
Variable and fixed costs (ISK/m²)				
Electricity distribution [2]	782	427	772	424
Electricity sale	2.607	1.437	2.560	1.424
Strawberry plants [3]	1.200	1.200	1.200	1.200
Soil for strawberries [4]	291	291	291	291
Pots [5]	7	7	7	7
Tape [6]	3	3	3	3
Gutters [7]	28	28	28	28
Loker [8]	28	28	28	28
Paraat [9]	250	250	250	250
Beneficial organismn [10]	254	254	254	254
Bumblebees [11]	12	12	12	12
Calcium nitrate [12]	23	22	25	26
Potassium sulfate [13]	5	5	5	6
Fe-DTPA 6% vlb [14]	4	4	5	5
FE-EDDHA 6% [15]	4	4	4	5
Monopotassium phosphate [16]	13	12	14	15
Magnesium sulphate [17]	7	6	7	8
Potassium nitrate [18]	26	24	28	30
Micronutrients [19]	1	1	1	1
CO_2 transport [20]	146	146	146	146
Liquid CO_2 [21]	1.029	1.029	1.029	1.029
Rent of CO_2 tank [22]	144	144	144	144
Rent of box from SfG [23]	153	148	130	132
Packing material [24]	367	355	312	317
Fee for SfG [25]	2.094	2.025	1.776	1.808
Transport from SfG [26]	129	125	109	111
Shared fixed costs [27]	24	24	24	24
Lamps [28, 29]	429	1091	429	1091
Bulbs [30]	229		229	
Flowering lamps [31]		18		18
∑ variable costs	**10.286**	**9.117**	**9.819**	**8.835**
Revenues -∑ variable costs	**8.817**	**9.358**	**6.382**	**7.662**
Working hours (h/m²)	0,92	0,94	0,84	0,89
Salary (ISK/h)	1.642	1.642	1.642	1.642
Labour costs (ISK/m²)	1.513	1.548	1.378	1.456
Profit margin (ISK/m²)	**7.304**	**7.810**	**5.004**	**6.206**

[1] price winter 2017/2018: 2.600 ISK/kg
[2] assumption: urban area, tariff "VA210", no annual fee (according to datalogger values)
[3] 100 ISK / strawberry plant
[4] 2.186 ISK / bag Klasmann soil 200 l TS-4
[5] 54 ISK / pot; assumption: 10 years life time, 3 circles / year
[6] 4.250 ISK / bund of tape; assumption: 10 years life time, 3 circles / year
[7] 660 ISK / m gutter; assumption: 10 years life time, 3 circles / year
[8] 25.500 ISK / 5 l Loker; assumption: spraying once per week (~ 8 times per growing season)
[9] 29.950 ISK / bund Paraat; assumption: spraying once per growing season, 400 ml / pot
[10] beneficials: 4.615 ISK / unit Orius laevigatus (predatory bug), once
2.995 ISK / unit mix of the parasitic wasp species Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre and Ephedrus cerasicola, once
[11] 4.622 ISK / unit bumblebees
[12] 2.750 ISK / 25 kg Calcium nitrate
[13] 3.550 ISK / 25 kg Potassium sulphate
[14] 17.050 ISK / 25 kg Fe-DTPA 6% vlb
[15] 14.770 ISK / 5 kg Fe-EDDHA 6%
[16] 7.050 ISK / 25 kg Monopotassium phosphate
[17] 1.700 ISK / 25 kg Magnesium sulfate
[18] 4.175 ISK / 25 kg Potassium nitrate
[19] 33.900 ISK / 5 kg micronutrients
[20] CO_2 transport from Rvk to Hveragerði / Flúðir: 8,0 ISK/kg CO_2
[21] liquid CO_2: 45,0 ISK/kg CO_2
[22] rent for 6 t tank: 72.000 ISK/month, assumption: rent in relation to 1.000 m^2 lightened area
[23] 90 ISK / box
[24] packing costs (material):
costs for packing of strawberries (0,20 kg): box: 4 ISK / 0,20 kg,
lid: 4 ISK / 0,20 kg,
label: 2 ISK / 0,20 kg
[25] fee for SfG for selling the strawberries: 57 ISK / 0,20 kg
[26] transport costs from SfG: 2.652 ISK / board
[27] 94 ISK/m^2/year for common electricity, real property and maintenance
[28] HPS lights: 30.000 ISK/lamp, life time: 8 years
[29] LED lights: 42.000 ISK/lamp, life time: 11 years
[30] HPS bulbs: 4.000 ISK/bulb, life time: 2 years
[31] flowering lamps: 3.950 ISK/lamp, life time: 8 years

A larger use (higher tariff: "VA 410" compared to "VA 210", "VA 430" compared to "VA 230"), did not influence the profit margin. Also, it did nearly not matter if the greenhouse is situated in an urban or rural area, however, there was a small advantage for the urban area (Fig. 29).

5 DISCUSSION

5.1 Yield in dependence of the light source

Strawberry plants need to have strong vegetative growth in order to flower and to produce berries. In winter production is flower induction highly dependent on the supplemental light. In this experiment, the effect of two light sources was tested on two varieties of strawberries. The number of flowers of Sonata and Magnum was independent of the light source. However, for Magnum was the number of unpollinated flowers higher under HPS lights compared to LEDs, while for Sonata were no differences found between light sources. Strawberry plants under LED lights showed a delayed growth that was 1,5-2 weeks behind the development of strawberries treated with HPS lights. Hence, started the harvest under HPS lights two weeks earlier. Consequently, the harvest under HPS lights was finished two weeks earlier than the harvest under LED lights, where it took 5-6 days longer for the berries to ripe. Thus, the accumulated yield of Magnum and Sonata was not influenced by the light source, reflecting also no differences in the number of fruits and the average weight between light sources. It has to be taken into account, that the growing period of strawberries under LED lights was longer than the one of strawberries under HPS lights. Due to increasing solar irradiation with longer growing period was the LED treatment taking advantage of more solar light. Therefore, the yield with LEDs supported with natural solar irradiation might have been lower when the natural solar irradiation might have been nearly zero as with the HPS treatment all the time. Also, *Lu* et al. (2012) reported a positive affect of natural light on tomato fresh and dry weight. *Stadler* (2010) studied the effect of light intensity at low solar irradiation: A high light intensity significantly increased marketable yield of sweet pepper during periods of low natural light level, the gain decreased with increasing natural light level and the yield was at high natural light level not different within light intensities. This is supporting that the LED treatment might had a yield advantage at the latter part of the harvest period.

But, not only the solar irradiation, also the temperature might have influenced the growth and yield of the strawberries. Despite of the fact that the temperature settings were put the same between treatments, was the recorded air temperature 0,4 °C higher, the soil temperature 1 °C higher and the leaf temperature nearly 3 °C higher in the HPS chamber compared to the LED chamber. This higher temperature might be the reason for the faster development of the plants in the HPS chamber and the earlier ripening, but the influence of each factor is unknown. 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.

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. Similarly, in the presented experiment might the lower temperature have led to a leaf number reduction, delayed initiation rate, but an increased fruits abortion rate was not observed. However, the lower leaf and therefore also fruit temperature had delayed, but not decreased fruit growth, contrary to *Särkka* et al. (2017), where the lower temperature might have decreased fruit growth of cucumbers in the LED treatment throught reduced cell growth and indirectly through sink strength. Also, *Hernández* & *Kubota* (2015) attributed the 28 % greater shoot dry mass of cucumber transplants, 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.

However, it has to be mentioned that both, the soil temperature as well as the leaf temperature was only measured once per week at the same time (10.00) and temperature differences between treatments might therefore be less or higher at other times. For an exact examination, it is therefore necessary to measure the temperature more often, best permanently to get a real picture of this effect. It is also necessary to repeat the experiment in the way that a higher temperature is choosen in the LED chamber to compensate the additional heating by the HPS lights to be able to get the same soil and leaf temperature in both chambers. With these settings might it be possible to get without delay ripe fruits in the LED treatment.

A yield increase of strawberries might be possible with a higher plant density. For example found *Paranjpe* et al. (2008) 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/m²). These yield increases were achieved without adversely affecting mean fruit size.

The importance of the photoperiod is shown by studies from *Verheul* et al. (2007), where a daily photoperiod of 12 h or 13 h resulted in the highest number of strawberry plants with emerged flowers. A photoperiod of 14 h or more reduced this number, while no flowers emerged at a photoperiod of 16 h, 20 h or 24 h (*Verheul* et al., 2006). Furtheron, interactions between photoperiod, temperature, duration of short-day treatment and plant age on flowering were documented from *Verheul* et al. (2006). In contrast, the presented experiment was conducted with a photoperiod of 16 h, which induced good flowering of strawberries.

A big issue was the pollination with bumblebees during the time with no solar irradiation. When it was not getting bright outside, were the bumblebees in the LED chamber in their hive and therefore not pollinating the flowers, while bumblebees in the HPS chamber were always pollinating despite of how bright it was outside. But, when it was not overclouded and getting bright outside, were bumblebees also working in the LED chamber. This is showing the importance of finding a solution of how to ensure pollination of the flowers at the darkest time in Iceland when it is not even getting a bit bright outside and therefore with no garanteed pollination in the LED chamber.

An other problem with the use of the LED lights is that LED glasses need to be used to distinguish between ripe and not ripe berries. The maintenance of the strawberry crop and the harvest of the berries was more difficult due to an other vision compared to the commonly used HPS lights. LED lights caused an irritation of the eyes.

Not only the yield, but also the appearance of the plant and the berries was affected by the light quality. Strawberry leaves and clusters were shorter with LED light than with HPS light, because the amount of the far red light of the flowering lamps was not enough in relation to the installed LED lights. This resulted in the danger of breaking clusters and the harvest was also more difficult due to close to each other hanging fruits. By increasing the number of the flowering lamps by 50 % should the stretching of the leaves and clusters get better. With that could the risk of breaking clusters be reduced and the harvest improved. Also, *Trouwborst* et al. (2010) measured a lower plant length of cucumbers under LEDs. The present experiment gave a clue that LED lights might have a positive influence on the firmness of the fruits. Strawberries might therefore be stored longer due to a possibly higher shelf life. However, this needs to be tested in further experiments. *Philips* (2018) reported sweeter fruits under LEDs compared to HPS lights and *Hanenberg* et al. (2016) mentioned that it was possible to increase the taste by using LED lights. However, this was not observed in the presented experiment.

Nadalini et al. (2017) showed that strawberries under red and blue LEDs are able to grow and yield fruits of standard quality. The use of blue lights was able to cause positive effects on fruit set by 25 % that caused a relevant higher yield compared to red LED and fluorescence neon tubes treated strawberries. The authors concluded that ways of application (blue light alone or in combination with other light sources) and timing must be further investigated.

Using LEDs was associated with nearly 45 % lower daily usage of kWh’s, resulting in lower expenses for the electricity compared to the use of HPS lights. Despite of the longer growing period of two weeks in the LED chamber, were energy costs (distribution + sale) lowered by 43 % / 44 % (Sonata / Magnum) compared to the use of HPS lights. However, it has to be mentioned that the investment into LEDs was nearly dobble as high as for the HPS lights. Meaning, that the lower use of electricity by LEDs was compensated by a higher price of the lights.

For both, Sonata and Magnum, resulted the use of LEDs in a higher profit margin than the use of HPS lights. In contrast to the fact that the yield was independent of the light source, was the profit margin increased by 1.200 ISK/m^2 for Magnum and by 500 ISK/m^2 for Sonata when LED lights were used instead of HPS lights (Fig. 30). When the yield of the HPS treatment would have been 0,3 kg/m^2 higher for Sonata and 0,6 kg/m^2 higher for Magnum, would the profit margin have been comparable to the one of the LED treatment.

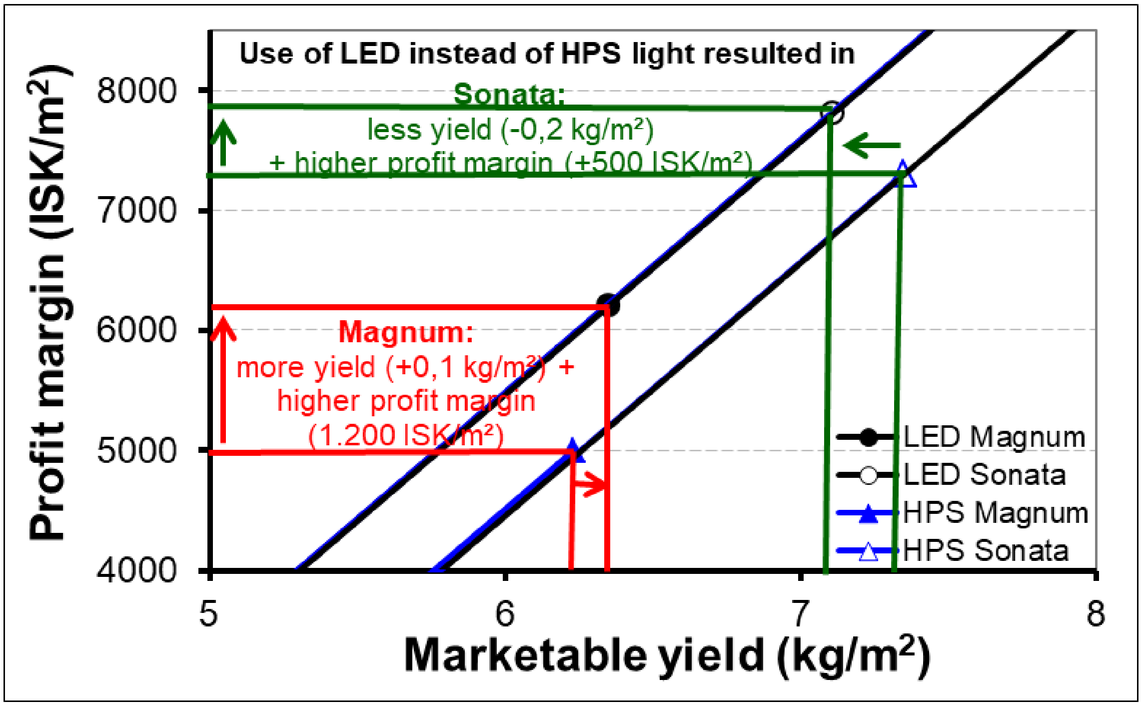


Fig. 30: Profit margin in relation to yield with different light sources – calculation scenarios (urban area, VA210).

Regarding the profit margin, it also has to be taken account to the longer growth period of two weeks under LED lights compared to HPS lights. In three years would it be possible to have ten circles of strawberries under HPS lights, while under LED lights only nine circles would be possible, assuming that cleaning between circles would take half a week. This would result in a 900 ISK/m^2 higher yearly profit margin with Sonata for the HPS treatment and a 1.900 ISK/m^2 higher yearly profit margin with Magnum for the LED treatment (Tab. 10).

Tab. 10: Calculation scenarios of profit margin per year.

Treatment	HPS		LED	
	Sonata	Magnum	Sonata	Magnum
Growth period in weeks	15	15	17	17
Possible circles in 3 years	10	10	9	9
Profit margin in 3 years (ISK/m^2)	73.042	50.044	70.291	55.854
Profit margin / year (ISK/m^2)	24.347	16.681	23.430	18.618

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. When LED lights and interlights were used was the light use efficiency (g fruit FW mol^{-1} PAR) highest, but resulted in a fewer number of fruits in mid-winter particularly and the lowest yield potential. However, the high capital cost is still an important aspect delaying the LED technology in horticultural lighting. *Singh* et al. (2015) showed that the introduction of LEDs allows, despite of high capital investment, reduction of the production cost of vegetables and ornamental flowers in the long-run (several years), due to the LEDs' high energy efficiency, low maintenance cost and longevity.

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.

The effect of different light compositions on strawberry growth, yield and quality was the object of some studies conducted recently with LEDs: Leaves and fruits biomass production was found increased in strawberry treated with different combinations of red and blue lights as compared to fluorescent lamps (*Piovene* et al., 2015). Spectral composition could have contributed to contrasting results. So far, limited information is available comparing HPS supplemental lighting with LED supplemental lighting in terms of plant growth and development (*Hernández* & *Kubota*, 2015). Reported results are controversial, first because of different plant species and cultivars are used 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.

5.2 Yield in dependence of the variety

It is known that different varieties of strawberries naturally result in different yield levels. Since years is Sonata the most used variety for winter greenhouse cultivation under lights in Iceland and Magnum has been tested in commercial production in Iceland in 2017.

While Sonata had about ten more flowers per plant than Magnum, were in addition for Magnum 15 % unpollinated flowers or later rejected flowers under LED lights and 27 % under HPS lights counted. The harvest period started half a week earlier for Magnum. The marketable yield was more than 10 % lower for Magnum compared to Sonata. This was attributed to a lower number of marketable fruits due to a significantly higher percentage of unshaped fruits. Magnum was ripe after 40 / 45 days (HPS / LED) and Sonata after 41 / 47 days (HPS / LED). *Stadler* (2016c) found comparable values for Sonata.

Sonata had more marketable fruits, mainly due to a higher number of 1st and 2nd class fruits, while there were no variety differences in the extra class fruits and in the average weight. There were more misshapened fruits at Magnum than at Sonata.

By the selection of Sonata instead of Magnum could the yield and the profit margin be increased: At the HPS treatment resulted the use of Sonata in a 1,1 kg/m^2 higher yield, which was reflected in a 2.300 ISK/m^2 higher profit margin (Fig. 31). At the LED treatment resulted the use of Sonata in a 0,8 kg/m^2 higher yield, which was reflected in a 1.600 IKS/m^2 higher profit margin. This means, by the choose of the variety can the profit margin be influenced positively.

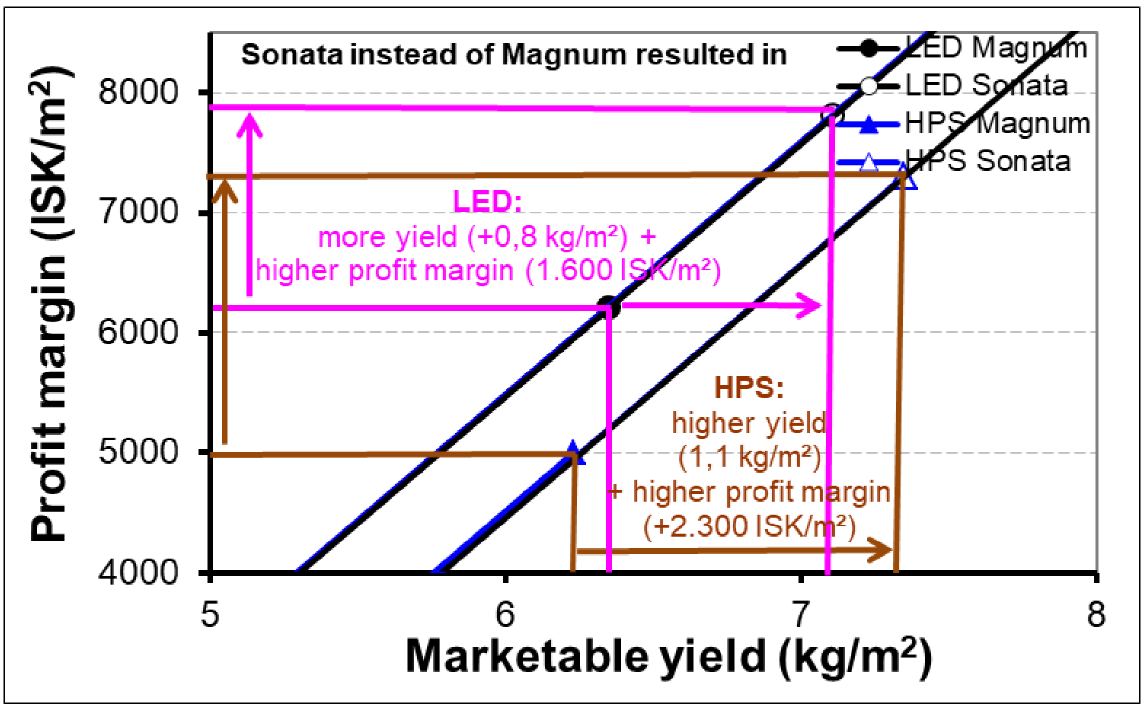


Fig. 31: Profit margin in relation to yield with different varieties – calculation scenarios (urban area, VA210).

Proefcentrum Hoogstraten (2016) measured an increasing sugar content from 7,4 to 8,7 with an average of 7,6°Brix for Sonata, while the Brix content decreased to the middle of the harvest period and increased again to the end of the harvest period. This is in accordance to the presented measurements, even though were higher values measured for Sonata. Compared to Sonata was the sugar content of Magnum most of the time significantly higher. The reason for that may lay in the higher DS content of Magnum compared to Sonata. Magnum fruits were evaluated more firm, while Sonata fruits were more juicy. *Proefcentrum Hoogstraten* (2016) evaluated Sonata with high grades (In total got the fruit assessment of Sonata a high score of 82,3 % with high grades particularly at "bruising skin", "colouring" and "regularity" (shape); Magnum was not in this test).

However, with the selection of the variety has to be payed not only attention to the yield, but also to the quality (e.g. sugar content). The consumer might be willing to pay more for sweeter fruits.

5.3 Future speculations concerning energy prices

In terms of the economy of lighting it is also worth to make some future speculations about possible developments also regarding the fact that the subsidy has been decreased by more than 20 %. So far, the lighting costs (electricity + bulbs) are contributing to a big part of the production costs of strawberries. In the past and present there have been and there are still a lot of discussions concerning the energy prices. Therefore, it is necessary to highlight possible changes in the energy prices (Fig. 32).

The white columns are representing the profit margin according to Fig. 29. Where to be assumed, that growers would get no subsidy from the state for the distribution of the energy, that would result in a profit margin of 3.600-7.000 ISK/m^2 (black columns, Fig. 32). Without the subsidy of the state, probably less Icelandic grower would produce strawberries over the winter months. When it is assumed that the energy costs, both in distribution and sale, would increase by 25 %, but growers would still get the subsidy, then the profit margin would range between 4.200-7.300 ISK/m^2 (dotted columns). When it is assumed that growers have to pay 25 % less for the energy, the profit margin would increase to 5.800-8.300 ISK/m^2 (gray columns). From these scenarios, it can be concluded that from the grower's side it would be preferable to get subsidy to be able to get a higher profit margin and grow strawberries over the winter. Referring to the reduction of the subsidy of 20 % from the year 2017 to the year 2018, it is obvious that actions must be taken, that growers are also producing during the winter at low solar irradiation. It is also showing clearly, that it is only paying of to produce strawberries during the winter in Iceland, when a high yield is guarantied. Also, the use of LEDs are showing the possibility to increase profit margin. This is getting especially important as the reduction of the subsidity is decreasing, because do to less use of electricity by the LED lights, a reduction became less appearent than with the use of HPS lights.

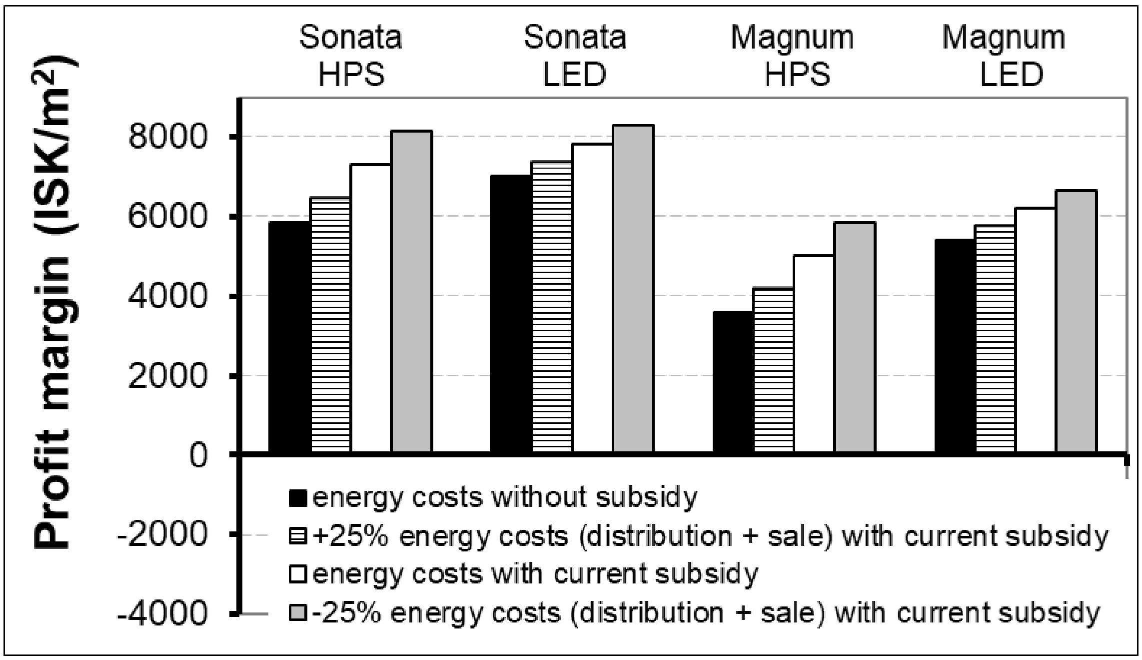


Fig. 32: Profit margin in relation to treatment – calculation scenarios (urban area, VA210).

5.4 Recommendations for increasing profit margin

The current economic situation for growing strawberries necessitate for reducing production costs to be able to heighten profit margin for strawberry production. On the other hand side, growers have to think, if strawberries should be grown during low solar irradiation and much use of electricity.

It can be suggested, that growers can improve their profit margin of strawberries by:

1. Getting higher price for the berries

   It may be expected to get a higher price, when consumers would be willing to pay even more for Icelandic berries than imported ones. Growers could also get a higher price for the fruits with direct marketing to consumers (which is of course difficult for large growers). They could also try to find other channels of distribution (e.g. selling directly to the shops and not over SfG). In doing so, growers could save the very high expences of the fee to SfG for selling the strawberries. This is especially important when a high yield is expected, because then the proportion of the fee for selling the strawberries through SfG is contributing to ¼ of the production costs. Therefore, it would be profitable for the grower to choose other channels of distribution.

2. Lower planting costs

   The price for the strawberry plant is quite high. By using the strawberry plant not only once, but twice, could costs be decreased. By that, also the costs for the soil would be lowered. However, it is necessary that the yield is staying at a high value when same plants are used more than once.

   According to the presented results, seems it not to pay off to use everbearers, and with that decreasing the planting costs by making it unnecessary to plant strawberries in about three months intervals as for junebearers due to a low yield. Also, with using everbearers it would not be possible to clean the greenhouse in between which is especially important if the crop has aphids or plant diseases.

3. Selection of good plants

   Not only the variety, but also within a variety yield differences are possible. Therefore, it is necessary to select first of all plants with a high yield guaranty. Beside that is the choose of the variety important and can result in a profit margin that is more than 1.600 ISK/m^2 higher (*Stadler*, 2016c).

3. Decrease plant nutrition costs

   Growers can decrease their plant nutrition costs by mixing their own fertilizer. When growers would buy different nutrients separately for a lower price and mix out of this their own composition, they would save fertilizer costs. However, this takes more time and it is more difficult to perform this task by employees.

4. Lower CO_2 costs

   The costs of CO_2 are pretty high. Therefore, the question arises, if it is worth to use that much CO_2 or if it would be better to use less and get a lower yield but all together have a possible higher profit margin. The CO_2 selling company has currently a monopoly and a competition might be good.

5. Decrease packing costs

   The costs for packing (material) from SfG and the costs for the rent of the box are high. Costs could be decreased by using cheaper packing materials.

6. Efficient employees

   The efficiency of each employee has to be checked regularly and growers will have an advantage to employ faster workers. Growers should also check the user-friendliness of the working place to perform only minimal manual operations. Very often operations can be reduced by not letting each employee doing each task, but to distribute tasks over employees. In total, employees will work more efficiently due to the specialisation.

7. Decrease energy costs

   - Lower prices for distribution and sale of energy (which is not realistic)
   - Growers should decrease artificial light intensity at increased solar irradiation, because this would possibly result in no lower yield (*Stadler* et al., 2010).
   - Growers should check if they are using the right RARIK tariff and the cheapest energy sales company tariff. Unfortunately, it is not so easy, to say, which is the right tariff, because it is grower dependent.
   - Growers should check if they are using the power tariff in the right way to be able to get a lowered peak during winter nights and summer (max. power -30 %). It is important to use not so much energy when it is expensive, but have a high use during cheap times.
   - Growers can save up to 8 % of total energy costs when they would divide the winter lighting over all the day. That means growers should not let all lamps be turned on at the same time. This would be practicable, when they would grow in different independent greenhouses. Of course, this is not so easy realisable, when greenhouses are connected together, but

can also be solved there by having different switches for the lamps to be able to turn one part of the lamps off at a given time. Then, plants in one compartment of the greenhouse would be lightened only during the night. When yield would be not more than 2 % lower with lighting at nights compared to the usual lighting time, dividing the winter lighting over all the day would pay off. However, a tomato experiment showed that the yield was decreased by about 15 % when tomatoes got from the beginning of November to the end of February light during nights and weekends (*Stadler*, 2012). This resulted in a profit margin that was about 18 % lower compared to the traditional lighting system and therefore, normal lighting times are recommended.

- For large growers, that are using a minimum of 2 GWh it could be recommended to change to “stórnotendataxti” in RARIK and save up to 35 % of distribution costs.
- It is expected that growers are cleaning their lamps to make it possible, that all the light is used effectively and that they are replacing their bulbs before the expensive season is starting.
- *Aikman* (1989) suggests to use partially reflecting material to redistribute the incident light by intercepting material to redistribute the incident light by intercepting direct light before it reaches those leaves facing the sun, and to reflect some light back to shaded foliage to give more uniform leaf irradiance.
- The use of LED lights instead of HPS lights can reduce electricity consumtion by 45%. However, the growing period was increased by two weeks and environmental settings need to be adapted to the use of this light source.

6 CONCLUSIONS

The strawberry yield was not influenced by the light source. The reduction of the lighting costs by 45 % by the use of LEDs instead of HPS lights was accompanied by a high increase of the investion costs. The profit margin could be increased by more than 500 ISK/m^2 by the use of LEDs. However, the growing period was increased by two weeks, possibly due to a lower air, leaf and soil temperature, resulting in a yearly profit margin that was not much different between light sources. Therefore, before LEDs can be adviced in practise, more experiments need to be conducted with adapted temperature settings. The high capital cost is an important aspect delaying the LED technology in horticultural lighting as long as more knowledge is available to different plant species. In addition, solutions for a successful pollination during the time when no solar light is entering the greenhouse must be found when LED lights are used. So far, a replacement of the HPS lamps by LEDs is not recommended from the economic side. Due to the lower yield of the Magnum compared to Sonata, is the selection of the variety important. Growers should pay attention to possible reduction in their production costs for strawberries other than energy costs.

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8 APPENDIX

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
5.des	plants came and were kept in a cold chamber		plants came and were kept in a cold chamber	
6.des	measuring light	more µmol in the LED chamber	measuring light	
7.des	taking brown leaves, planting, day starts at 5:00, watering at 10:00, 14:00, 18:00		taking brown leaves, planting, day starts at 5:00, watering at 10:00, 14:00, 18:00	
8.des				
9.des				
10.des				
11.des	Paraat (400 ml/pot), one watering per day (10:00) for 3 min, day starts 4 h before light	temperature increases too less	Paraat (400 ml/pot), three lights were added (total: 18 lights), one watering per day (10:00) for 3 min	temperature increases too less
12.des	day starts at 3:00, measuring light (279 µmol), humidity set to 75 % to be able to reach 70 %		day starts at 3.00, measuring light (277 µmol), humidity set to 75 % to be able to reach 70 %	
13.des				
14.des				
15.des	16 h light reached		16 h light reached	
16.des				
17.des				
18.des	day starts at 4:00 instead of 3:00		day starts at 4:00 instead of 3:00	
19.des	measuring growth	less than 1 cm/day growth		
20.des	measuring growth, leaf- and soil temperature, day starts at 5:00, opening windows changed (from 20 °C to 17 °C)	growth was less than 1 cm/day for Magnum, but nearly 1 cm/day for Sonata	measuring leaf- and soil temperature, day starts at 5:00, opening windows changed (from 20 °C to 17 °C)	first flowers and clusters are coming
21.des	measuring growth, Loker		Loker	

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
22.des	measuring growth, roots checked, day starts at 4:00 instead of 5:00	little of new white roots, plants were wet from rain coming in through open windows	roots checked, day starts at 4:00 instead of 5:00	little of new white roots, plants were wet from rain coming in through open windows
23.des				
24.des				
25.des	added watering at 16:00		added watering at 16:00	
26.des				
27.des	measuring growth, leaf- and soil temperature	first flowers visible	measuring leaf- and soil temperature	
28.des	roots at the bottom of the pot, fast interval (3 x between 9:00-21:00), 800 ppm (500 ppm with open windows), measuring growth, Loker		roots at the bottom of the pot, fast interval (3 x between 9:00-21:00), 800 ppm (500 ppm with open windows), Loker	ordered hive was not coming due to a problem at Koppert
29.des	measuring growth, day starts at 3:30		day starts at 3:30	
30.des				
31.des				
1.jan				
2.jan	2 h between waterings, setting up band for the leaves, taking leaves		2 h between waterings, taking leaves	
3.jan	measuring growth, 3 h between waterings, setting up band for the leaves, turning flowering lamp on for 24 h, 2° C opening windows, TZ 1: 03:30, 3° C	too much drain	1 h between waterings, setting up band for the leaves, 2° C opening windows, TZ 1: 03:30, 3° C	new leaves brown, no drain, windows are too much open
4.jan	measuring growth, Prev-Magnum		3 h between waterings, setting tape for the clusters, putting hive up (1 h open), Prev-Magnum	too much watering
5.jan	measuring growth		checking pollination	

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
6.jan			hive open for 2 h	dark outside, bees are not working well
7.jan				
8.jan	measuring growth, setting up tape for clusters, Fe+Mn shoot (0,3 l Fe (6 %) + 40 g Mn-sulfate /1000 m^2)	not possible to take clusters to the front due to short clusters	Fe+Mn shoot (0,3 l Fe (6 %) + 40 g Mn-sulfate /1000 m^2), working on clusters, checking pollination	
9.jan	measuring growth, weekly measurements	substrate is very wet, short clusters	weekly measurements	
10.jan	measuring growth, leaf- and soil temperature, first hive (open: 12:00-15:00), checking pollination, Topaz		hive open for 3 h, measuring leaf- and soil temperature, Topaz	
11.jan	measuring growth, checking pollination		checking pollination	
12.jan	measuring growth, checking pollination	no bees outside the hive at 13:00		
13.jan				
14.jan				
15.jan	measuring growth, Fe+Mn shoot, watering set to 1,5 h interval	18-20 cm leave hight reached, first bright day since hive was set into the chamber: bees were pollinating in the afternoon	Fe+Mn shoot, working on clusters	
16.jan	weekly measurements	bright outside and bees working	weekly measurements, working on clusters	leaves are light
17.jan	measuring growth, leaf- and soil temperature, light, water sample taken, working on clusters, checking pollination		working on clusters, measuring leaf- and soil temperature, light, water sample taken, working on clusters, checking pollination	
18.jan	working on clusters	pots are wet (but little drain), bright outside and bees working		

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
19.jan	measuring growth, Loker, working on clusters, problems with watering system caused too much watering, continuing to use flowering lamps	growth: about 0,5 cm/dag, 22 cm reached	Loker, Magnum: 1 h interval watering, Sonata: 1,5 h interval watering	
20.jan				
21.jan		CO_2 finished		CO_2 finished
22.jan	measuring growth, Topaz		Topaz, working on clusters	
23.jan	weekly measurements	substrate is wet	weekly measurements, working on clusters	
24.jan	measuring growth, leaf- and soil temperature, checking pollination, CO_2 was filled		measuring leaf- and soil temperature, checking pollination, CO_2 was filled	
25.jan	working on clusters, watering intervall changed from 2:00 to 2:30		watering Magnum: intervall changed fom 1:20 to 1:00	more watering to decrease E.C. and to flush out
26.jan	measuring growth, working on clusters, watering: 4 h intervall (additional at 9:30 and 10:30)	short clusters, difficult to work with	watering: 4 h intervall	
27.jan	working on clusters			
28.jan				
29.jan	measuring growth	much development since 26.01: clusters have stretched	working on clusters	Sonata fruits seem not to increase much
30.jan	weekly measurements, Orius laevigatus	some flowers, not pollinated and too much pollinated	weekly measurements, Orius laevigatus	
31.jan	measuring growth, leaf- and soil temperature, checking pollination		measuring growth, leaf- and soil temperature	
1.feb	working on clusters		changing fertilizer, working on clusters	
2.feb	Loker, working on clusters		Loker	
3.feb				stop watering due to problem with the electricity

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
4.feb				
5.feb	measuring growth	clusters shorter than in the HPS chamber, difficult to work with them	stop watering	Magnum og Sonata with first red berries, electricity went off
6.feb	weekly measurements, working on clusters, stop watering (additional waterings taken off)		weekly measurements	leaves very light
7.feb	measuring growth, leaf- and soil temperature, 07.02-12.02 no watering because soil is too wet (drying up), working on clusters, checking pollination, 2 waterings (10:30, 14:30)	substrate too wet	measuring leaf- and soil temperature	
8.feb	Loker		first harvest, Loker	
9.feb	watering increased			
10.feb				
11.feb				
12.feb	fertilizer changed		harvest	Sonata clusters have lengthened much, Sonata berries are light red
13.feb	weekly measurements		weekly measurements	
14.feb	Aphiscout		Aphiscout, working on clusters	
15.feb	working on clusters, measuring leaf- and soil temperature, Loker, Fe+Mn shoot		harvest, Brix, measuring leaf- and soil temperature, Loker, Fe+Mn shoot	
16.feb				
17.feb				
18.feb	turning off flowering lamps			
19.feb	working on clusters		harvest	
20.feb	weekly measurements		weekly measurements	
21.feb				

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
22.feb	first harvest, measuring leaf- and soil temperature		harvest, measuring leaf- and soil temperature	
23.feb				
24.feb				
25.feb				
26.feb	harvest		harvest	
27.feb	weekly measurements, taking leaves and runners	substrate is wet	weekly measurements, taking leaves and runners	
28.feb	measuring leaf- and soil temperature, added 100 ml acid to stock solution		measuring leaf- and soil temperature, added 100 ml acid to stock solution	
1.mar	harvest, Brix		harvest, Brix	
2.mar	tasting experiment, Loker		tasting experiment, Loker	
3.mar				
4.mar				
5.mar	harvest		harvest	
6.mar	weekly measurements	substrate is wet, short clusters are beginning to brake	weekly measurements	
7.mar	measuring leaf- and soil temperature		measuring leaf- and soil temperature	
8.mar	harvest		harvest	
9.mar				
10.mar				
11.mar				
12.mar	harvest		harvest	
13.mar	weekly measurements	substrate is wet	weekly measurements	
14.mar	measuring leaf- and soil temperature		measuring leaf- and soil temperature	
15.mar	harvest		harvest	

	LED		HPS	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
16.mar				
17.mar				
18.mar				
19.mar	harvest		harvest, last harvest of Magnum	
20.mar	weekly measurements		weekly measurements	
21.mar	measuring leaf- and soil temperature		measuring leaf- and soil temperature	
22.mar	harvest, Loker		last harvest of Sonata	
23.mar				
24.mar				
25.mar				
26.mar	harvest, Brix			
27.mar	weekly measurements			
28.mar	harvest			
29.mar				
30.mar				
31.mar				
1.apr				
2.apr				
3.apr	harvest, last harvest of Magnum, weekly measurements			
4.apr				
5.apr	last harvest of Sonata			