Rit LbhÍ nr. 117

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

FINAL REPORT

Christina Stadler

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Landbúnaðarháskóli Íslands

Desember 2019

Final report of the research project

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Table of contents

List of figures

List of tables

Abbreviations

DS	dry substance
E.C.	electrical conductivity
HPS	high-pressure vapour sodium lamps
kWh	kilo Watt hour
LED	light-emitting diodes
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 together with appropriate temperature settings 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 October 2018 to the middle of January 2019 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, 269 µmol/m^2/s) or under LED lights (278 µmol/m^2/s) for a maximum of 16 hours light. The day temperature was 16 °C in the HPS chamber, but 19 °C in the LED chamber to compensate for additional heating by the HPS lamps. The night temperature was 8 °C in both chambers, CO_2 800 ppm. Strawberries received standard nutrition through drip irrigation. The effect of the light source and appropriate temperature settings was tested and the profit margin was calculated.

The CO_2 amount was nearly 100 ppm higher in the LED chamber due to more open windows in the HPS chamber. Air temperature was in average 1,3 °C higher under LEDs due to the fact that the day temperature was set 3 °C higher. This settings caused an about 1 °C higher soil temperature in the LED treatment, whereas the leaf temperature was comparable between light sources. This temperature advantage might have positively influenced growth and yield of the plants under LEDs: The development of the flowers and berries was delayed by one week under HPS lights and therefore, gave the plants under LEDs and increased temperature one week earlier ripe berries and harvest was also finished one week earlier than the harvest under HPS lights. It took 1-2 days from flowering to pollination. The fruits were ripe in 45 / 50 days (Magnum / Sonata) under HPS lights and in 45 / 43 days (Magnum / Sonata) under LEDs. For Sonata were 1-3 % of the total flowers unpollinated. For Magnum were 24 % unpollinated flowers or later rejected flowers counted under LED lights and increased temperature and 12 % under HPS lights.

Sonata had with 560 g per plant under LEDs and 600 g per plant under HPS lights a significantly higher marketable yield than Magnum with 430 g per plant under LEDs

and 520 g per plant under HPS lights. The reason for the more than 13 % lower marketable yield of Magnum compared to Sonata was attributed to a significant 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. The light source did not affect the weight of marketable yield of Sonata. However, Magnum had a significantly higher marketable yield under HPS lights. This was possibly be related to a significantly higher amount of unpollinated flowers or later rejected flowers under LEDs, which resulted in a tendentially lower amount of marketable fruits compared to the HPS treatment. Assuming, the number of unpollinated flowers or later rejected flowers under LED lights and increased temperature, would have been lower, could it be expected that also here an equal yield under HPS and LED lights would have been measured, as with Sonata.

Magnum had most of the time a significantly higher sugar content than Sonata. The sugar content of Magnum was independent of the light source. However, for Sonata was the sugar content under LEDs and increased temperature lower than under HPS lights. This difference was also found in the tasting experiment: Higher grades were given for the the sweetness and the flavour of Sonata under HPS lights, whereas for Magnum was this difference not observed. Sonata fruits seem to be evaluated juicier and Magnum fruits firmer. The use of Sonata increased the yield by 0,9 kg/m^2 and the profit margin by 1.700 ISK/m^2 under HPS lights, respectively by 1,5 kg/m^2 and 3.200 ISK/m^2 under LEDs and increased temperature.

Using LED lights was associated with nearly 46 % 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 decreased the profit margin by 1.500 ISK/m^2 for Magnum, but was independent of the light source for Sonata. 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. 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 adapted temperature settings was it possible to compensate the additional heating by the HPS lights and prevent a delayed growth and harvest. However, more experience under LED lights is needed. 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 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 ásamt viðeigandi hitastillingu hefði áhrif á vöxt, uppskeru og gæði yfir hávetur á junebearers og hvort það væri hagkvæmt.

Gerð var jarðarberjatilraun með junebearers (*Fragaria x ananassa* cv. Sonata og cv. Magnum) frá byrjun október 2018 og fram í miðjan janúar 2019 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, 269 µmol/m^2/s) eða undir LED ljósi (278 µmol/m^2/s) að hámarki í 16 klst. Daghiti var 16 °C í HPS klefa, en 19 °C í LED klefa til að bæta viðbótarhitun sem varð með HPS ljósunum. Næturhiti var í bæðum klefum 8 °C, CO_2 800 ppm. Jarðarberin fengu næringu með dropavökvun. Áhrif ljósgjafa og viðeigandi hitastillingar var prófuð og framlegð reiknuð út.

CO_2 magnið var nærri því 100 ppm hærra í LED klefa vegna þess að gluggarnir í HPS klefa voru að opnast meira. Lofthitastigið var að meðaltali 1,3 °C hærra í LED klefanum vegna dagshita sem var sett 3 °C hærri. Út af þessum stillingum var jarðvegshiti í LED klefanum um 1 °C hærri en í HPS klefanum, en laufhiti var eins á milli klefa. Þessi kostur í hitastigi getur líka haft jákvæð áhrif á vöxt plantna og uppskeru undir LED ljósi: Þroski blómanna og berjanna var um einni viku seinni með HPS ljósum og því byrjaði meðferð undir LED ljósum og hærra hitastigi einni viku fyrr að gefa þroskuð ber og uppskeran var einnig búin einni viku fyrr. Það tók 1-2 daga frá blómgun til frjóvgunar. Ávextir voru þroskaðir á 45 / 50 dögum (Magnum / Sonata) undir HPS ljósi og á 45 / 43 dögum (Magnum / Sonata) undir LED ljósi. Sonata var með 1-3 % af ófrjóvguðum heildarblómum. Hins vegar var hlutfall hjá Magnum 24 % ófrjóvgað eða blómin blómstruðu og visnuðu síðan undir LED ljósum og hærra hitastigi og 12 % undir HPS ljósum.

Sonata var með 560 g á plöntur undir LED ljósi og 600 g á plöntur undir HPS ljósum marktækt hærri markaðhæfrar uppskeru en Magnum með 430 g á plöntur undir LED

ljósi og 520 g á plöntur undir HPS ljósum. Ástæðan fyrir meira en 13 % 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 %. Ljósgjafinn hafði ekki áhrif á þyngd markaðshæfrar uppskeru af Sonata. Hins vegar var yrkið Magnum með marktækt hærri markaðshæfrar uppskeru undir HPS ljósum. Það tengdist mögulega marktækt hærra magni af ófrjóvguðvum blómin eða blómin blómstruðu og visnuðu síðan undir LED ljósum og hærra hitastigi, sem olli tilhneigingu til minna magns af söluhæfu aldin samanborið við HPS meðferðina. Ef svo færi að fjöldi af ófrjóvguðum blómum eða blómin sem blómstruðu og visnuðu síðan undir LED ljósum og hærra hitastig hefði verið lægri, mætti búast við að einnig hér hefði verið eins uppskera undir HPS og LED ljósum, eins og með Sonata.

Sykurinnihaldið var yfirleitt marktækt meira hjá Magnum en hjá Sonata. Enginn munur var á sykurinnihaldi milli ljósgjafa fyrir Magnum, en Sonata var með lægra sykurinnihaldi undir LED ljósum og hærra hitastig miðað við HPS ljós. Þessi munur fannst líka í bragðprófun: Einkunn voru hærri fyrir sætu og bragð af Sonata undir HPS ljósum, en fyrir Magnum kom þessu munur í einkunn ekki upp. Sonata var með meiri safa og Magnum með meiri þéttleika. Ræktun af Sonata í staðin fyrir Magnum jók uppskeru um 0,9 kg/m^2 og framlegð um 1.700 ISK/m^2 undir HPS ljósi og um 1,5 kg/m^2 og 3.200 ISK/m^2 undir LED og hærra hitastig.

Með notkun LED ljóss var næstum 46 % 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 minnkaði framlegð um 1.500 ISK/m^2 fyrir Magnum, en ljósgjafi hafði engin áhrif á framlegð hjá Sonata. Hærri rafmagnsgjald-skrá 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 rannsóknum. Með viðeigandi hitastillingar var samkvæmt þessum tilraun hægt að bæta viðbótarhitun sem varð með HPS ljósunum við LED klefann til að ekki var seinkun á vexti og uppskeru. Hins vegar vantar meira reynslu með ræktum undir LED ljósi. 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 Flúðir 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 2002 and in 2011 more growers joined. 2019 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 is grown in Iceland since the year 2017.

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 less 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 UV and blue region (*Krizek* et al., 1998). However, HPS lights suffer from restricted controllability and dimming range limitations (*Pinho* et al., 2013).

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). In contrast, the light source did not affect the weight of marketable yield of winter grown strawberries. But, the development of flowers and berries and their harvest was delayed by two weeks under LED lights. This was possibly be related to a higher leaf temperature in the HPS treatment due to additional radiation heating. However, nearly 45 % lower daily usage of kWh's under LEDs were recorded (*Stadler*, 2018b). These results are requesting scientific studies with different temperature settings to compensate the additional heating by the HPS lights and the delayed growth and harvest. Therefore is the question, if the development under LEDs can be pushed up by a higher temperature than in the HPS treatment and if energy costs could be reduced without extending the growing period.

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 together with appropriate temperature settings 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 2018/2019.

Four heavy tray plants of Sonata respectively Magnum were planted on 01.10.2018 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 the day in the HPS chamber, but 19 °C in the LED chamber. The night temperature was set in both chambers to 8 °C. Ventilation started at 18 °C respectively 21 °C. It was heated up with 1,5-2 °C per hour. The aim was to reach 16 °C / 19 °C at one hour after day starts. At the end of the day was the temperature dropped without delay. The underheating in the LED chamber started heating up two hours before lights were turned on and reached 45 °C during the day and was turned off one hour before night (10 °C). The heating pipes in the HPS chamber were during night and day set to 10 °C.

Carbon dioxide was provided (800 ppm CO_2 (from the beginning until the end) with no ventilation and 500 ppm CO_2 with ventilation). A misting system was installed. Humidity was set to 75 % (from 07.00-23.00) 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). Plant protection was managed by beneficial organisms. Aphiscout (mix of parasitic wasps) and Spidex (Predatory mite, *Phytoseiulus persimilis*) was used (see details in appendix).

Strawberry plants got fertilizer according to Tab. 1. 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.

Tab. 1: Used fertilizer mixture for strawberries.

Fertilizer (amount in kg) (amount in l) * (amount in g) **	Stem solution A (100 l)			Stem solution B (100 l)									Relation
	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

3.2 Treatments

Strawberries were grown from 01.10.2018-14.01.2019 in two chambers with different light sources:

1. HPS top lighting (Philips bulbs, 600 W) 180 W/m^2, 269 µmol/m^2/s, **HPS 16 °C**
2. LED top lighting (GreenPower LED, Philips), 278 µmol/m^2/s µmol, **LED 19 °C**

Lamps for top lighting were mounted horizontally over the canopy. Light was provided for 16 hours (07.00-23.00). 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 269 µmol/m^2/s in the HPS chamber and 278 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/m^2/s)				**LED** (µmol/m^2/s)			
repetition	**door**	**middle**	**glas**	**average**	**door**	**middle**	**glas**	**average**
1	268	271	246	**262**	268	297	271	**279**
2	269	278	250	**266**	269	292	275	**279**
3	285	288	259	**277**	275	294	267	**279**
4	289	264	269	**274**	277	293	273	**281**
5	284	275	259	**273**	277	297	272	**282**
6	284	265	231	**260**	260	284	266	**270**
average	**280**	**274**	**252**	**<u>269</u>**	**271**	**293**	**271**	**<u>278</u>**

In addition, nine flowering lamps (Philips GreenPower, deep red / white / far red) were set up in the LED chamber in the same height as the LED lights. Also, in the HPS chamber were nine flowering lamps set up in the same position as in the LED chamber. Ten days after planting was started to turn on the flowering lamps in both chambers during the time, when the supplemental lights were turned off. The desired growth was one cm/day. When measurements were lower than this value, the flowering lamps were turned on for 24 hours in the LED chamber on the 09.11.2018, but for 3 hours in the HPS chamber as stretching was enough in this chamber. The flowering lamps were turned off shortly before harvest started.

3.3 Measurements, sampling and analyses

Soil temperature and leaf temperature was measured by hand and was also continuously recorded by dataloggers. 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 $p \le 0{,}05$.

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 October to the beginning of January were less than 3 kWh/m^2 reached (Fig. 2).

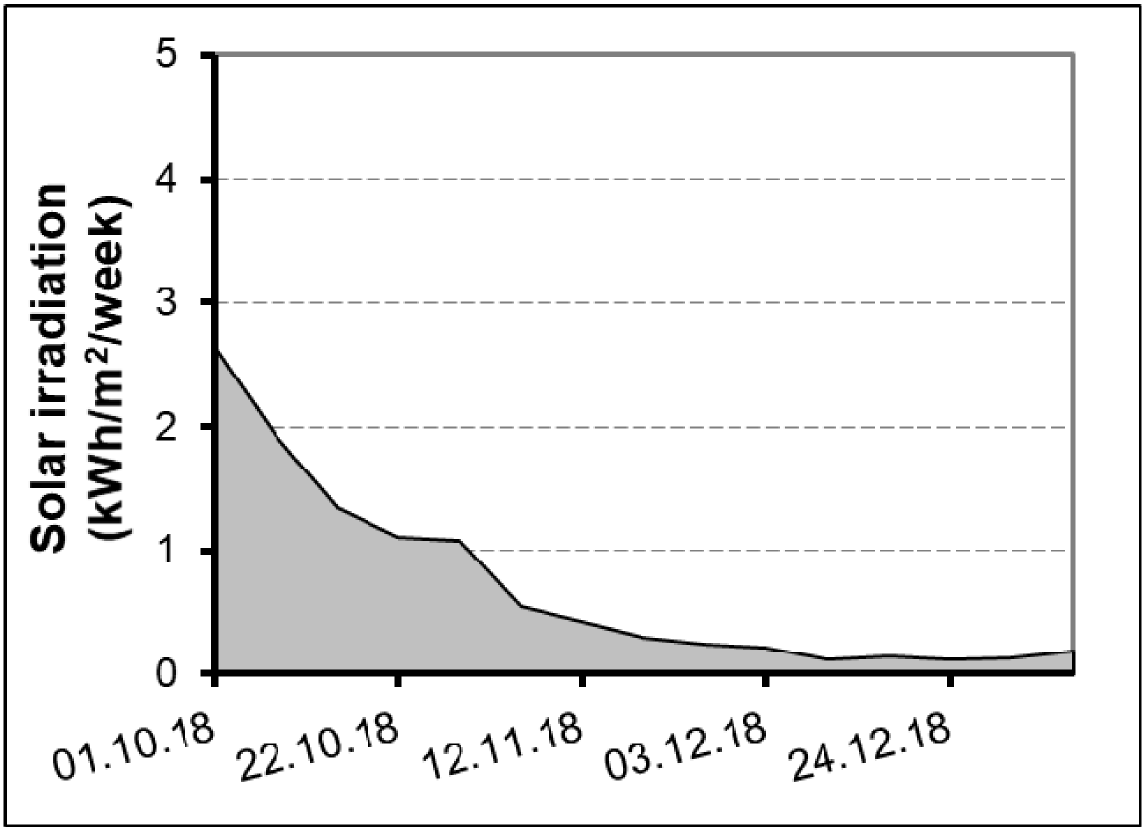

Fig. 2: Time course of solar irradiation.
Solar irradiation was measured every day and values for one week were cumulated.

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 nearly 100 ppm higher in the LED treatment due to nearly 75 % more often open windows in the HPS chamber. The CO_2 amount was all the time higher in the LED chamber.

The air temperature was in average 1,3 °C higher in the LED chamber and increased temperature. This was due to the higher day temperature of 1,6 °C in the LED chamber (because of the 3 °C higher settings in the day temperature), while differences between chambers were 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	608	649	15,8 (17,2 / 11,5)	16,3 (17,9 / 11,7)	32,0 / 20,4	34,2 / 19,1
2	613	680	16,3 (17,7 / 11,8)	17,7 (19,3 / 12,6)	34,9 / 20,9	35,0 / 19,4
3	*	*	16,4 (17,6 / 12,1)	18,2 (19,8 / 13,0)	34,9 / 21,3	35,0 / 19,4
4	618	718	16,0 (17,5 / 11,5)	17,8 (19,3 / 12,6)	34,9 / 20,9	35,0 / 19,6
5	638	733	16,2 (17,5 / 11,6)	17,7 (19,2 / 12,3)	35,1 / 20,8	35,0 / 19,9
6	605	717	16,4 (17,5 / 12,7)	17,8 (19,3 / 13,1)	35,1 / 20,9	35,0 / 19,9
7	599	712	16,6 (17,7 / 13,0)	18,1 (19,4 / 13,7)	35,1 / 20,5	35,0 / 20,4
8	572	698	16,4 (17,6 / 12,4)	17,9 (19,3 / 12,8)	34,4 / 20,2	34,4 / 20,2
9	707	740	15,7 (17,0 / 11,5)	17,2 (18,7 / 12,2)	35,0 / 21,0	35,1 / 19,4
10	700	761	15,7 (16,9 / 11,5)	17,1 (18,5 / 12,3)	35,0 / 21,7	35,1 / 20,8
11	586	746	16,9 (17,9 / 13,6)	17,6 (19,0 / 12,9)	35,0 / 23,2	35,1 / 21,1
12	610	749	16,4 (17,5 / 12,9)	17,4 (18,9 / 12,3)	35,0 / 23,0	35,1 / 20,3
13	572	745	17,3 (18,2 / 13,9)	17,7 (19,2/ 12,6)	35,0 / 23,6	35,1 / 20,9
14	585	747	16,4 (17,5 / 12,8)	17,4 (18,9 / 12,5)	35,0 / 22,6	35,1 / 20,3
15	594		17,1 (18,0/ 13,8)		35,0 / 23,1	
Ø	**617**	**725**	**16,3 (17,5 / 12,4)**	**17,6 (19,1 / 12,6)**	**34,8 / 21,5**	**35,0 / 20,1**

* CO_2 was not working

Humidity amounted in average 65 % in the LED chamber and 69 % in the HPS chamber.

4.1.3 Soil temperature

Soil temperature was measured weekly at low solar radiation at 10.00 and fluctuated between 15-19 °C. Soil temperature was significantly higher in the LED chamber and the increased temperature compared to the HPS chamber. In average amounted the difference about 1,5 °C. No significant differences between varieties were observed, however, the temperature was tendentially higher with Magnum than with Sonata in the LED chamber during the latter part of the growing period (Fig. 3).

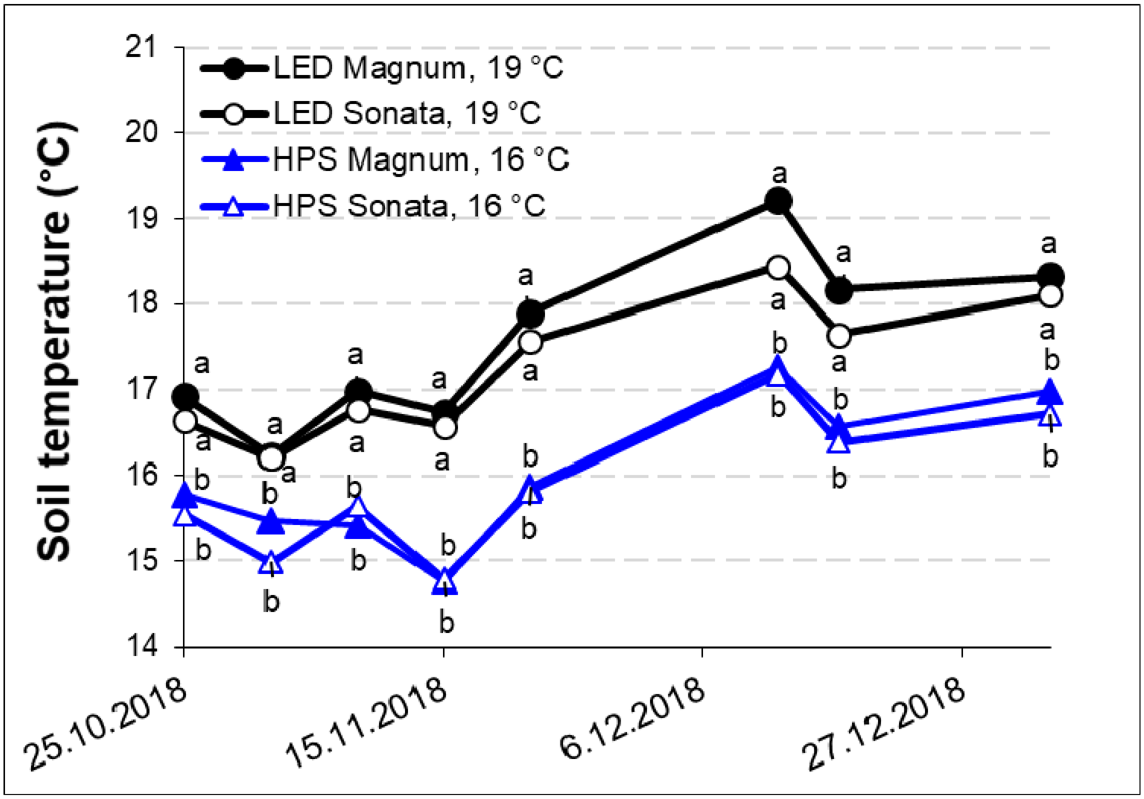

Fig. 3: Soil temperature measured by hand.

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

In addition, the soil temperature was continuously recorded by dataloggers. Therefore, this measurement is giving a clearer picture about the soil temperature than the temporally selected measurement by hand. In average was the soil temperature 1 °C higher in the LED chamber. Differences between varieties were not recorded (Fig. 4).

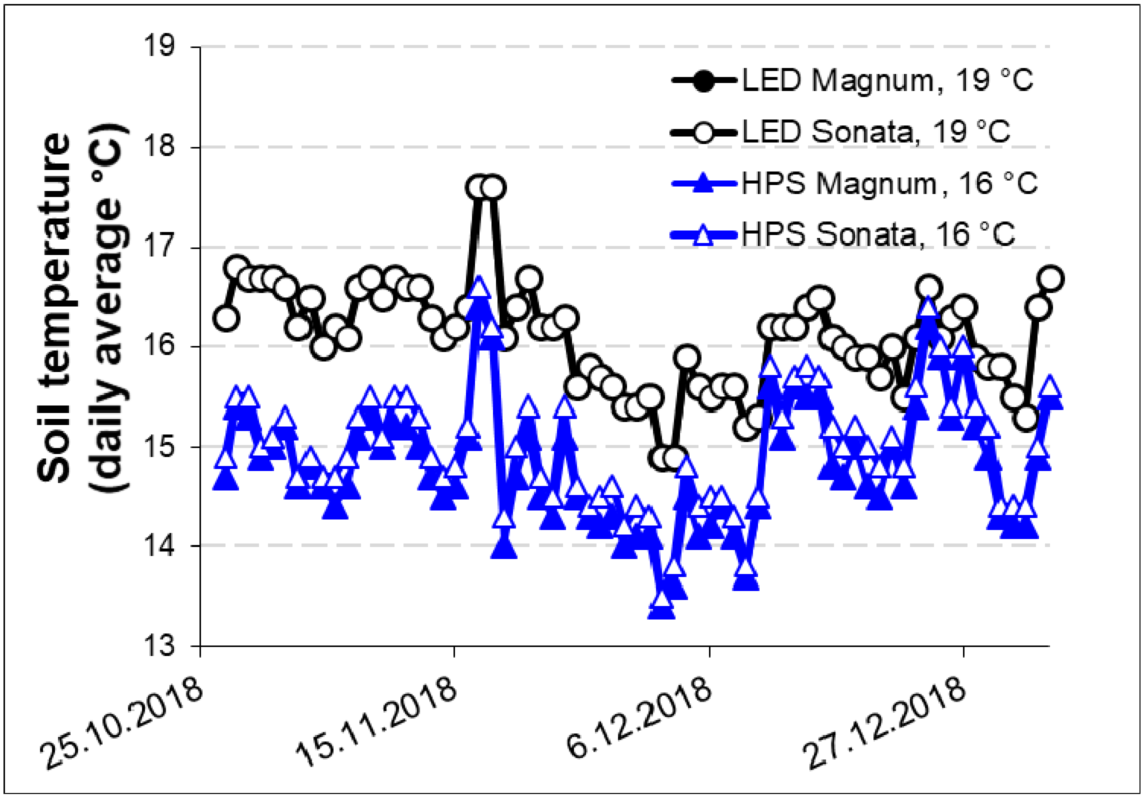

Fig. 4: Soil temperature measured continuously by dataloggers.

4.1.4 Leaf temperature

Leaf temperature was measured weekly at low solar radiation at 10.00. Leaf temperature fluctuated between 14-20 °C. Leaf temperature was significantly higher in the LED chamber with the increased temperature compared to the HPS chamber. In average was the leaf temperature nearly 3 °C higher in the LED chamber. Differences between varieties were not observed (Fig. 5).

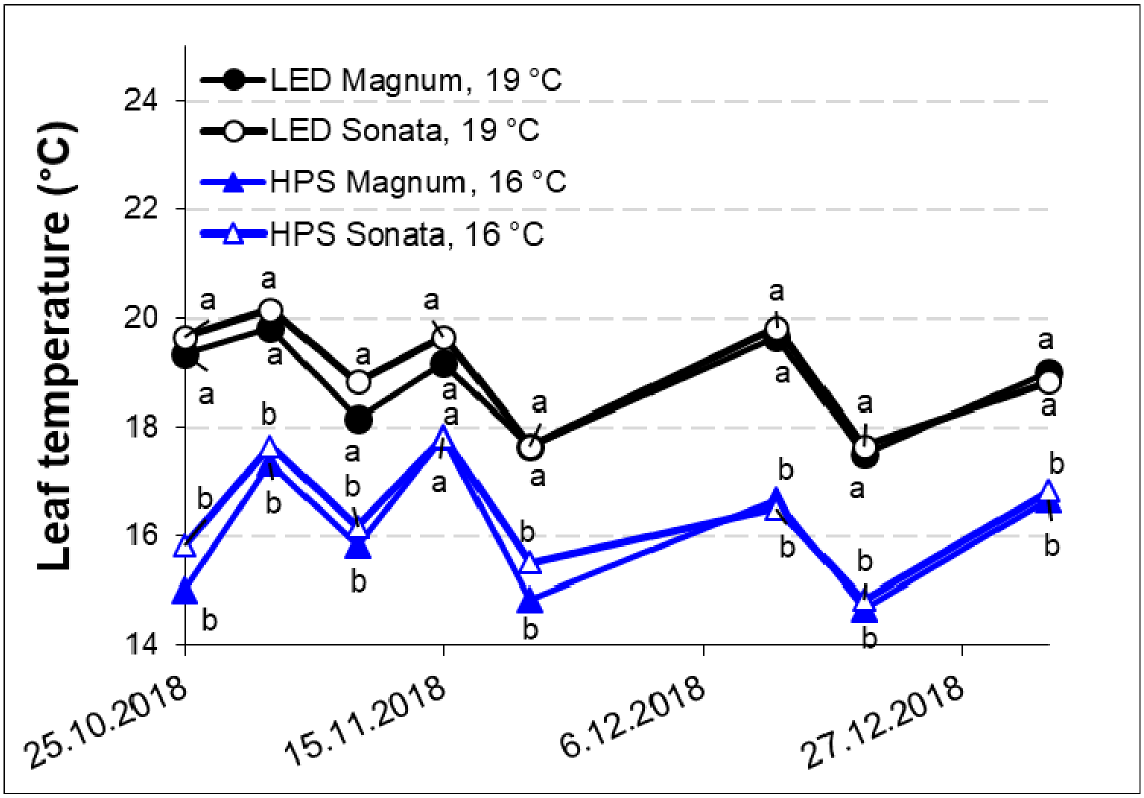

Fig. 5: Leaf temperature measured by hand.

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

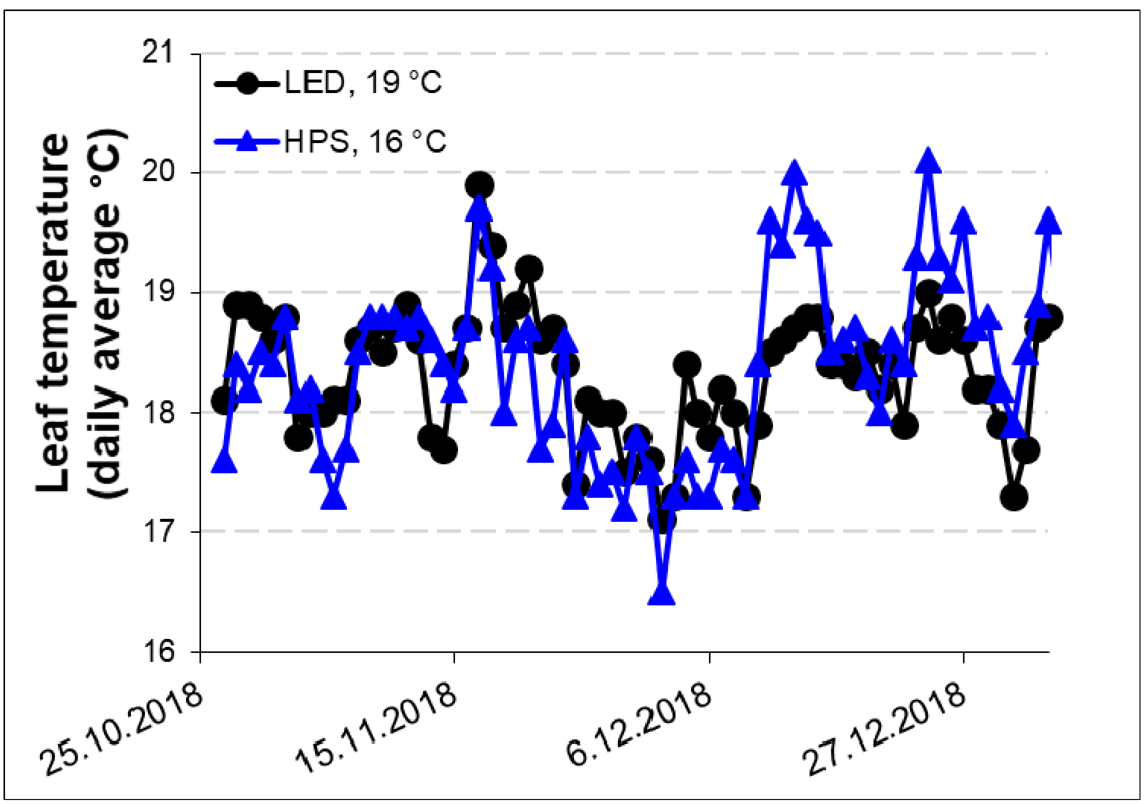

Fig. 6: Leaf temperature measured continuously by dataloggers.

In addition, the leaf temperature was continuously recorded by dataloggers. Therefore, this measurement is giving a clearer picture about the leaf temperature than the temporally selected measurement by hand. In average was the leaf temperature comparable between both chambers (LED: 18,3 °C and HPS: 18,6 °C) (Fig. 6). The continuously measurement of the leaf temperature by dataloggers is showing the importance of measuring the leaf temperature not only at one special time to be able to get representative results.

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. 7). The plants in the LED chamber and increased temperature 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.

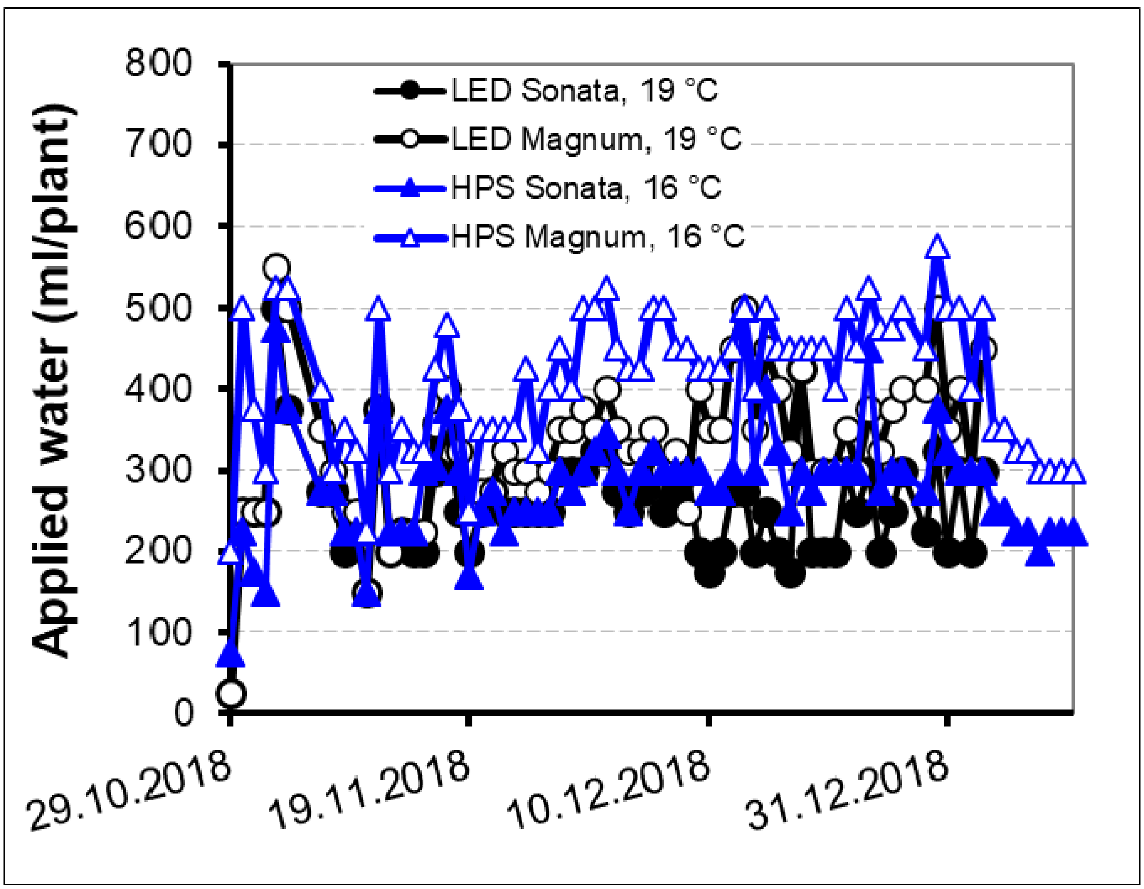

Fig. 7: Daily applied water.

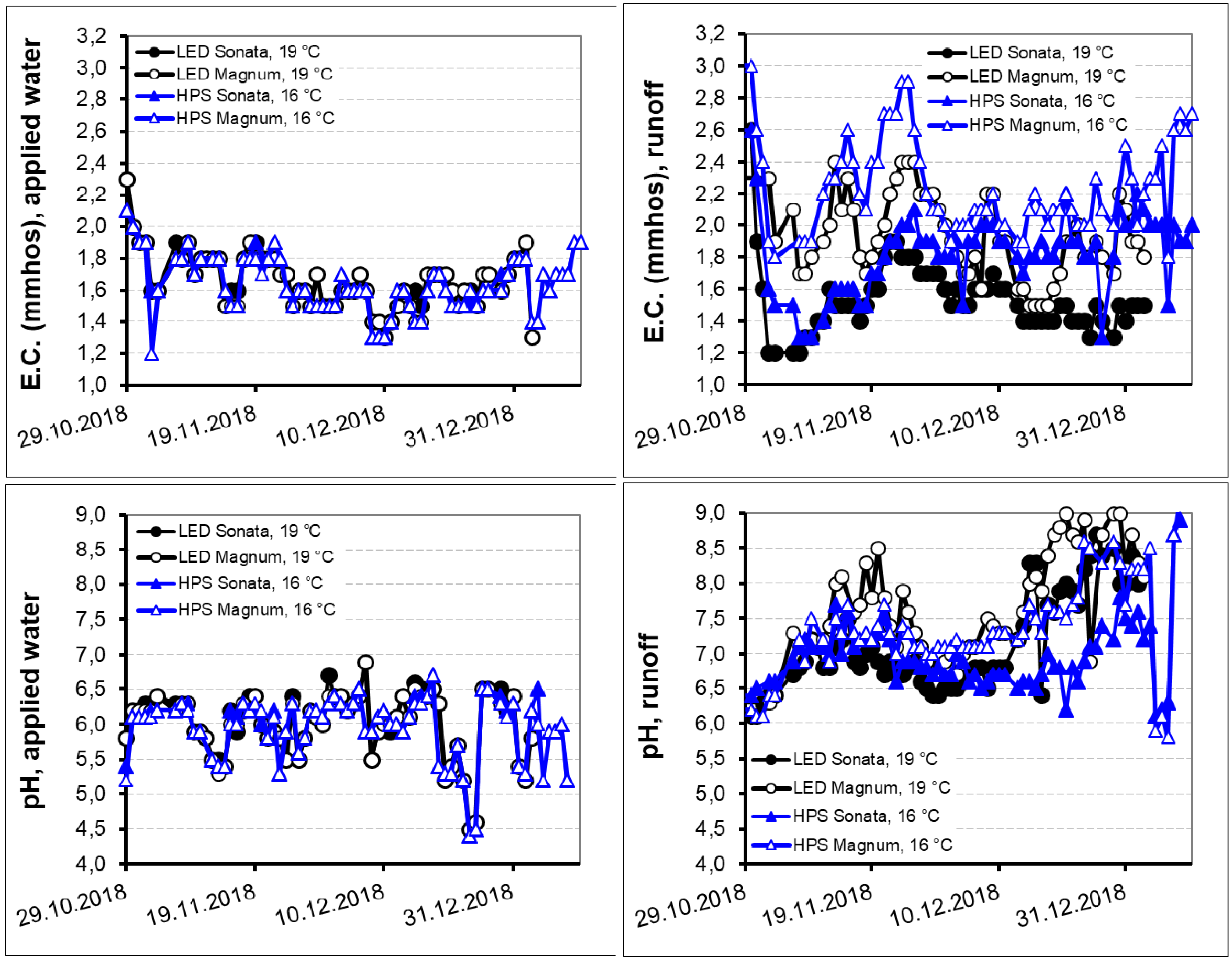

Fig. 8: **E.C. and pH of irrigation water and runoff.**

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

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. 9).

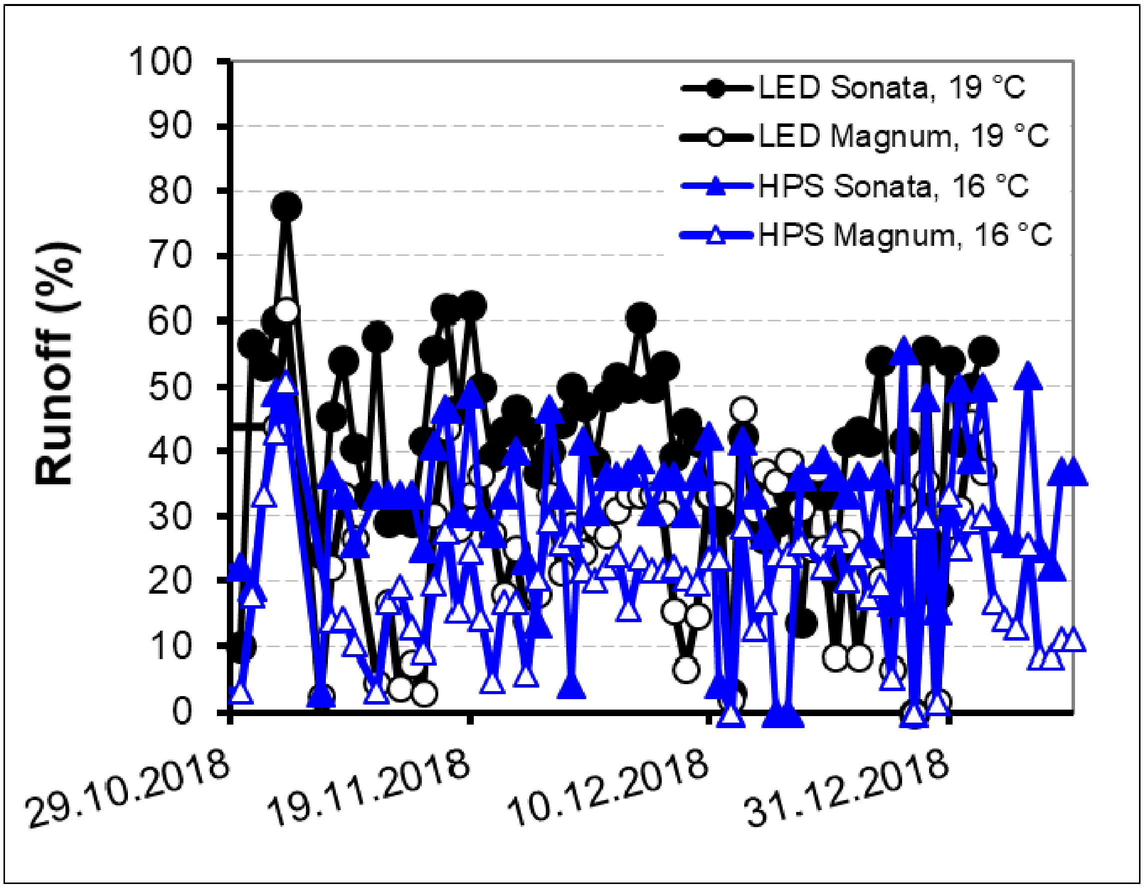

Fig. 9: Proportion of amount of runoff from applied irrigation water.

4.2 Development of strawberries

4.2.1 Plant diseases and pests

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 0 % in the LED chamber. Magnum was not infected with phytopthora. Plants were infected with grey mold (*Botrytis cinerea*). At the end of the harvest period were in the LED chamber spider mites (*Tetranychus urticae)* observed.

4.2.2 Number of leaves

The number of leaves increased for Sonata from 14 to 24 and for Magnum from 18 to 32 (Fig. 10). No significant differences in the number of leaves between light sources were found, whereas the number of leaves was significantly different between varieties. The leaves in the LED chamber and increased temperature started earlier to grow after planting. Leaves were taller in the HPS chamber. Under both light sources had Magnum taller leaves than Sonata (data not shown).

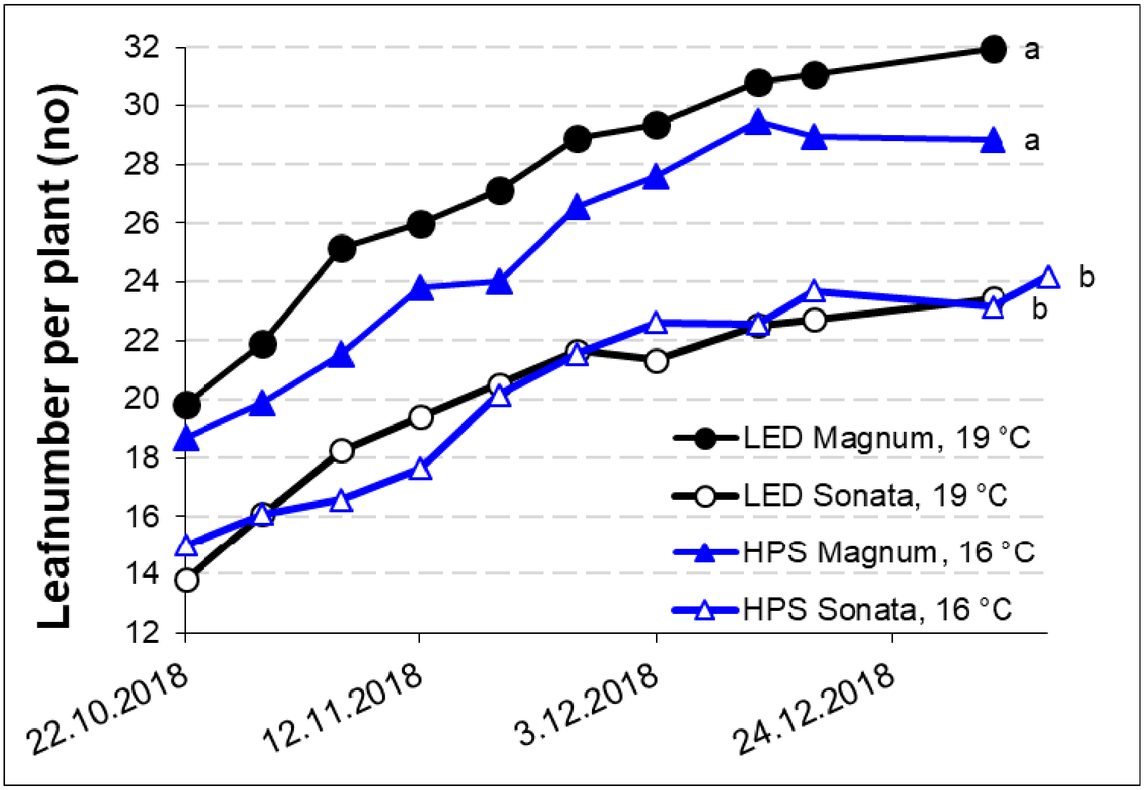

Fig. 10: Number of leaves at strawberry plants.

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 around seven runners per plant while Sonata had about two runners per plant. The light source was not influencing the number of runners (Fig. 11).

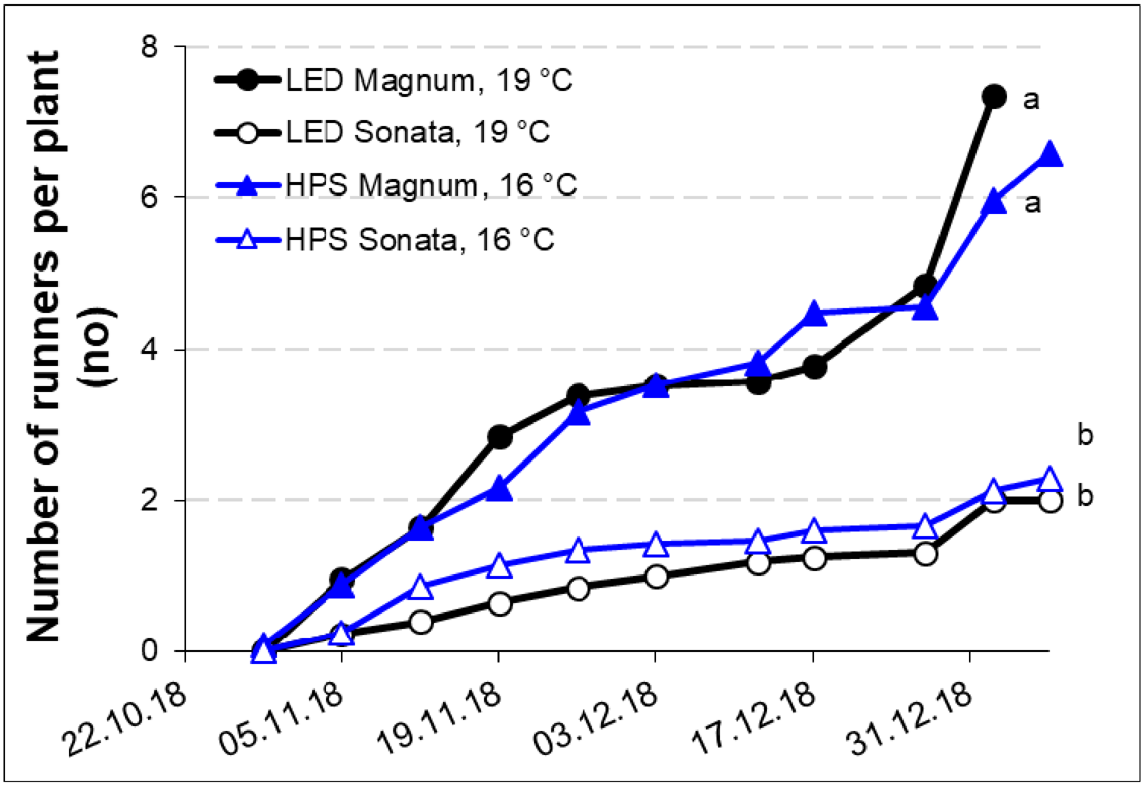

Fig. 11: Number of runners at strawberry plants.

Letters indicate significant differences at the end of each growing period (HSD, p ≤ 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 (Fig. 12).

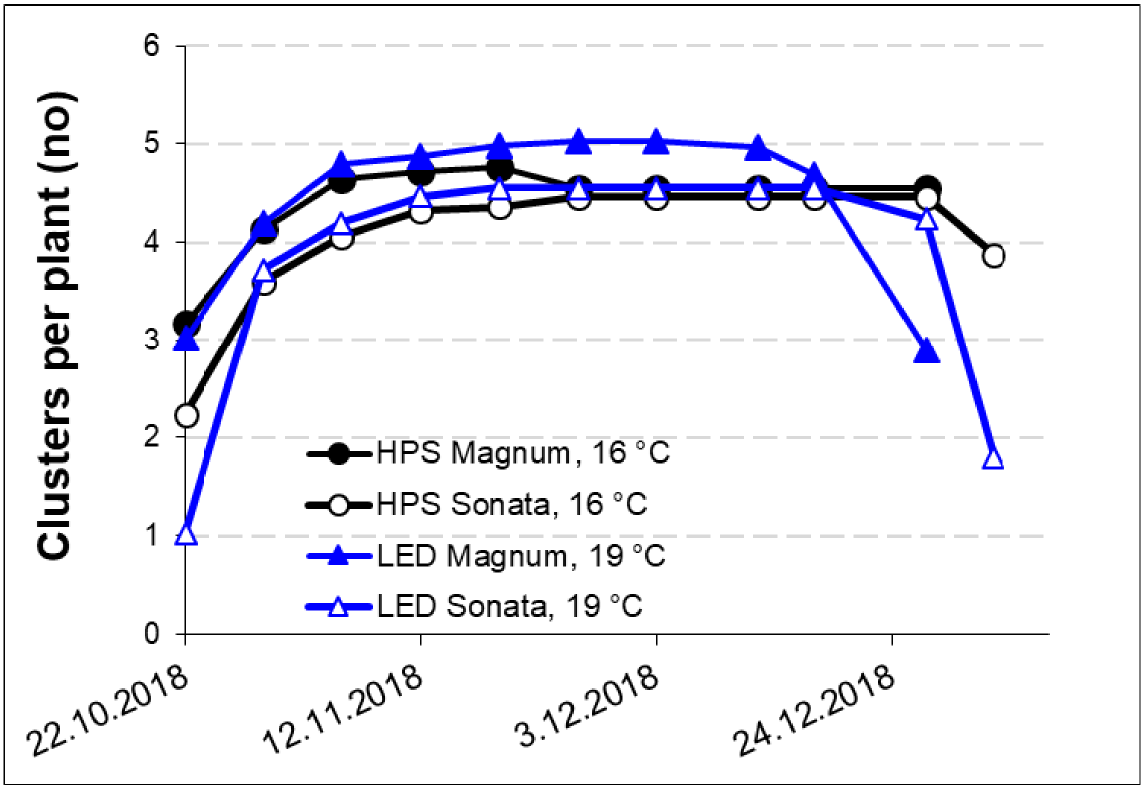

Fig. 12: Number of clusters at strawberry plants.

4.2.5 Open flowers / fruits per cluster

The number of open flowers / fruits per cluster reached about 13 for Sonata and 11 for Magnum (Fig. 13). After that, the number decreased naturally due to harvested fruits. The peak was delayed at the HPS treatment compared to the LED treatment and increased temperature.

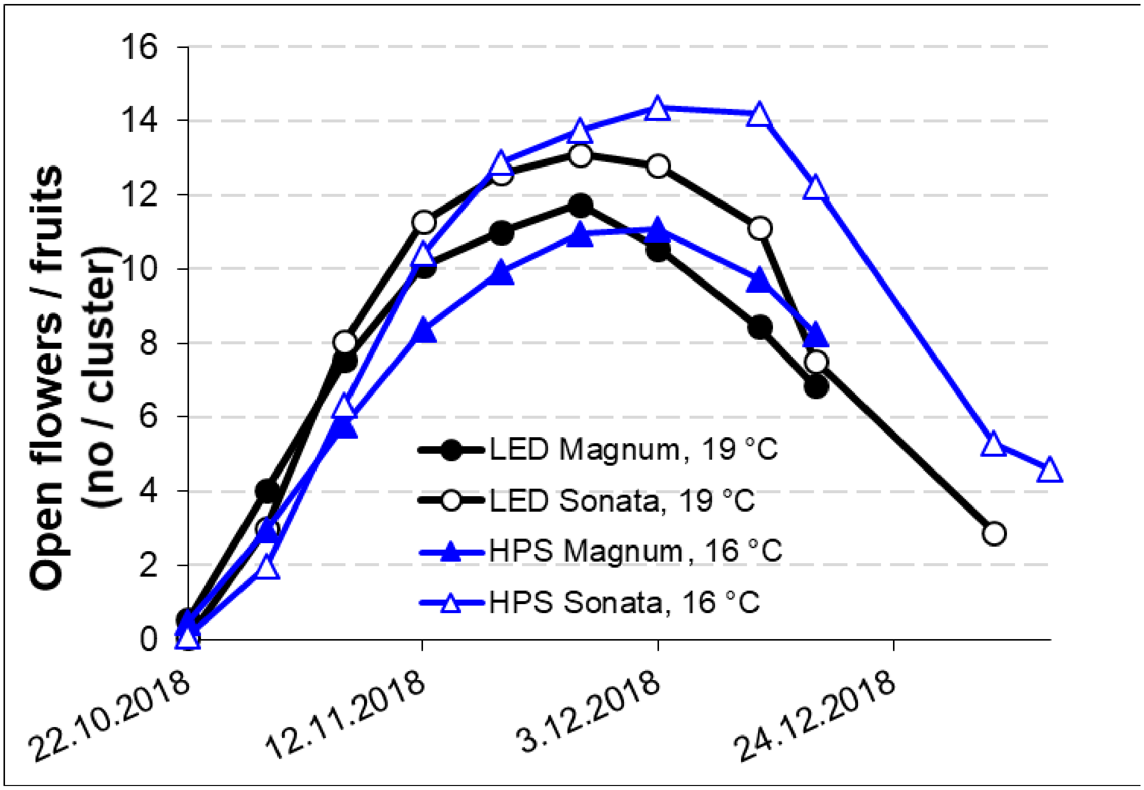

Fig. 13: Number of flowers / fruits per cluster.

4.2.6 Open flowers / fruits per plant

The number of open flowers / fruits of the Sonata plant reached about 60, while the Magnum plant reached under HPS about 50 before harvest started, but was on a similar level under LEDs as Sonata (Fig. 14). Thereafter, this number decreased naturally due to harvested fruits. The open flowers appeared earlier in the LED chamber and increased temperature than in the HPS chamber, where the development was one week behind plants from the LED chamber. However, the number of the flowers / fruits was not different between chambers and varieties, except the number of flowers / fruits was a bit lower for the variety Magnum under HPS lights (Fig. 14).

However, the total number of flowers of Magnum consisted of a high amount of unpollinated flowers and later rejected flowers, 24 % under LEDs and 12 % under HPS lights (Fig. 15). This was not observed for Sonata, where the percentage of unpollinated flowers was 1-3 %.

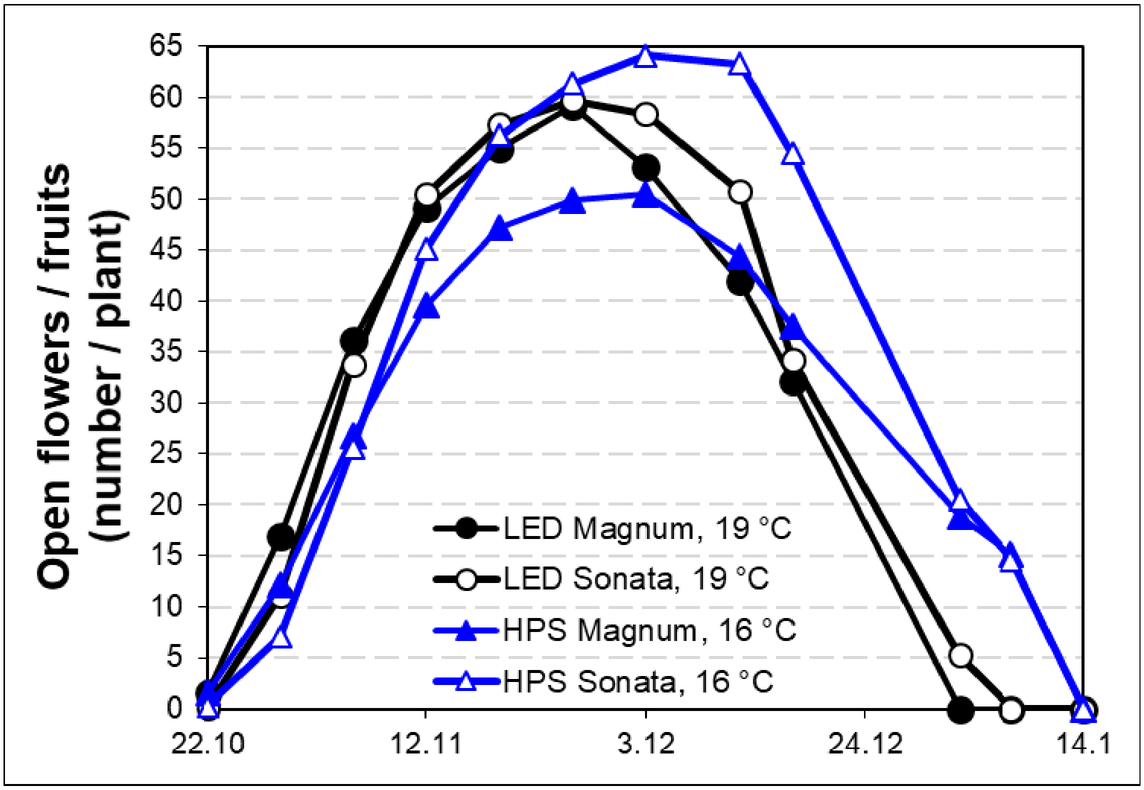

Fig. 14: Open flowers / fruits per plant.

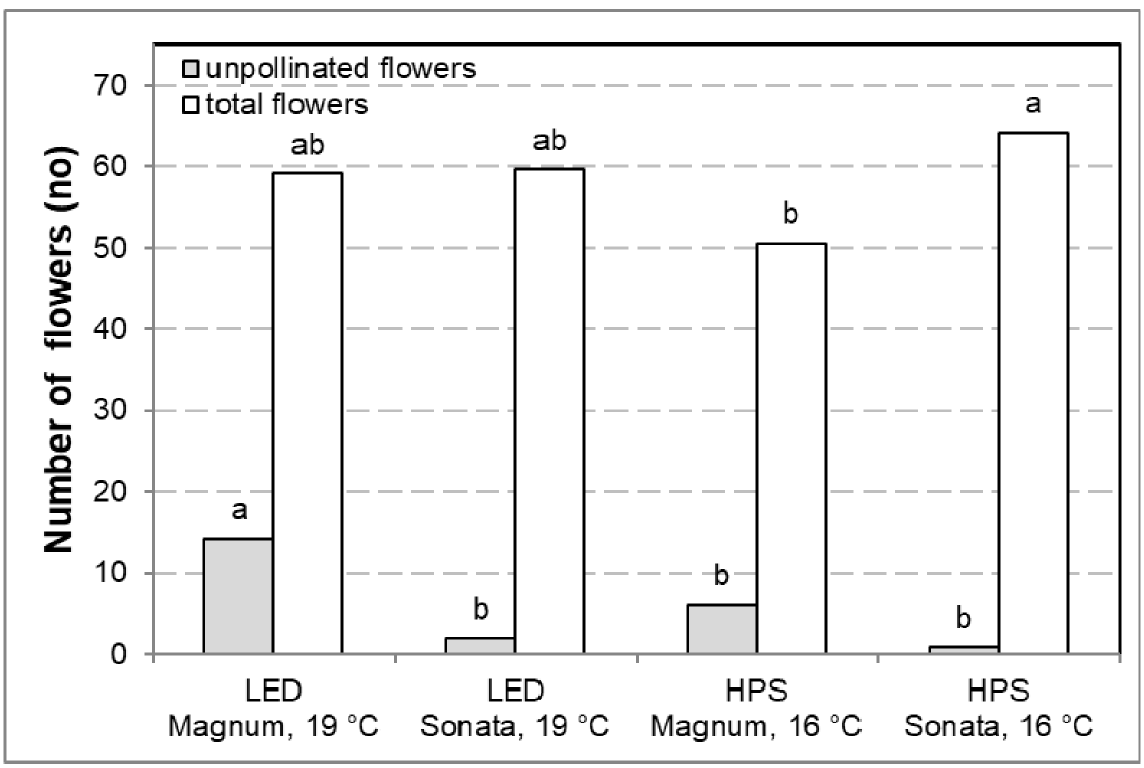

Fig. 15: Number of total flowers and unpollinated flowers.

Letters indicate significant differences at the end of each growing period (HSD, p ≤ 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 0,45-0,67 g/plant (Fig. 16). For the experimental plants was a significantly higher yield of Sonata measured under HPS lights. For Magnum was the yield tendentially higher under HPS lights (Fig. 16a). This difference was also observed for the plants, where only the yield was measured (Fig. 16b). There seem to be a small advantage in the total yield for Sonata compared to Magnum. This difference was most of the time significant.

4.3.2 Marketable yield of strawberries

At the end of the harvest period amounted yield of strawberries 0,38-0,61 g/plant (Fig. 17a, Fig. 17b). The light source had in dependence of the variety an influence on marketable yield of the plants: At the end of the harvest, the marketable fruit yield of Magnum was significantly higher under HPS (450 / 520 g/plant) than LED lights and increased temperature (380 / 430 g/plant). However, for Sonata was only for the measurement plants (610 g/plant) the yield significantly higher under HPS than under LED lights and increased temperature (480 g/plant), whereas for the plants where only the yield was measured, were no significant yield differences found between light sources (HPS, 16 °C: 600 g/plant, LED, 19 °C: 560 g/plant).

The marketable yield of Magnum was 78 % (LED, 19 °C) / 73 % (HPS, 16 °C) (Fig. 17a) and 77 % (LED, 19 °C) / 87 % (HPS, 16 °C) (Fig. 17b) 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.

Strawberries under LEDs with increased temperature were one week earlier ripe than under HPS lights. Also, the harvest in the LED treatment ended one weeks before the HPS treatment.

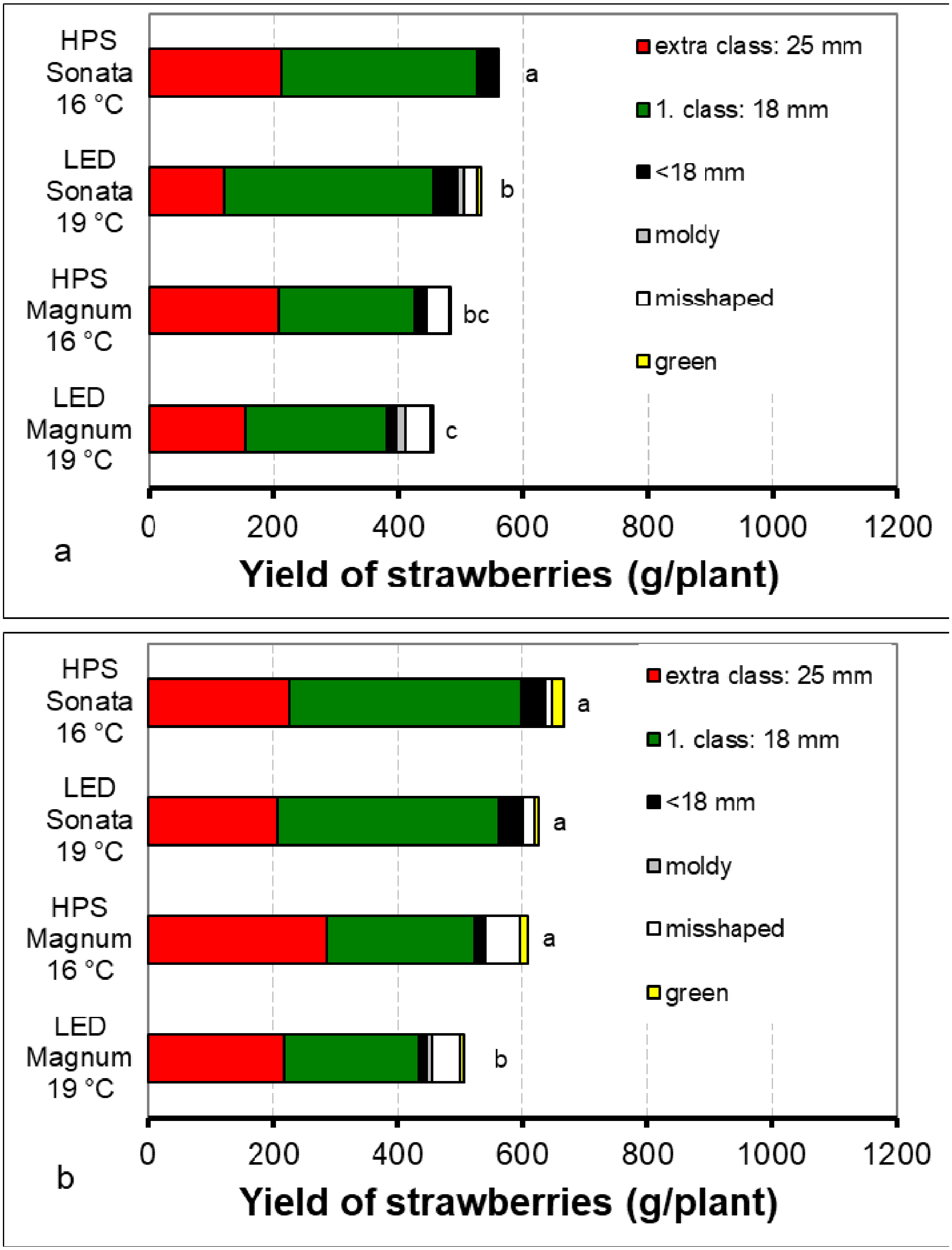

Fig. 16: Cumulative total yield of strawberries.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

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

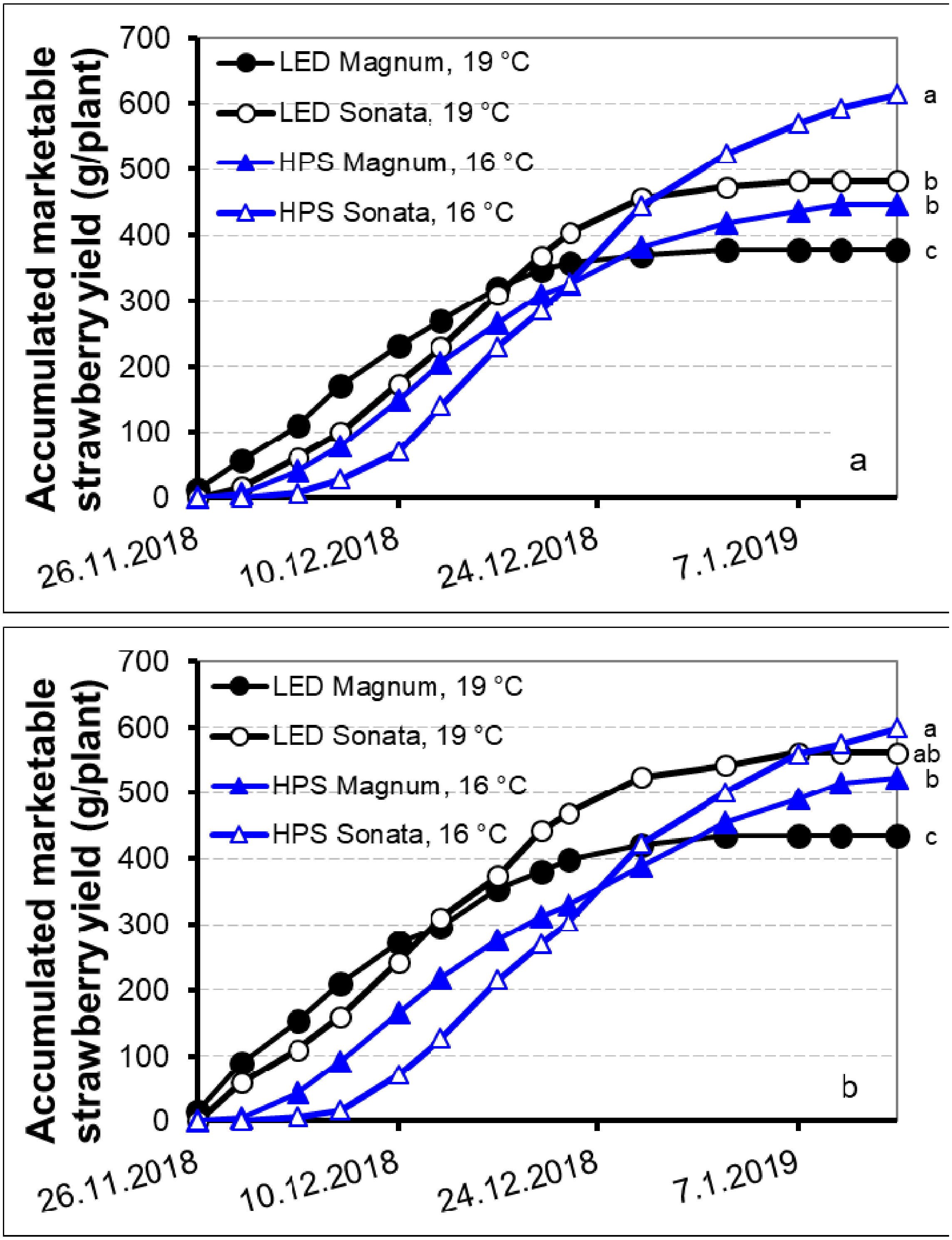

Fig. 17: Time course of accumulated marketable yield of strawberries.
“a” is the yield of the measurement plants, “b” the yield of the plants, where only the yield was measured.

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

Also, the marketable yield of the whole chamber was measured. A higher marketable yield was reached with Sonata (LED, 19 °C: 540 g/plant, HPS, 16 °C: 560 g/plant) compared to Magnum (LED, 19 °C: 460 g/plant, HPS, 16 °C: 500 g/plant) (Fig. 18). Regarding light sources, for both varieties was an advantage of the HPS treatment compared to the LED treatment and increased temperature reached.

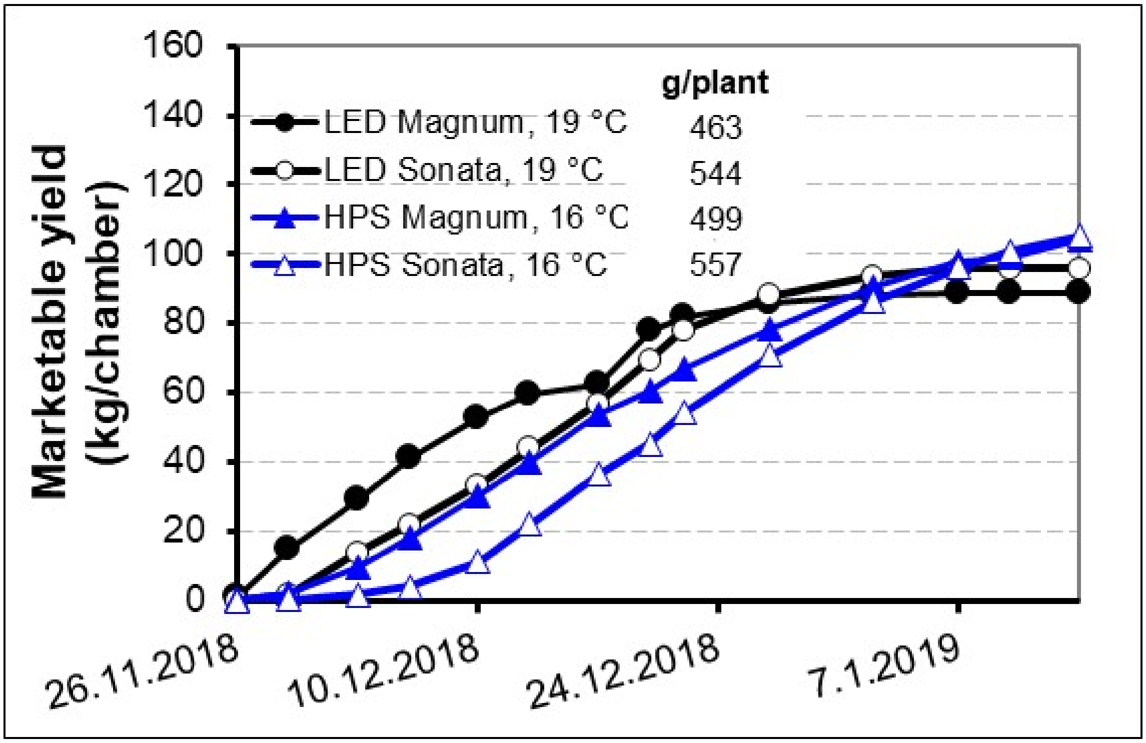

Fig. 18: Time course of accumulated marketable yield of strawberries for the whole chamber.

Fruits in the LED chamber with increased temperature started earlier to ripe, resulting in a higher first yield, whereas later the marketable yield increase decreased. In the HPS treatment gave the plants later than the LED treatment and increased temperature marketable ripe berries. Except for the two first weeks, the marketable yield on each harvest day was always higher for Sonata than for Magnum (Fig. 19).

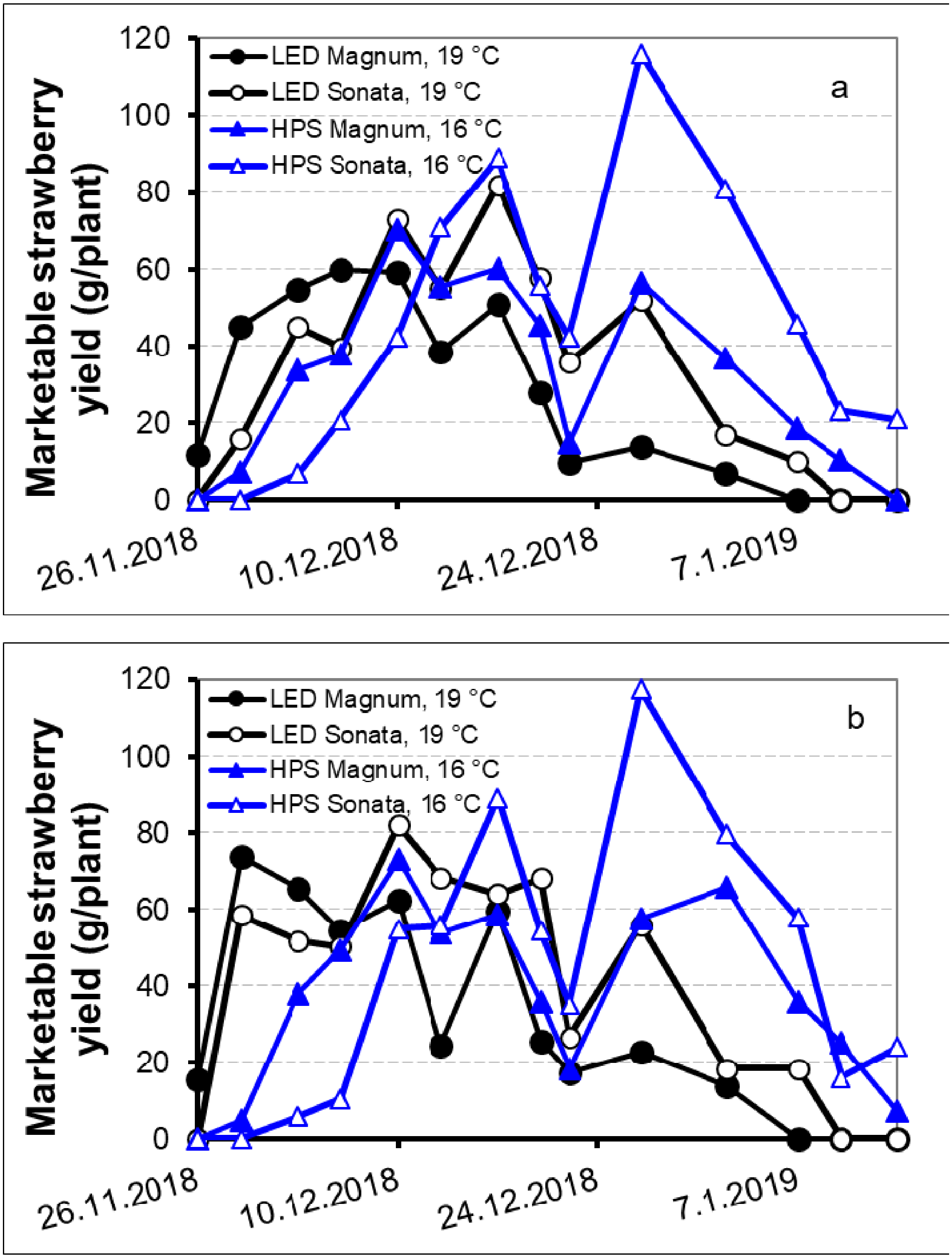

Fig. 19: Time course of marketable yield.
"a" is the yield of the measurement plants, "b" the yield of the plants, where only the yield was measured.

There were no differences in the number of extra class fruits, neither between light sources nor between varieties when the significant lower number of extra class fruits with the variety Sonata under LED lights and increased temperature compared to HPS lights at the measurement plants was excluded (Tab. 4). For “class I + II” were no significant differences between light sources counted. In contrast, Sonata had a significant higher number of first and second class fruits than Magnum. When the sum of the marketable fuits was observed, was also a significant higher number of fruits for Sonata examined, whereas no differences between light sources were found when the significant higher number of Sonata under HPS lights at the measurement plants was excluded.

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, 16 °C	13 a	39 a	52 a
LED Sonata, 19 °C	7 c	39 a	46 b
HPS Magnum, 16 °C	11 ab	23 b	34 c
LED Magnum, 19 °C	8 bc	22 b	30 c
HPS Sonata, 16 °C *	12 a	40 a	52 a
LED Sonata, 19 °C *	10 a	38 a	48 a
HPS Magnum, 16 °C *	13 a	25 b	38 b
LED Magnum, 19 °C *	11 a	22 b	33 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 25-35 g to around 10 g during the harvest period (Fig. 20a, 20b). No significant differences between light sources were observed in the average weight of the marketable fruits, but there seem to be a small tendency of heavier fruits under HPS lights. The average weight of Magnum was significantly higher than of Sonata and amounted 1-2 g more.

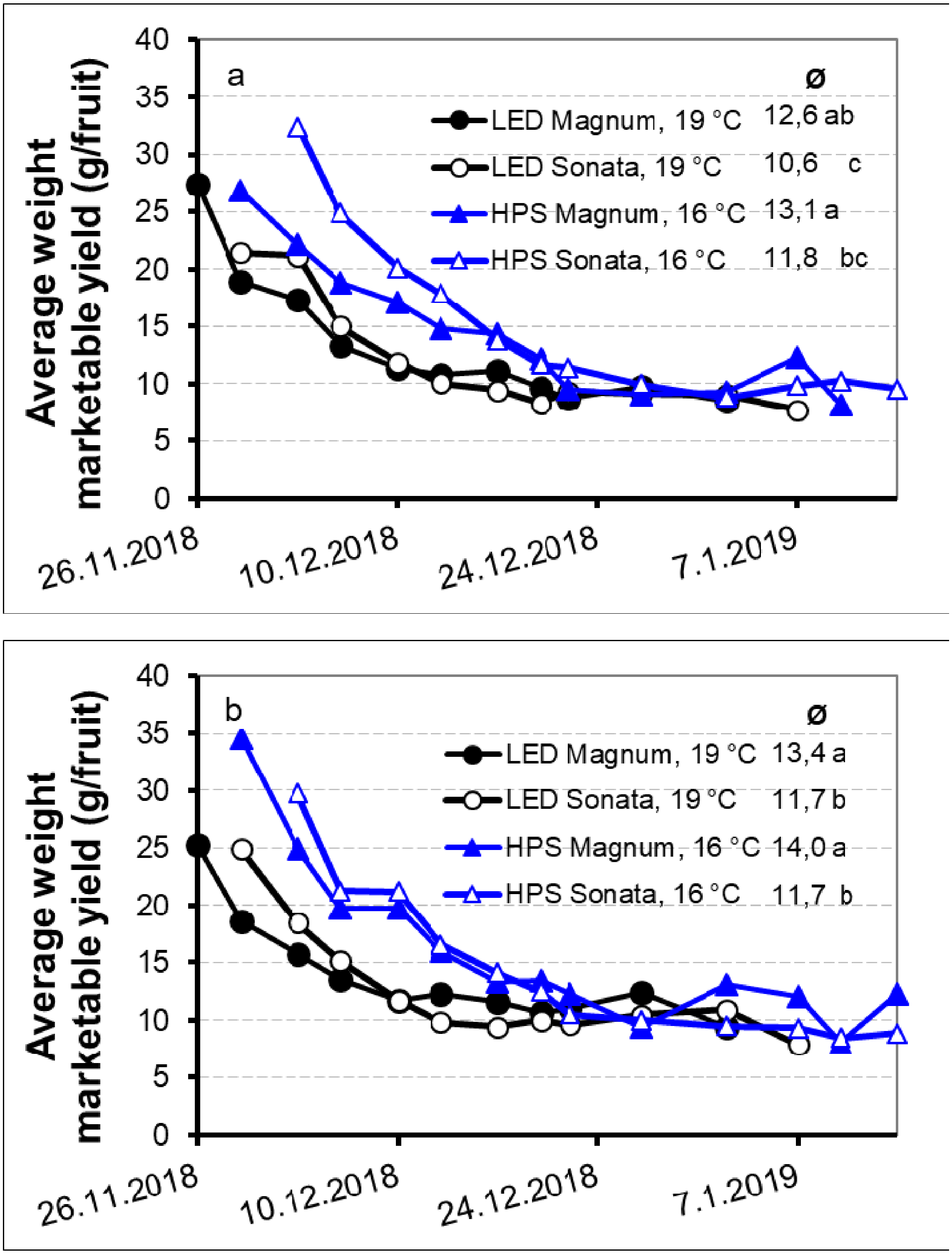

Fig. 20: Average weight of strawberries.
"a" is the average weight of the measurement plants, "b" the yield of the plants, where only the yield was measured.

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). While for Magnum were no differences in the duration of ripening between light sources observed, seems the light source to influence the number of days for Sonata: Magnum needed in average 45 days to ripe under both HPS (40-51 days) and LED lights and increased temperature (37-51 days). However, for Sonata it took in average 43 days (38-50 days) under LEDs and increased temperature and in average 50 days (43-56 days) under HPS lights (Fig. 21). No relationship was found between the number of days from pollination to harvest and the weight of the fruit.

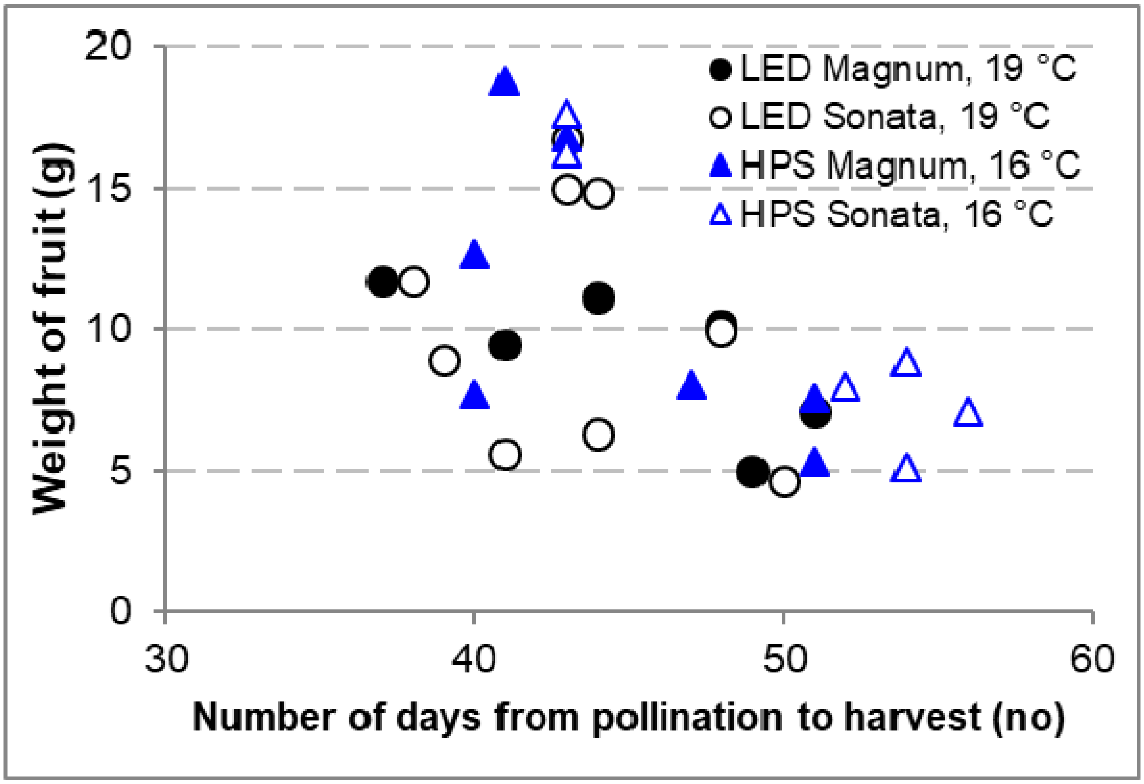

Fig. 21: Number of days from pollination to harvest and weight of the harvested fruit.

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 15 fruits were weekly harvested when harvest reached its maximum (Fig. 22a). In contrast, for Magnum was the harvest more even during the harvest period and weekly were around eight fruits harvested (Fig. 22b).

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 70 flowers / fruits for Magnum and 69-65 flowers / fruits for Magnum.

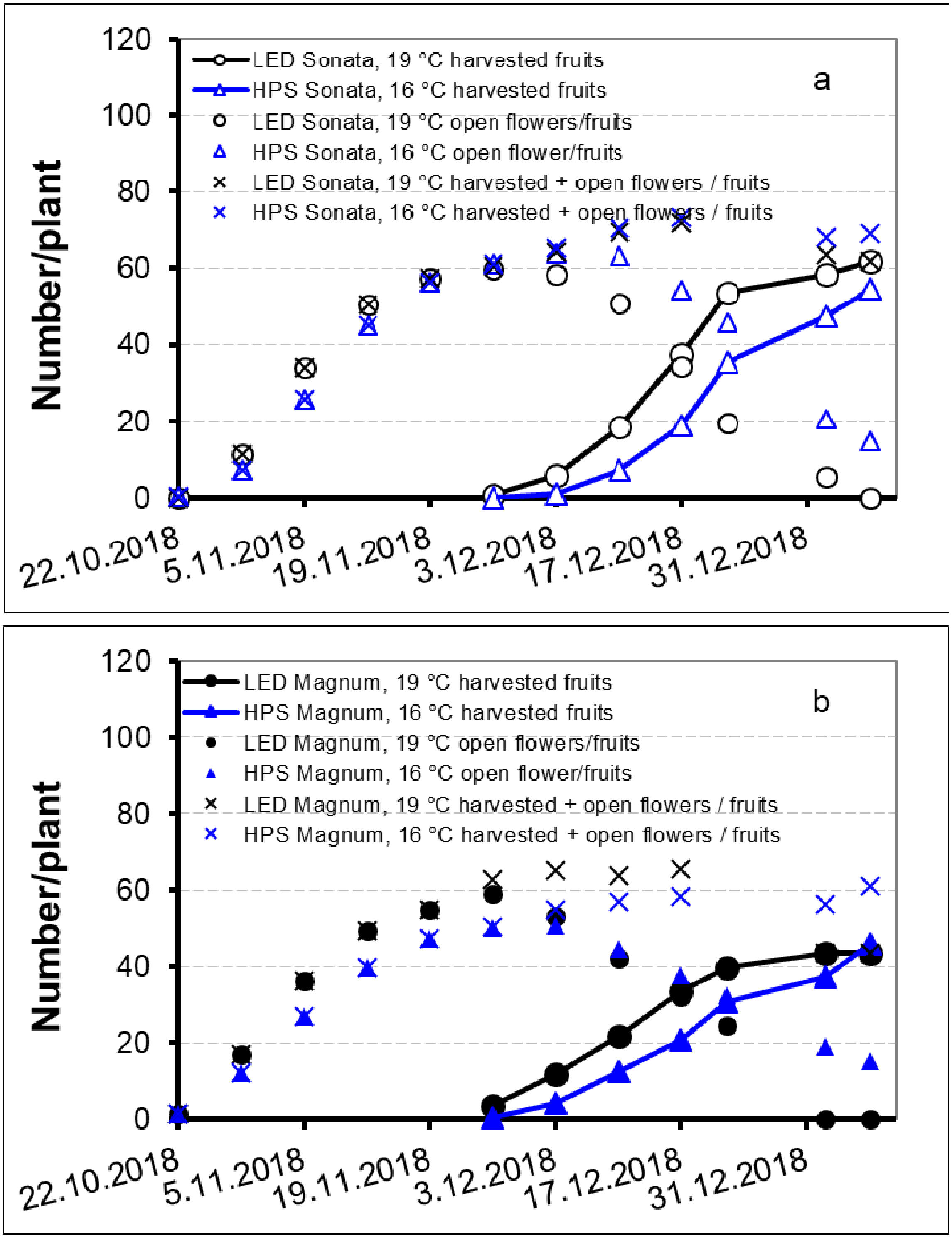

Fig. 22: Development of open flowers / fruits, harvested fruits and their sum during the growth of the strawberries.

4.3.3 Outer quality of yield

Marketable yield was about 90 % (Tab. 5). Sonata had a slightly 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 mostly a significantly 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, 16 °C	38 a	54 b	5 ab	0 a	1 c	2 a
LED Sonata, 19 °C	23 b	65 a	7 a	1 a	3 bc	1 ab
HPS Magnum, 16 °C	46 a	42 c	5 ab	0 a	6 ab	1 ab
LED Magnum, 19 °C	37 a	48 bc	4 b	2 a	9 a	0 b
HPS Sonata *, 16 °C	34 b	56 a	5 a	0 a	2 b	3 a
LED Sonata *, 19 °C	33 b	57 a	5 a	1 a	3 b	1 b
HPS Magnum *, 16 °C	47 a	39 b	3 b	0 a	9 a	2 ab
LED Magnum *, 19 °C	43 ab	42 b	2 b	2 a	9 a	2 ab

* for the plants, where only the yield was measured

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

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. Magnum had with values of 8-11°BRIX a higher sugar content than Sonata with values of 6-9°BRIX. There were no differences between light sources for Magnum measured. However, Sonata seem to have a lower sugar content under LED lights and increased temperature. It seems that the sugar content increased at the end of the harvest period (Fig. 23).

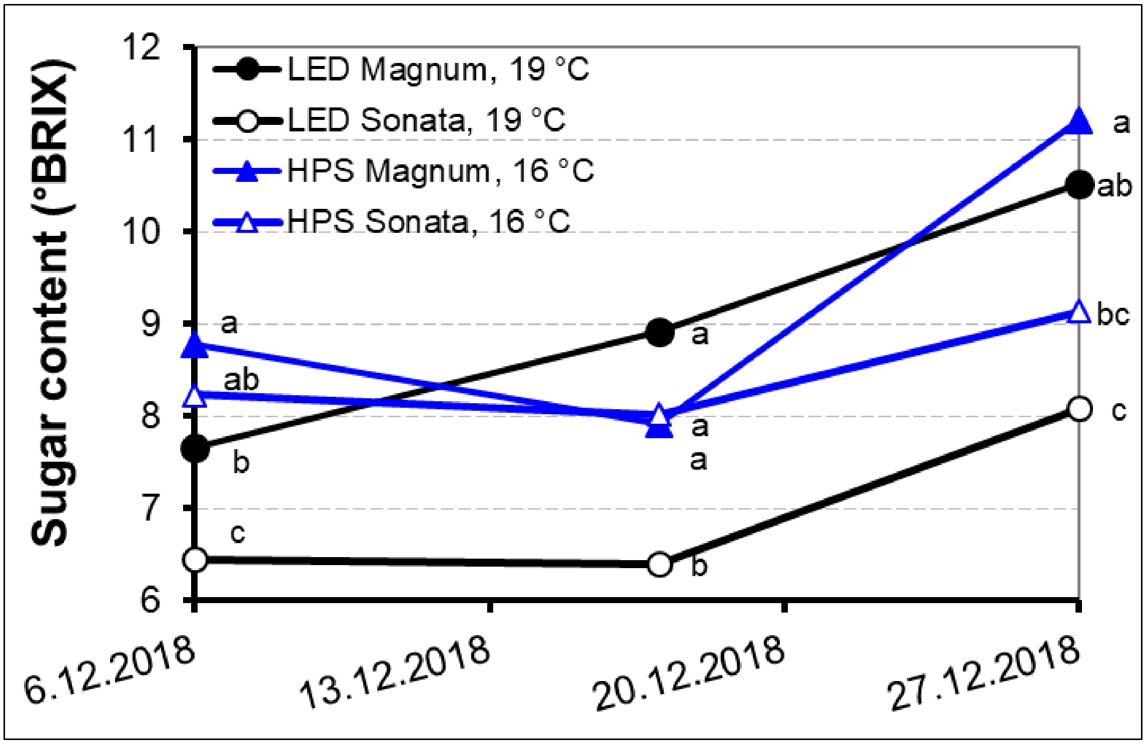

Fig. 23: Sugar content of strawberries.

Letters indicate significant differences (HSD, p ≤ 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 07.12.2018. The rating within the same sample was varying very much and therefore, same treatments resulted in a high standard deviation. As in the BRIX measurements, it seems that also in the tasting experiment was the variety Sonata under HPS lights evaluated a bit sweeter. In addition, Sonata was evaluated with more flavour than under LEDs and increased temperature. However, this was not observed with the variety Magnum. It seems that the light source did not influence the juiciness and formness of strawberries. Sonata seems to be evaluated sweeter than Magnum under HPS lights, while this variety effect was not observed under LED lights. Sonata was evaluated with more juiciness while Magnum was evaluated with more firmness (Fig. 24).

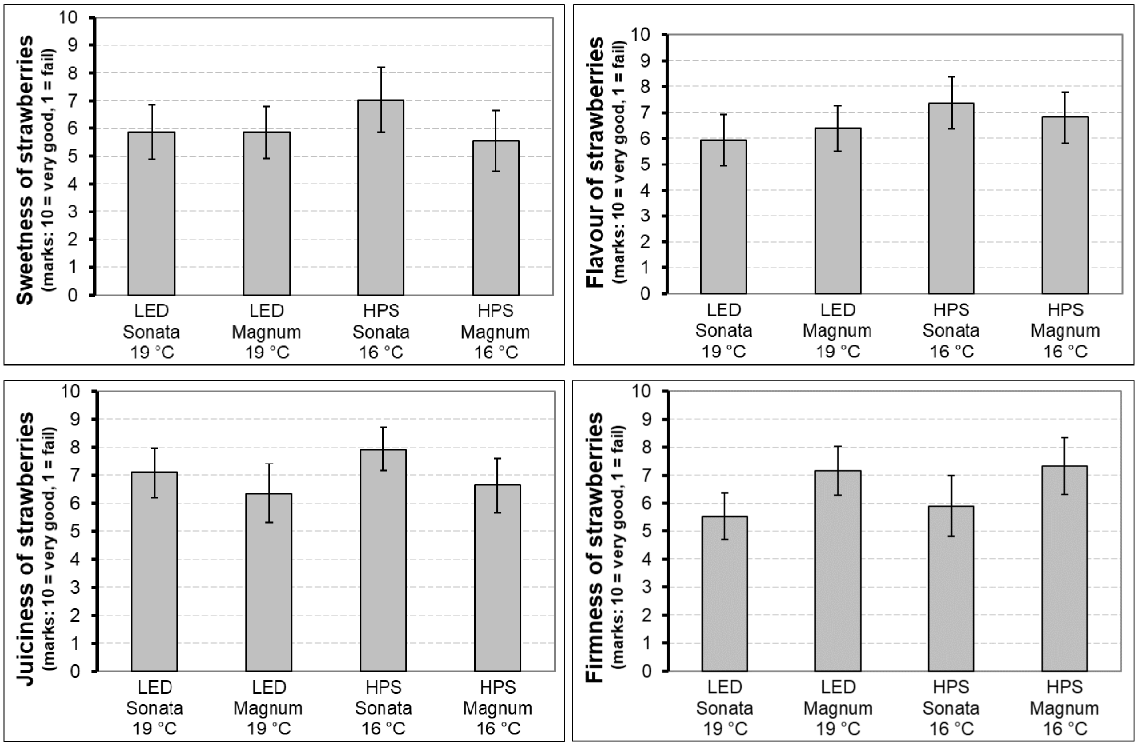

Fig. 24: Sweetness, flavour, juiciness and firmness of strawberries.

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 most of the times a higher DS than Sonata. It seems that fruits under HPS lights had a higher DS than under LEDs and increased temperature. Also, it seems that the DS increased during the harvest period from about 7 to 8 % for Sonata and from 8 to 10 % for Magnum (Fig. 25).

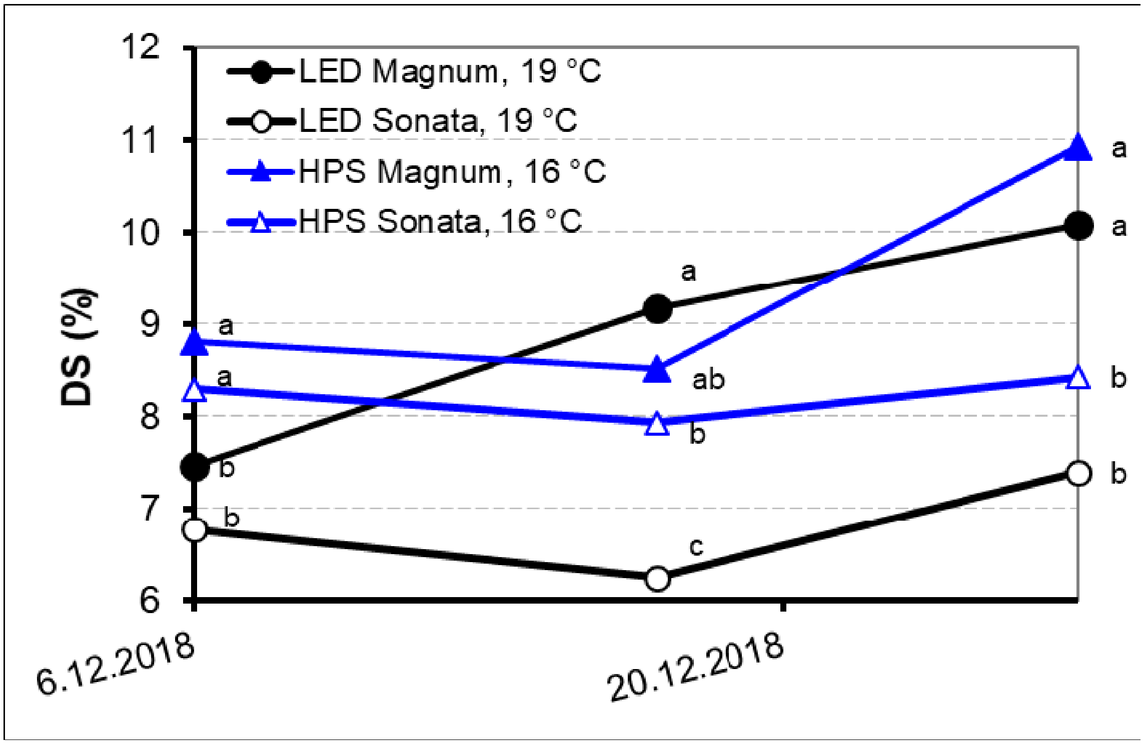

Fig. 25: **Dry substance of strawberries.**

4.3.4.4 Relationship between dry substance and sugar content of fruits

There was a relationship between DS and sugar content of fruits (Fig. 26). A higher

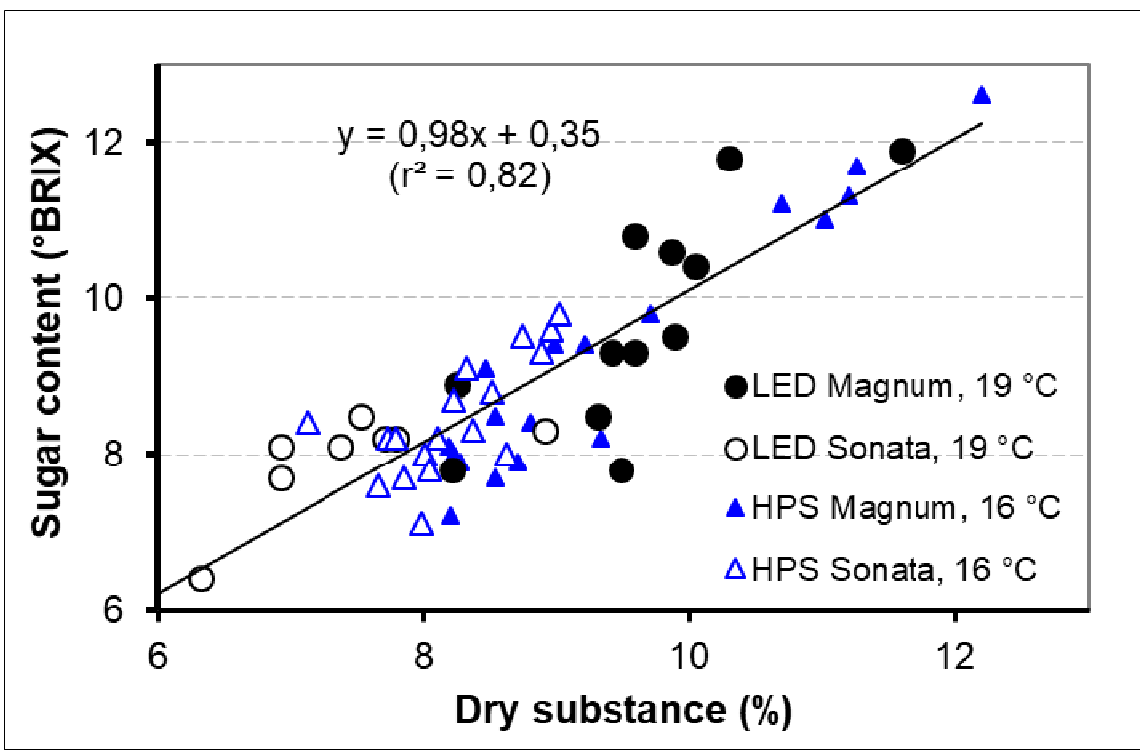

Fig. 26: **Relationship between dry substance and sugar content of fruits.**

DS was involved with a higher sugar content. Sonata had a lower DS and a lower sugar content than Magnum (Fig. 26).

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 200 kWh (Fig. 27), while the LED chamber had with 107 kWh nearly 46 % less than the HPS chamber.

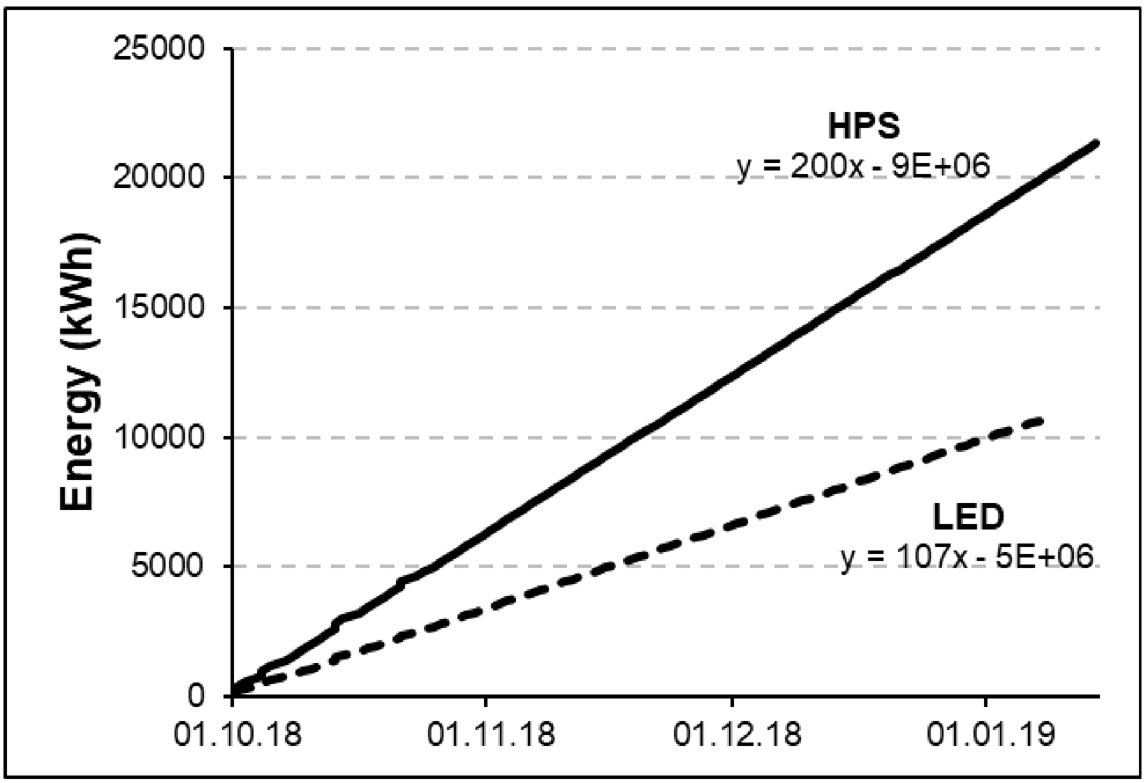

Fig. 27: Used kWh in the different chambers.

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). The measured lighting hours were higher for the HPS chamber, because the harvest was finished one week later than the LED chamber with increased temperature.

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, 16 °C				
Measured values	1.659	257	21.321	426
Simulated values				
0 % more power consumption (nominal)	1.648	180	14.832	297
6 % more power consumption	1.648	191	15.722	314
10 % more power consumption	1.648	198	16.315	326
LED Sonata, 19 °C				
Measured values	1.610	132	10.596	212
Simulated values				
0 % more power consumption (nominal)	1.536	117	8.986	180
6 % more power consumption	1.536	124	9.525	190
10 % more power consumption	1.536	129	9.884	198
HPS Magnum, 16 °C				
Measured values	1.596	257	20.514	410
Simulated values				
0 % more power consumption (nominal)	1.632	180	14.688	294
6 % more power consumption	1.632	191	15.569	311
10 % more power consumption	1.632	198	16.157	323
LED Magnum, 19 °C				
Measured values	1.539	132	10.124	202
Simulated values				
0 % more power consumption (nominal)	1.504	117	8.798	176
6 % more power consumption	1.504	124	9.326	187
10 % more power consumption	1.504	129	9.678	194

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. In recent years, the subsidies fluctuated quite much. Currently 82 % and 86,1 % of variable cost of distribution for urban and rural areas respectively are subsidised. However, in 2018 the values were 64,8 % respectively 69,2 % and in 2017 87 % respectively 92 %. This amount can be expected to change in the future. In contrast to the previous years, now also the annual fee is subsidised.

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 0,81-1,04 ISK/kWh for „VA210" and 1,20-1,52 for „VA230", 0,68-0,92 ISK/kWh for „VA410" and 0,89-1,08 ISK/kWh for „VA430". The energy costs for sale are for „Afltaxti" 5,53-6,59 ISK/kWh and for „Orkutaxti" 6,86-8,35 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 lower than for the HPS chamber.

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			
Treat-ment	HPS Sonata, 16 °C		HPS Magnum, 16 °C		HPS Sonata, 16 °C		HPS Magnum, 16 °C	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					82 % subsidy from the state			
VA210	0,99	0,84	1,01	1,00	421	250 265 275	413	293 311 322
VA410	0,86	0,72	0,88	0,87	368	213 226 235	362	256 271 282
RARIK Rural					86,1 % subsidy from the state			
VA230	1,46	1,29	1,48	1,47	623	384 407 422	608	432 458 475
VA430	1,03	0,92	1,05	1,04	441	274 290 301	430	306 324 336
SALE								
Afltaxti	6,40	5,71	6,49	6,44		1.693		1.885
Orkutaxti	8,35	8,19	8,39	6,97	2.729	1.798	2.662	1.998
						1.863		2.073

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 2019.

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 m² ISK/m²			
	LED Sonata, 19 °C		LED Magnum, 19 °C		LED Sonata, 19 °C		LED Magnum, 19 °C	
	real	calculated	real	calculated	real	calculated	real	calculated
DISTRIBUTION								
RARIK Urban					82 % subsidy from the state			
VA210	1,00	0,81	1,03	1,04	213	145 154 159	208	184 195 202
VA410	0,88	0,68	0,90	0,92	186	123 130 135	183	161 171 178
RARIK Rural					86,1 % subsidy from the state			
VA230	1,48	1,25	1,51	1,52	313	225 239 248	305	268 284 295
VA430	1,05	0,89	1,07	1,08	222	161 170 177	216	190 201 209
SALE								
Afltaxti	6,48	5,53	6,59	6,66		994		1.117
Orkutaxti	8,30	8,19	8,35	6,86	1.373	1.054	1.334	1.184
						1.094		1.228

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 2019.

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 around 40 % (Sonata: 40 %, 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, 16 °C		LED Sonata, 19 °C		HPS Magnum, 16 °C		LED Magnum, 19 °C	
Yield kg/m²	7,2		6,7		6,3		5,2	
	real	calculated	real	calculated	real	calculated	real	calculated
Urban area (Distribution + Sale)								
VA210	3.150	1.943 2.060 2.138	1.606	1.139 1.207 1.253	3.076	2.178 2.308 2.395	1.542	1.300 1.378 1.430
VA410	3.097	1.907 2.021 2.097	1.586	1.117 1.184 1.228	3.024	2.141 2.269 2.355	1.517	1.278 1.355 1.406
Rural area (Distribution + Sale)								
VA230	3.351	2.077 2.202 2.285	1.559	1.219 1.292 1.341	3.270	2.317 2.456 2.548	1.639	1.385 1.468 1.523
VA430	3.170	1.967 2.085 2.164	1.595	1.155 1.224 1.270	3.093	2.191 2.322 2.410	1.550	1.306 1.385 1.437

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. 28). With the choose of the variety Sonata increased the revenue slightly compared to Magnum. The light source had a small influence on the revenue, however, the influence of the variety was bigger.

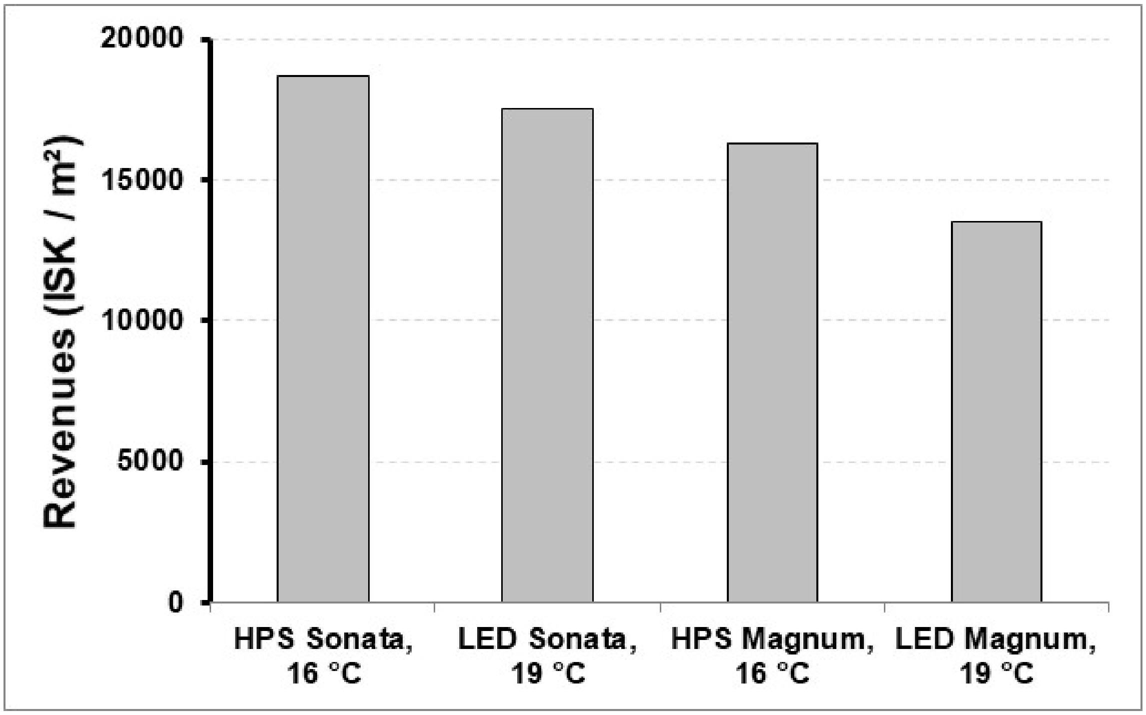

Fig. 28: Revenues at different treatments.

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 (≈ 40 ISK/m^2), costs for plant protection (≈ 300 ISK/m^2) and beneficial organism (≈ 500 ISK/m^2), plant nutrition (≈ 100 ISK/m^2), CO_2 transport (≈ 150 ISK/m^2), liquid CO_2 (≈ 1.070 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. 29).

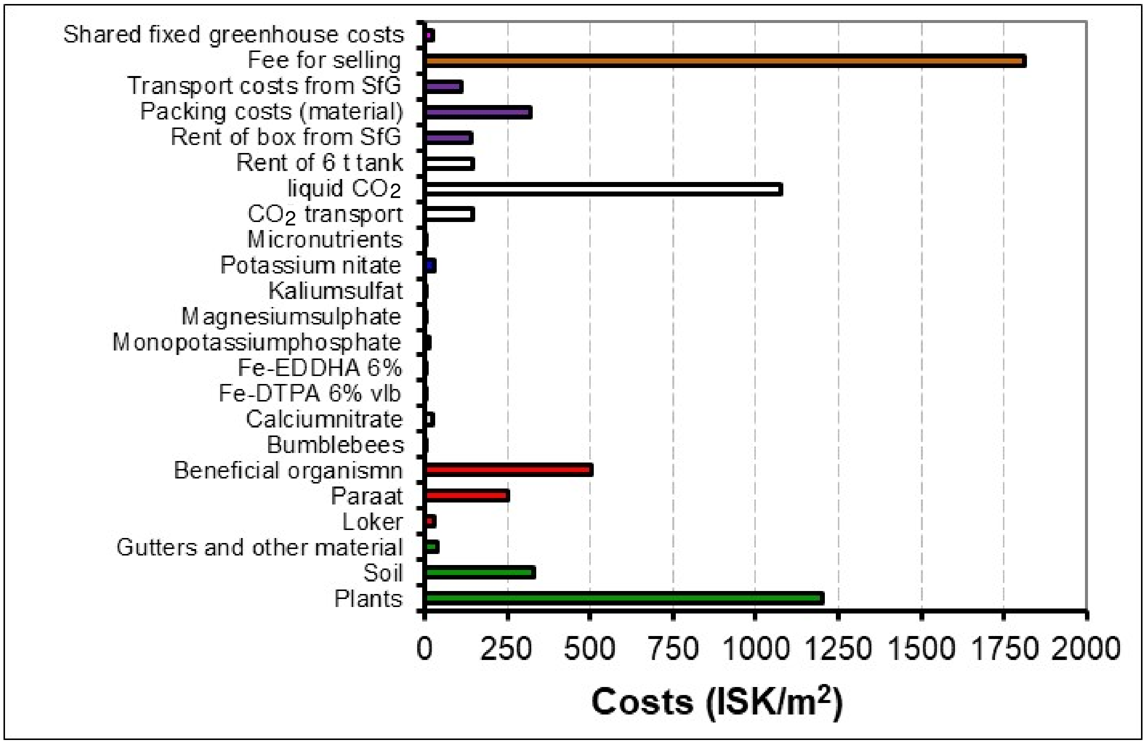

Fig. 29: Variable and fixed costs (without lighting and labour costs).

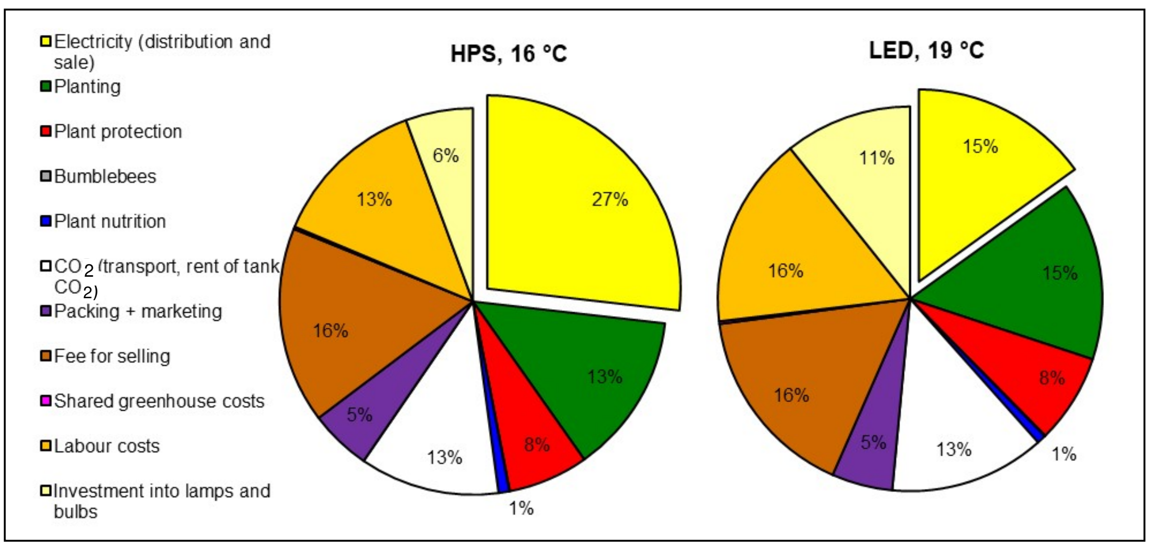

Fig. 30: Division of variable and fixed costs.

However, in Fig. 29 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. 30 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 3.400-6.800 ISK/m^2 (Fig. 31). The profit margin was higher for Sonata (6.600-6.800 ISK/m^2) than for Magnum (3.400-5.000 ISK/m^2). The choose of Sonata instead of Magnum increased the profit margin by 1.700-1.900 ISK/m^2 when HPS lights were used and by 3.100-3.200 ISK/m^2 when LED lights and increased temperature were used. For Sonata was the profit margin independent of the light source. However, for Magnum was the profit margin 1.300-1.500 ISK/m^2 higher with HPS lights than with LEDs and increased temperature. However, it has to be taken into account that the profit margin depends much on the actual price of the LEDs.

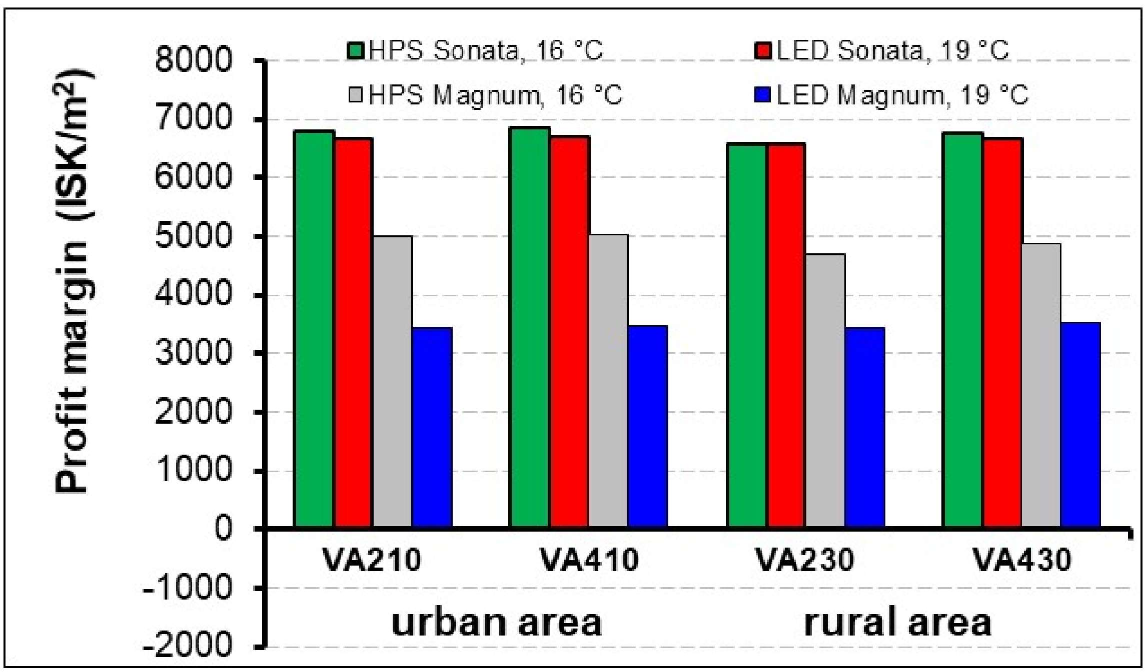

Fig. 31: Profit margin in relation to tariff and treatment.

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

Treatment	HPS Sonata, 16 °C	LED Sonata, 19 °C	HPS Magnum, 16 °C	LED Magnum, 19 °C
Marketable yield kg/m²	7,2	6,7	6,3	5,2
Sales				
SfG (ISK/kg) [1]	2.600	2.600	2.600	2.600
Revenues (ISK/m²)	**18.693**	**17.517**	**16.300**	**13.539**
Variable and fixed costs (ISK/m²)				
Electricity distribution [2]	421	213	413	208
Electricity sale	2.729	1.373	2.560	1.424
Strawberry plants [3]	1.200	1.200	1.200	1.200
Soil for strawberries [4]	330	330	330	330
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]	505	505	505	505
Bumblebees [11]	6	6	6	6
Calcium nitrate [12]	22	18	32	23
Potassium sulfate [13]	5	4	7	5
Fe-DTPA 6 % vlb [14]	4	4	6	5
FE-EDDHA 6 % [15]	4	3	6	4
Monopotassium phosphate [16]	13	10	19	13
Magnesium sulphate [17]	7	5	10	7
Potassium nitrate [18]	29	23	42	30
Micronutrients [19]	1	1	2	1
CO_2 transport [20]	146	146	146	146
Liquid CO_2 [21]	1.074	1.074	1.074	1.074
Rent of CO_2 tank [22]	144	144	144	144
Rent of box from SfG [23]	156	147	136	113
Packing material [24]	359	337	313	260
Fee for SfG [25]	2.049	1.920	1.787	1.484
Transport from SfG [26]	126	118	110	91
Shared fixed costs [27]	24	24	24	24
Lamps [28, 29]	429	1.091	429	1.091
Bulbs [30]	229		229	
Flowering lamps [31]		26		26
∑ variable costs	**10.328**	**9.039**	**9.846**	**8.532**
Revenues -∑ variable costs	**8.365**	**8.479**	**6.454**	**5.007**
Working hours (h/m²)	0,91	1,04	0,84	0,90
Salary (ISK/h)	1.740	1.740	1.740	1.740
Labour costs (ISK/m²)	1.583	1.808	1.465	1.564
Profit margin (ISK/m²)	**6.782**	**6.670**	**4.989**	**3.443**

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 2.476 ISK / bag Klasmann soil 200 l TS-4
5 54 ISK / pot; assumption: 10 years lifetime, 3 circles / year
6 4.250 ISK / bund of tape; assumption: 10 years lifetime, 3 circles / year
7 660 ISK / m gutter; assumption: 10 years lifetime, 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: 1.814 ISK / unit Phytoseiulus persimilis (predatory mite), once
3.337 ISK / unit mix of the parasitic wasp species Aphidius colemani, Aphidius ervi, Aphelinus abdominalis, Praon volucre and Ephedrus cerasicola, four times
11 4.999 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: 47,0 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 94 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, lifetime: 8 years
29 LED lights: 42.000 ISK/lamp, lifetime: 11 years
30 HPS bulbs: 4.000 ISK/bulb, lifetime: 2 years
31 flowering lamps: 4.950 ISK/lamp, lifetime: 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 and adapted temperature settings was tested on two varieties of strawberries. The number of flowers of Sonata was independent of the light source, whereas Magnum had more flowers under HPS lights than under LEDs and increased temperature. For Magnum was the number of unpollinated and later rejected flowers higher under LED and increased temperature than under HPS lights, while for Sonata were no differences recorded between light sources. In contrast, the year before, were more unpollinated and later rejected flowers found under HPS lights (*Stadler*, 2018b). Strawberry plants under HPS lights showed a delayed growth that was one week behind the development of strawberries treated with LEDs and increased temperature. Hence, started the harvest under LEDs one week earlier. Consequently, the harvest under LEDs was finished one week earlier than the harvest under HPS lights. It took one week longer for the Sonata berries to ripe under HPS lights compared to LEDs and increased temperature, while no differences in the riping for the variety Magnum were found between light sources. The accumulated marketable yield of Magnum under HPS lights (520 g/plant) was significantly higher than under LEDs and increased temperature (430 g/plant), while there were no significant yield differences between light sources for Sonata where only the yield was measured (HPS lights, 16 °C: 600 g/plant, LEDs, 19 °C: 560 g/plant).

The number of first and second class fruits was independent of the light source, likewise was the average fruit size, however, with a small tendency of heavier fruits under HPS lights.

But, also the temperature might have influenced the growth and yield of the strawberries. By increasing the day temperature by 3 °C in the LED treatment was it possible to compensate for the additional radiation heat of the HPS lights and prevent with that a harvest delay under LED lights as it was observed from *Stadler* (2018b) when temperature settings very the same between the HPS and the LED treatment. Despite of the fact that the temperature was set during the day 3 °C higher in the LED chamber, was the measured air temperature 1,3 °C higher under LEDs due to a 1,6 °C higher measured day temperature. The soil temperature, recorded by dataloggers, was 1 °C higher in the LED chamber, while the leaf temperature was according to dataloggers comparable between the light treatments. However, when the leaf temperature was measured by hand, were higher temperatures measured for strawberries growing under LEDs and increased temperature. This is showing the importance of measuring the leaf temperature not only at a given time, but continuously by dataloggers to be able to get representative results. The higher air and soil temperature might have been the reason for the one week faster development of plants in the LED 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. 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.

Indeed, *Davis* & *Burns* (2016) reported that in all experiments that compare HPS and LED light there is a need to assess the differences in plant temperature to ensure that any effect of temperature can be separated from the effects of light on plants responses. The authors concluded that the switch from HPS to LED lighting will require a period of learning to develop protocols for correct management of plant irrigation and growth.

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.

In contrast to the previous strawberry experiment (*Stadler*, 2018b), where in the presented experiment no problems with the pollination with bumblebees in the LED chamber during the time with no solar irradiation observed.

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 (*Stadler* & *Hrafnkelsson*, 2019).

Not only the yield, but also the appearance of the plant and the berries was affected by the light quality. Despite of the 50 % higher number of flowering lamps compared to the previous year (*Stadler*, 2018b), were the strawberry leaves and clusters still shorter with LEDs and increased temperature than with HPS light indicating that the amount of the far red light of the flowering lamps was still 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. Possibly could a stretching of the leaves and clusters be achieved by even more increasing the number of the flowering lamps. 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.

Strawberries under HPS seems to have a higher DS than under LEDs and increased temperature. But, the light source did not affect juiciness and firmness of both varieties in the tasting experiment. With the variety Magnum were no differences in the BRIX content between light sources measured, whereas Sonata seems to have a lower BRIX content under LEDs and increased temperature. Indeed, Sonata was rated a bit sweeter and with more flavor under HPS lights, whereas no light source effect regarding the sweetness and flavor was observed with the variety Magnum. In contrast, *Philips* (2018) reported sweeter fruits under LEDs compared to HPS lights and also *Hanenberg* et al. (2016) mentioned that it was possible to increase the taste by using LED lights.

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.

The presented results show that LED lighting resulted in energy savings without compromising yield of Sonata. Using LEDs was associated with nearly 46 % lower daily usage of kWh's, resulting in lower expenses for the electricity compared to the use of HPS lights. In addition, the growing period was one week longer in the HPS chamber. With the use of LED lights were energy costs (distribution + sale) lowered by 40 % / 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 Sonata resulted the use of LEDs in the same profit margin than the use of HPS lights. The yield was reduced by 0,5 kg/m^2, but without an effect of the profit margin. In contrast, for Magnum resulted the use of LEDs in a lower profit margin than the use of HPS lights: The yield was reduced by 1,1 kg/m^2 and the profit margin by 1.500 ISK/m^2 when LEDs were used instead of HPS lights (Fig. 32). When the yield of the LED treatment would have been 0,75 kg/m^2 higher for Magnum, would the profit margin have been comparable to the one of the HPS treatment.

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.

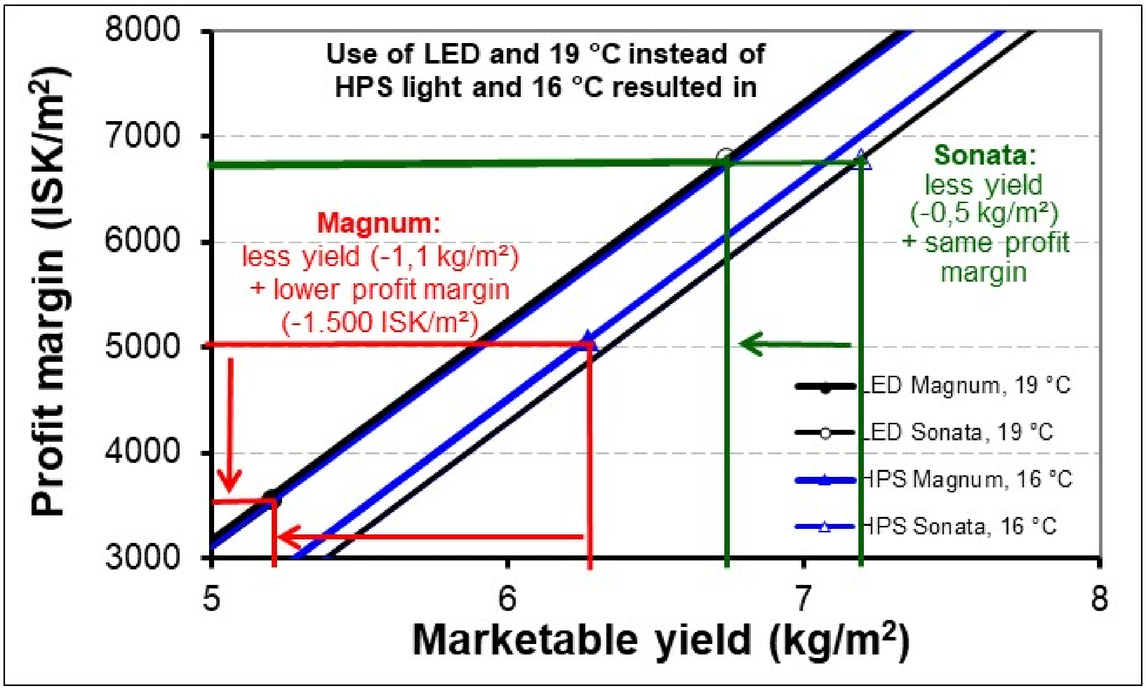

Fig. 32: Profit margin in relation to yield with different light sources – calculation scenarios (urban area, VA210).

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. Also, *Dueck* et al. (2012) suggested that a combination of HPS and LEDs as toplighting is the most promising alternative for greenhouse grown tomatoes in the Netherlands when taking into consideration different production parameters and costs for lighting and heating.

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; *Gómez* et al., 2013; *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.

The amount of applied water might also had an influence on the amount of yield. Less water was applied under LEDs and increased temperature than under HPS lights. It might be possible that too little water was applied to the variety Magnum. However, this assumption is not explaining the lower yield of Magnum under LEDs and increased temperature, as the average amount of the runoff showed even lower values under HPS lights. Rather might the lower yield of Magnum under LEDs and increased temperature be caused by the significantly higher amount of unpollinated Magnum flowers under LEDs than under HPS lights. Assuming, the number of unpollinated flowers would have been lower under LEDs, the yield of Magnum might also have been independent of the light source, as it was observed for Sonata. This assumption is emphasized by the fact that the number of marketable Magum fruits was a bit higher under HPS lights, even though this difference was not statistically significant. In contrast, the about 100 ppm higher CO_2 amount under LEDs and increased temperature might have favoured the development and yield of strawberries compared to plants grown under HPS lights. The variety Sonata might have converted this advantage better into yield than the variety Magnum.

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.

Sonata had about ten more flowers per plant than Magnum under HPS lights, while the number was independent of the variety under LEDs and increased temperature. In addition were for Magnum 24 % unpollinated flowers or later rejected flowers under LED lights and 12 % under HPS lights counted. The harvest period started half a week earlier for Magnum. The marketable amount of yield was slightly higher for Sonata compared to Magnum. This was attributed to a lower number of marketable Magnum fruits due to a significantly higher percentage of unshaped fruits, while Sonata had a higher proportion of too little fruits. Magnum was ripe after 45 days (HPS, 16 °C / LED, 19 °C) and Sonata after 50 / 43 days (HPS, 16 °C / LED, 16 °C). *Stadler* (2016c, 2018b) found comparable values for Sonata.

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

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 0,9 kg/m^2 higher yield, which was reflected in a 1.700 ISK/m^2 higher profit margin (Fig. 33). At the LED treatment resulted the use of Sonata in a 1,5 kg/m^2 higher yield, which was reflected in a 3.200 IKS/m^2 higher profit margin. This means, by the choose of the variety can the profit margin be influenced positively.

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. Compared to Sonata was the sugar content of Magnum most of the time significantly higher, which was also found the previous year (*Stadler*, 2018b). 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).

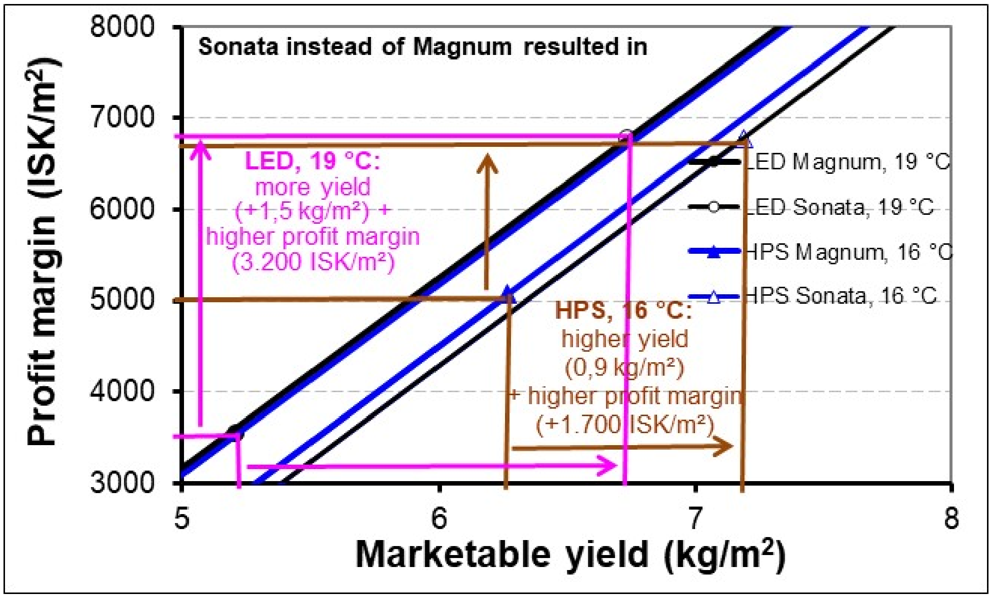

Fig. 33: Profit margin in relation to yield with different varieties – calculation scenarios (urban area, VA210).

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 fluctuation of the subsidy between 64,8-87,0 % in urban areas in the years 2017-2019 and 69,2 and 92,0 % in rural areas in the years 2017-2019. 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. 34).

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 3.200-6.000 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 3.400-6.600 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 3.800-7.000 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 constant fluctuation of the subsidy between the years 2017 to 2019, 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. In this case, the selection of the variety is getting important.

Also, the use of LEDs are showing the possibility to increase profit margin compared to HPS lights for the variety Sonata in case subsidy would be lowered or energy costs increased. This is getting especially important as the reduction of the subsidity fluctuated much in the past years. Due to a lower use of electricity by the LED lights would a reduction of the subsidity became less appearent than with the use of HPS lights.

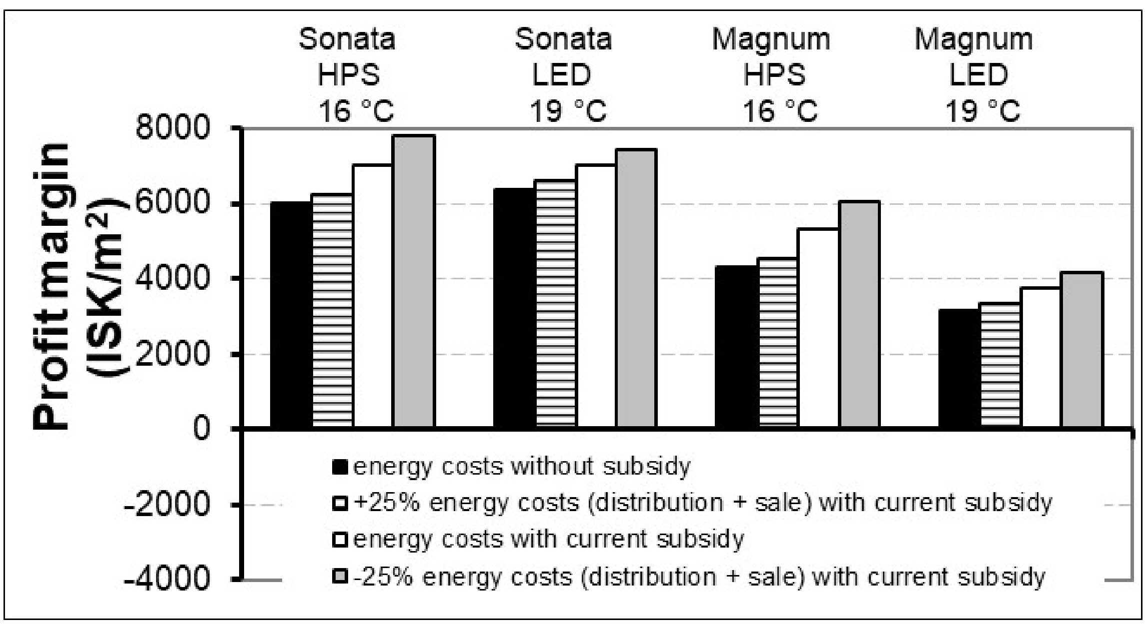

Fig. 34: Profit margin in relation to treatment – calculation scenarios (urban area, VA210).

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 1/6 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.

   It is not paying 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 (*Stadler*, 2018a).

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).

4. 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.

5. 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.

6. 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.

7. 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.

8. 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 around 45 %. To be able to get no delay in the harvest, environmental settings need to be adapted to the use of this light source.

6 CONCLUSIONS

The strawberry yield of Sonata was not influenced by the light source. However, the lower yield of Magnum under LEDs and increased temperature might be attributed to a higher number of unpollinated flowers. Therefore, by eliminating this effect, can it be expected that an equal yield under HPS and LED lights might be possible.

The reduction of the lighting costs by 40 % / 44 % (Sonata / Magnum) by the use of LEDs instead of HPS lights was accompanied by a high increase of the investion costs. Therefore, the profit margin could not be increased by the use of LEDs and increased temperature. By applying 3 °C more heat to the LED chamber, was it possible to prevent a delayed harvest as it was observed with no adapted temperature settings were the temperature was kept equal between different light sources. Furthermore, the LED treatment benefited by a higher air and soil temperature, resulting in a one week earlier begin of harvest. However, 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. 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.

7 REFERENCES

AIKMAN DP, 1989: Potential increase in photosynthetic efficiency from the redistribution of solar radiation in a crop. J. Exp. Bot. 40, 855-864.

BANTIS F, SMIRNAKOU S, OUZOUNIS T, KOUKOUNARAS A, NTAGKAS N, RADOGLOU K, 2018: Current status and recent achievements in the field of horticulture with the use of light-emitting diodes (LEDs). Sci. Hortic 235, 437-451.

BROWN CS, SCHUERGER AC, SAGER JC, 1995: Growth and photomorphogenesis of pepper plants under red light-emitting diodes with supplemental blue or far-red lighting. J. Amer. Soc. Hort. Sci. 120, 808-813.

BULA RJ, MORROW EC, TIBBITTS TW, BARTA DJ, IGNATIUS RW & MARTIN TS, 1991: Light-emitting diodes as a radiation source for plants. HortScience 26, 203-205.

DAVIS PA, BURNS C, 2016: Photobiology in protected horticulture. Foot and Energy Security 5(4), 223-238.

DEMERS DA, DORAIS M, WIEN CH, GOSSELIN A, 1998a: Effects of supplemental light duration on greenhouse tomato (*Lycopersicon esculentum* Mill.) plants and fruit yields. Sci. Hortic. 74, 295-306.

DEMERS DA, GOSSELIN A, WIEN HC, 1998b: Effects of supplemental light duration on greenhouse sweet pepper plants and fruit yields. J. Amer. Hort. Sci. 123, 202-207.

DUECK TA, JANSE J, EVELEENS BA, KEMPKES FLK, MARCELIS LFM, 2012: Growth of tomatoes under hybrid LED and HPS lighting. Acta Hortic. 952, 335-342.

EGGERTSSON H, 2009: Personal communication (Notice in writing) from Haukur Eggertsson, Orkustofnun, October 2009.

GÓMEZ C, MORROW RC, BOURGET CM, MASSA G, MITCHELL CA, 2013: Comparison of intracanopy light-emitting diode towers and overhead high-pressure sodium lamps for supplemental lighting of greenhouse-grown tomatoes. HortTechnology 23 (1), 93-98.

HANENBERG MAA, JANSE J, VERKERKE W, 2016: LED light to improve strawberry flavour, quality and production. Acta Hortic. 1137, 207-212.

HAO X, PAPADOPOULOS AP, 1999: Effects of supplemental lighting and cover materials on growth, photosynthesis, biomass partitioning, early yield and quality of greenhouse cucumber. Sci. Hortic. 80, 1-18.

HERNÁNDEZ R, KUBOTA C, 2015: Physiological, morphological, and energy-use efficiency comparisons of LED and HPS supplemental lighting for cucumber transplant production. HortScience 50 (3), 351-357.

HOENECKE ME, BULA RJ, TIBBITTS TW, 1992: Importance of "blue" photon levels for lettuce seedlings grown under red-light-emitting diodes. HortScience 27, 427-430.

KRIZEK DT, MIRECKI RM, BRITZ SJ, HARRIS WG, THIMIJAN RW, 1998: Spectral properties of microwave sulfur lamps in comparison to sunlight and high pressure sodium/metal halide lamps. Biotronics 27, 69-80.

NADALINI S, ZUCCHI P, ANDREOTTI C, 2017: Effects of blue and red LED lights on soilless cultivated strawberry growth performances and fruit quality. Eur. J. Hortic. Sci 92 (1), 12-20.

PARANJPE A, CANTLIFFE DJ, STOFFELLA PJ, LAMB EM, POWELL CA, 2008: Relationship of plant density to fruit yield of 'Sweet Charli' strawberry grown in a pine bark soilless medium in a high-roof passively ventilated greenhouse. Sci. Hortic. 115, 117-123.

PHILIPS, 2015: The ideal replacement for the incandescent lamp. http://www.lighting.philips.com/b-dam/b2b-li/en_AA/Experience/cases/Brook-berries/PHIL_143918_CaseStudy_Brookberries_UK.pdf visited: 01.02.2017.

PHILIPS, 2017: Higher yields of better quality tomatoes. http://images.philips.com/is/content/Philips Consumer/PDFDownloads/Global/Case-studies/CSLI20170119_001-UPD-en_AA-PHIL_164209_CaseStudy_MartinSigg.pdf visited: 01.02.2017.

PHILIPS, 2018: Strawberries ahead of the rest. http://www.lighting.philips.com/main/cases/cases/horticulture/welroy-fruit. visited: 11.09.2018.

PINHO P, HYTÖNEN T, RANTANEN M, ELOMAA P, HALONEN L, 2013: Dynamic control of supplemental lighting intensity in a greenhouse environment. Lighting Res. Technol. 45, 295-304.

PIOVENE C, ORSINI F, BOSI S, SANOUBAR R, BREGOLA V, DINELLI G, GIANQUINTO G, 2015: Optimal red:blue ratio in led lighting for nutraceutical indoor horticulture. Sci. Hortic. 193, 202-208.

PROEFCENTRUM HOOGSTRATEN VZW., 2016: Screening trail of new strawberry cultivars 2016.

SÄRKKA L, JOKINEN K, OTTOSEN CO, KAUKORANTA T, 2017: Effects of HPS and LED lighting on cucumber leaf photosynthesis light quality penetration and temperature in the canopy, plant morphology and yield. Agricultural and Food Science 26, 102-110.

SCHUERGER AC, BROWN CS, STRYJEWSKI EC, 1997: Anatomical features of pepper plants (Capsicum annum L.) grown under red light-emitting diodes supplemented with blue or far-red light. Ann. Bot. 79, 273-282.

SINGH D, BASU C, MEINHARDT-WOLLWEBER M, ROTH B, 2015: LEDs for energy efficient greenhouse lighting. Renewable and Sustainable Energy Reviews 49, 139-147.

STADLER C, 2010: Effects of plant density, interlighting, light intensity and light quality on growth, yield and quality of greenhouse sweet pepper. Final report, Rit LbhÍ nr. 30.

STADLER C, 2012: Effects of lighting time and light intensity on growth, yield and quality of greenhouse tomato. Final report, Rit LbhÍ nr. 40.

STADLER C, 2013: Áhrif ljósstyrks, rótarbeðsefnis, vökvunar og umhirðu á vöxt, uppskeru og gæði gróðurhúsatómata. Final report, Rit LbhÍ nr. 43.

STADLER C, 2015: Áhrif LED lýsingar á vöxt, uppskeru og gæði gróðurhúsasalats að vetri. Final report, Rit LbhÍ nr. 61.

STADLER C, 2016a: Áhrif ljósstyrks á vöxt, uppskeru og gæði gróðurhúsajarðarberja að vetri. Final report, Rit LbhÍ nr. 63.

STADLER C, 2016b: Jarðarberjaræktun á óhefðbundnum tíma á Íslandi. Bændablaðið, 04. tölublað, 25.02.2016, Blað nr. 461, 54.

STADLER C, 2016c: Áhrif ljósstyrks á vöxt, uppskeru og gæði gróðurhúsajarðarberja að vetri – önnur tilraun. Final report, Rit LbhÍ nr. 72.

STADLER C, 2018a: Áhrif ljósstyrks á vöxt, uppskeru og gæði „everbearers" í samanburði við hefðbundna gróðurhúsaræktun jarðarberja að vetri. Lokaskýrsla, Rit LbhÍ nr. 94.

STADLER C, 2018b: Áhrif LED lýsingar á vöxt, uppskeru og gæði gróðurhúsajarðarberja að vetri. Final report, Rit LbhÍ nr. 103.

STADLER C, HELGADÓTTIR Á, ÁGÚSTSSON, M, RIIHIMÄKI MA, 2010: How does light intensity, placement of lights and stem density affect yield of wintergrown sweet pepper? Fræðaþing landbúnaðarins, 227-232.

STADLER C, HRAFNKELSSON BH BI, 2019: Vinnuskilyrði undir LED-ljósum. Bændablaðið 532, 41.

TAMULAITIS G, DUCHOVSKIS P, BLIZNIKAS Z, BREIVE K, ULINSKAITE R, BRAZAITYTE A, NOVICKOVAS A, ZUKAUSKAS A, 2005: High-power light-emitting diode based facility for plant cultivation. J. Phys. D: Appl. Phys. 38, 3182-3187.

TROUWBORST G, OOSTERKAMP J, HOGEWONING SW, HARBINSON J, VAN IEPEREN W, 2010: The responses of light interception, photosynthesis and fruit yield of cucumber to LED-lighting within the canopy. Physiol. Plant 138, 289-300.

VAN DELM T, MELIS P, STOFFELS K, VANDERBRUGGEN R, BAETS W, 2016: Advancing the strawberry season in Belgian glasshouses with supplemental assimilation lighting. Acta Hortic. 1134, 147-154.

VERHEUL M, SØNSTEBY A, GRIMSTAD S, 2006: Interactions of photoperiod, temperature, duration of short-day treatment and plant age on flowering of *Fragaria x ananasa* Duch. cv. Korona. Sci. Hortic. 107, 164-170.

VERHEUL M, SØNSTEBY A, GRIMSTAD S, 2007: Influences of day and night temperatures on flowering of Fragaria x ananassa Duch., cvs. Korona and Elsanta, at different photoperiods. Sci. Hortic. 112, 200-206.

8 APPENDIX

	LED, 19 °C		HPS, 16 °C	
Date	tasks	observations / problems	tasks	observations / problems
1.okt	planting, after planting was the light turned on (16 h), day temperature 18 °C, heating pipe 35/10 °C (day/night), 800 ppm	Magnum plants were fine and better than Sonata plants, many moldy leaves were taken from Sonata plants, there were also quite much not usable plants	planting, after planting was the light turned on (16 h), day temperature 16 °C, heating pipe 10/10°C (day/night), 800 ppm	Magnum plants were fine and better than Sonata plants, many moldy leaves were taken from Sonata plants, there were also quite much not usable plants
2.okt	3 h between waterings		1 h between waterings	accidently wrong intervall between waterings
3.okt	7 h between waterings		7 h between waterings	
4.okt				
5.okt	Paraat, 12 h between waterings		Paraat, 12 h between waterings	
6.okt				
7.okt				
8.okt	heating pipe 45/10 °C, day temperature 19 °C to be able to have the same leaf temperature between chambers			
9.okt				
10.okt				
11.okt	measuring growth, flowering lamps turned on		measuring growth, flowering lamps turned on	
12.okt	measuring lights	CO_2 not working	measuring lights	CO_2 not working
13.okt				
14.okt				
15.okt	7 hours interval watering		7 hours interval watering	
16.okt	measuring growth	white roots at Magnum coming down, flowering starts	measuring growth	white roots at Magnum coming down, flowering starts
17.okt				

	LED, 19 °C		HPS, 16 °C	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
18.okt	measuring growth	daily growth is around or more than 1 cm/day, no runoff	measuring growth	no runoff
19.okt	Loker		Loker	
20.okt	4 h between waterings		4 h between waterings	
21.okt				
22.okt	weekly measurements, measuring growth, 7 h between waterings	Sonata has very short clusters, Magnum is further developed compared to the HPS chamber, little of white roots	weekly measurements, measuring growth, CO_2 sensor repaired, 4 h between waterings	little of white roots at Sonata, Magnum was good
23.okt	setting up one hive		setting up one hive	
24.okt	opening the hive the first time for 2 hours, setting up band for the leaves		opening the hive the first time for 2 hours, setting up band for the leaves	
25.okt	measuring growth, measuring leaf- and soil temperature, setting up band for the clusters	roots much better than last time	measuring growth, measuring leaf- and soil temperature, setting up band for the clusters	roots from Sonata much better than last time
26.okt	Loker		Loker	
27.okt	3 h between waterings	watering computer is not working		
28.okt				
29.okt	weekly measurements, measuring growth, 1 h between waterings	a lot of flowers open, clusters shorter compared to the HPS chamber, the flower are a little bit too much pollinated	weekly measurements, measuring growth, 1 h between waterings	a lot of bumblee bees on the flower, still no drain
30.okt				
31.okt	Aphiscout, 3 h between waterings		Aphiscout, 3 h between waterings	

	LED, 19 °C		HPS, 16 °C	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
1.nóv	2 h between waterings, measuring growth, measuring leaf- and soil temperature, Fe+Mn shoot (30 g Fe-EDTA + 3 g Mn-sulfate / 1000 m^2), eqal watering of Sonata and Magnum	no runoff at Sonata, plants are growing less than 1 cm/day	2 h between waterings, watering the same between Magnum and Sonata, measuring growth, measuring leaf- and soil temperature, Fe+Mn shoot (30 g Fe-EDTA + 3 g Mn-sulfate / 1000 m^2)	no runoff at Sonata
2.nóv	Loker, 1 h between waterings		Loker, 1 h between waterings	
3.nóv				
4.nóv		the fertilizer tank was getting empty and therefore was not watered		the fertilizer tank was getting empty and therefore was not watered
5.nóv	weekly measurements, measuring growth, 2 h between waterings		weekly measurements, measuring growth, 2 h between waterings	
6.nóv				
7.nóv	Aphiscout, working on clusters		Aphiscout, working on clusters	
8.nóv	measuring growth, measuring leaf- and soil temperature, 2,5 h between waterings		measuring growth, measuring leaf- and soil temperature, 2,5 h between waterings	
9.nóv	time changed for the flowering lamps into 24 h, Loker		time changed for the flowering lamps into 3 h, Loker	
10.nóv			2 h between waterings	
11.nóv				
12.nóv	weekly measurements, measuring growth		weekly measurements, measuring growth	
13.nóv				
14.nóv				
15.nóv	measuring growth, measuring leaf- and soil temperature, 2 h beweeen waterings	about 10 fruits/plant white	measuring growth, measuring leaf- and soil temperature, 2 h between waterings	

	LED, 19 °C		HPS, 16 °C	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
16.nóv	fertilizer changed, Loker, 1,5 h between waterings		fertilizer changed, Loker, 1,5 h between waterings	
17.nóv	1,8 h between waterings		1,8 h between waterings	
18.nóv				
19.nóv	weekly measurements, measuring growth	no electricity at 0.15-8.30: plants under the windows were very wet (the windows were open), cold in the chamber, the heating pipe is not working, the first fruits starting to ripe, lot of chancelled fruits	weekly measurements, measuring growth	no electricity at 0.15-8.30: plants under the windows were very wet (the windows were open), cold in the chamber, the heating pipe is not working, the first fruits starting to ripe
20.nóv				
21.nóv			Magnum 3:30 min watering, Sonata continuing with 3 min	
22.nóv	measuring growth, measuring leaf- and soil temperature, turning off flowering lamps		measuring growth, measuring leaf- and soil temperature, raising the tabe for the clusters to reduce risk of breaking, turning off flowering lamps	
23.nóv	Loker, Fe+Mn shoot (30 g Fe-EDTA + 3 g Mn-sulfate /1000 m^2)		Loker, Fe+Mn shoot (30 g Fe-EDTA + 3 g Mn-sulfate /1000 m^2)	
24.nóv				
25.nóv	1,5 h between waterings		1,5 h between waterings	
26.nóv	weekly measurements, first harvest Magnum		weekly measurements	
27.nóv				
28.nóv				
29.nóv	harvest		harvest	
30.nóv	Loker		Loker	

	LED, 19 °C		HPS, 16 °C	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
1.des				
2.des				
3.des	harvest, weekly measurements	a lot of moldy fruits	harvest, weekly measurements	
4.des	Aphiscout		Aphiscout	
5.des	1,7 h between waterings			
6.des	harvest, water sample taken, BRIX		harvest, water sample taken, BRIX	
7.des	tasting experiment, Loker		tasting experiment, Loker	
8.des				
9.des				
10.des	harvest, Aphiscout		harvest, Aphiscout	
11.des				
12.des	weekly measurements, measuring leaf- and soil temperature		weekly measurements, measuring leaf- and soil temperature	
13.des	harvest		harvest	
14.des	Loker		Loker	
15.des				
16.des				
17.des	harvest		harvest	
18.des				
19.des	Spidex		Spidex	
20.des	harvest		harvest	
21.des	Loker		Loker	
22.des	harvest		harvest	
23.des				
24.des				
25.des				
26.des				
27.des	weekly measurements, harvest, BRIX		weekly measurements, harvest, BRIX	

	LED, 19 °C		HPS, 16 °C	
Date	**tasks**	**observations / problems**	**tasks**	**observations / problems**
28.des				
29.des				
30.des				
31.des				
1.jan				
2.jan	harvest, final harvest Magnum		harvest	
3.jan	weekly measurements, measuring leaf- and soil temperature	spider mites	weekly measurements, measuring leaf- and soil temperature	
4.jan				
5.jan				
6.jan				
7.jan	final harvest Sonata	leaves are shorter but more green than in the HPS chamber	harvest, weekly measurements	
8.jan				
9.jan				
10.jan			harvest, final harvest Magnum	
11.jan				
12.jan				
13.jan				
14.jan			final harvest Sonata	