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Yield and fruit quality of Norwegian production-ready strawberry plants

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i. Abstract

Cold-stored large strawberry plants with high yield potential (production-ready plants) was propagated at two locations: 'Oppland', a South-East Norwegian location (60° 40' N; 10° 52' E; 250 m altitude) and 'Rogaland', a West Norwegian locality (58° 44' N; 5° 37' E, 31 m altitude), with different raising methods. It has previously been shown for the cultivars 'Korona', 'Sonata' and 'Polka', that production-ready plants with high yield potential, can be produced in Norway by raising the temperature (>15 °C) and give a high N-dose pulse (EC 3) when the plants have entered short day (SD) in September. In this study, two new promising Norwegian cultivars, 'Nobel' and 'Saga', as well as 'Korona' and 'Sonata' were tested. 'Nobel' and 'Korona' were raised at both locations. At 'Oppland', the temperature was manipulated and the plants received pulses of fertilizer in September. The plants from 'Rogaland' received no fertilization treatment, but were kept in artificial 10 h-SD and 20/16 ºC day/night temperature from September through October. In addition, the changes in fruit quality in a late season (August-October) with decreasing natural light were studied for the cultivars from 'Oppland'. The results indicate that the method of manipulating temperature and increasing fertilizer gave various results. The method seems best adapted to plants of 'Korona', which had excessive flowering and high yield when raised in 'Oppland'. 'Nobel' and 'Saga' gave dissatisfactory results, and despite their good taste, yield and berry size were not acceptable in this type of production. Nonetheless, the chemical berry composition did not vary much between the cultivars, even in a late season under limited light conditions. The success for using this method is to know when the plants of different cultivars enter a generative stage in SD. From these varying results, it can be concluded that flower bud dissection prior to raising of temperature and application of fertilizer needs to be better specified and developed to obtain a maximum yield potential for plants of different cultivars.

ii. Sammendrag

Produksjonsklare planter ble alt opp ved to forskjellige lokaliteter i Norge: 'Oppland' på Østlandet (60° 40' N; 10° 52' Ø; 250 moh) og 'Rogaland' på Sør-Vestlandet (58° 44' N; 5° 37' Ø, 31 moh). Det ble benyttet ulike oppalsmetoder ved de to lokalitetene. Det er tidligere vist at det er mulig å produsere produksjonsklare planter med høyt avlingspotensiale av sortene 'Korona', 'Sonata' og 'Polka' dersom temperatur (>15 °C) og N-gjødsel (EC 3) heves under oppalet. Det er særlig viktig at plantene får denne behandlingen kort tid etter at daglengden er optimal for blomsterknoppdanning i september. I dette forsøket ble to nye lovende norske sorter, 'Nobel' og 'Saga', i tillegg til de velkjente 'Korona' og 'Sonata', testet. 'Nobel' og 'Korona' ble alt opp ved begge lokaliteter. I 'Oppland' ble temperaturen hevet og plantene ble gjødslet med høy nitrogen-dose, mens plantene fra 'Rogaland' fikk ikke denne gjødslingsbehandlingen. Der fikk plantene kunstig 10 timer-KD og 20/16 ºC dag/natt temperatur fra september til oktober. Bærkvaliteten sent i sesongen (august-oktober) med avtagende naturlig lys ble vurdert sensorisk og ved kjemisk analyse. Metoden ga varierende resultater, og så ut til å være best tilpasset 'Korona', da denne sorten produserte mange blomster og fikk meget høy avling da planetene ble drevet i en åpen plasttunell året etter. 'Nobel' og 'Saga' ga ikke de samme tilfredsstillende resultatene. På tross av god smak for disse sortene, var ikke avlingsnivået eller bærstørrelsen gode nok for denne type produksjon. Bærkvaliteten var omtrent den samme for alle sorter, og den holdt seg godt, også sen-høstes. For at denne metoden skal være vellykket er det viktig å kjenne til tidspunktet for når plantene av aktuelle sorter er i generativ fase. Utfra resultatene i denne oppgaven kan det konkluderes med at planter for den aktuelle sort bør dissekeres for å bestemme utviklingsstadiet på blomstrer-meristemet, slik at temperatur- og gjødslingsbehandlingen kan bli bedre tidfestet for å kunne oppnå et maksimalt avlingspotensiale for denne plantetypen i Norge.

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iv. List of abbreviations

AOC	Total antioxidant capacity
DW	Dry weight
FRAP	Ferric Reducing Antioxidant Power
FW	Fresh weight
GAE	Gallic acid equivalents
GCE	Cyanidin-3-glucoside equivalents
HPLC	High-performance liquid chromatography
LD	Long day
OD	Optical density
SD	Short day
SS	Soluble solids
TA	Titratable acidity
TMA	Total monomeric anthocyanins
TP	Total phenolic compounds
WBL	Waiting-bed little
WBH	Waiting-bed heavy
WBM	Waiting-bed medium

1. Introduction

The Norwegian market for fresh strawberries (*Fragaria* x *ananassa* Duch.) demands a year-round supply (Sønsteby et al. 2013). The strawberry season in Norway begins mid-June (at about 58°N), and ends about mid-August (at about 63°N) (Haffner & Vestrheim 1997). Most of the strawberry production is, however, largely concentrated in the South-Eastern part of the country (Haslestad 2016), giving a short season of only 3-4 weeks in this period. In order to meet the demand, strawberries are imported rest of the year from southern European countries (Davik et al. 2000)

Strawberry production in Norway is currently dominated by conventional open field production with the Dutch short day (SD) cultivars 'Korona' and 'Sonata' as the main cultivars (Sønsteby et al. 2017). These cultivars are well suited for the Norwegian fresh market, due to their good taste and aroma. However, 'Korona' has several weaknesses. Producers face troubles with its susceptibility to diseases and its fruit's keepability. The Norwegian breeding company, Graminor AS, is continuously working to develop new cultivars better adapted to the Norwegian climate, which can compete with 'Korona' in flavor. In 2016, the Norwegian cultivars 'Saga' and 'Nobel' were named and released. However, they have existed as selections since 2004/2005 and have been tested in small plots together with growers and the industry (Alsheikh et al. 2010). Both cultivars have 'Korona' as one of their parents. The cultivars need further testing to determine their different quality aspects in field, such as e.g. overwintering, disease-resistance and fruit quality.

The growing season in Norway are shorter compared to other countries further south, with relatively low summer temperatures and long days. The long days prevailing in summer are also known to favor leaf and runner production and delay flower initiation and crown branching in SD cultivars (Darnell 2003). Therefore, cultivation in semi- and controlled environments (protected production) in combination with the use of cold-stored large plants with already initiated flower initials (called 'production-ready plants'), is an option to extend the season.

Controlled production normally involves producing and cropping plants under a cover of plastic (plastic tunnels or greenhouses), where the climate can be more controlled (Jensen & Malter 1995). This type of production might be advantageous to avoid external threats such as unfavorable abiotic conditions and diseases (Lieten 1998). Such production systems also offer

the possibility of a more timely planned and programmed production (Dijkstra 1989; Sønsteby et al. 2006). Production-ready plants are cold stored after flower development in autumn, and can be planted to program the production either before or after the regular season. These plants are often called "60-day plants" as they can be harvested approximately 60 days after planting (Strik 2012). Programmed production in greenhouses using production-ready plants are methods that have long been applied in leading horticultural countries such as the Netherlands and Belgium (Lieten 2002b). These countries are also the greatest exporters of production-ready plants (Lieten 2014). These countries' climate is very well suited for plant propagation as temperatures are mild in September and October, so that the plants have a long flower initiation period, and can differentiate flowers sufficiently (Lieten 2014). In Norway, flower bud initiation occurs from mid-August, and continues as long as temperatures are sufficient (>5 ºC) (Opstad et al. 2011). However, temperatures fall quickly in this period, meaning that the plants usually experience insufficient time to develop crown branches and flowers. These plants therefore give a low yield if they are to be harvested the same season as planted. Thus, the single inflorescence usually being developed in the plant is normally cut off, so the plant can use the energy for rooting, giving higher yield the following year (Sønsteby et al. 2013).

After increased pressure from the berry industry, the department for food and agriculture opened up for import of strawberry plants in January 2015 (Milford & Haukås 2017). This opened the possibility to import new cultivars, and different plant qualities, including production-ready plants (waiting-bed and tray plants). Because of this, many producers have gained new hope for higher yields, and a longer production season, also in the northern part of Norway. However, reactions are not all positive. There is an increased risk of new diseases being introduced over time, of special concern is the plant pathogen *Phytophthora fragariae* that can cause red stele (Milford & Haukås 2017). There are also worries concerning the Norwegian plant production system, and that this will be closed as Norwegian produced plants cannot compete in price with the imported plants due to high production costs (Milford & Haukås 2017). Being completely reliant on imports can lead to limited or no access to certain cultivars in some years. Graminor AS is also discussing to ban the import of plants of their cultivars in order to protect Norwegian production. Therefore, to secure a reliable supply of plants in the future for Norwegian growers, it would be beneficial if a production system for different plant qualities including Norwegian cultivars could be developed to compete with imported plants and cultivars.

There has been some experimenting on the production of production-ready plants in Norway. Sønsteby et al. (2013) reported that producing such plants is possible in Norway, but not under natural conditions. The sub-optimal temperatures prevailing in September are a limiting factor. They found that raising the temperature in September in ambient photoperiod, in addition to giving pulses of fertilizer (particularly nitrogen) gave good results on flowering and yield.

For a successful programmed production using Norwegian production-ready plants in an extended season, the berry quality needs to hold high quality, also late in autumn when the natural light intensity is reduced. Therefore, chemical and sensory analyses with the two newly released Norwegian cultivars ('Saga' and 'Nobel') were performed from late August.

The objectives of this investigation were:

- Firstly, to determine whether a successful production of tray plants is possible in Norway.
- Secondly, to ascertain if new Norwegian cultivars ('Nobel and Saga') respond similarly to the production methods developed for other cultivars.
- Lastly, if Norwegian cultivars show good berry quality, in a late growing season.

To determine plant quality, potential fruit yield, total fruit yield and berry weight were registered. In addition, recordings were done on flowering and growth. A quality analysis was completed measuring chemical content of the berries for a 7 weeks period in September-October.

2. Literature review

2.1. The strawberry plant *(Fragaria x ananassa* Duch.*)*

The cultivated strawberry originated by extensive hybridization between species in genus *Fragaria* in the Rosaceae (rose) family. Strawberries are cultivated worldwide, but 95% of the production is centered within the Northern Hemisphere (Mahmood et al. 2012).

The strawberry plant is a perennial herbaceous plant that reproduces by either runners or seeds. It has a short thickened stem with a rosette-like leaf formation, called the crown (Fig. 1). From the crown arise runners, leaves, roots, inflorescences and branch crowns (Darnell et al. 2003). Growth occurs in the meristem (the terminal of the crown) which adds leaves and nodes sequentially (Strand 2008). The crown is a compact shoot in which the leaves are located 2 mm apart in a 2/5 pattern (phyllotaxis). This means there are five leaves per two circulations (Heide 2000). Between each leaf and the stem are axillary buds. These may become either stolons or branch crowns, depending on environmental conditions and nutrient availability (Taylor 2002). The primary roots develop at the basis of the stem. These branch out and develop side or secondary roots, which in turn may branch out further. Despite this, the strawberry plant has a little developed root system.

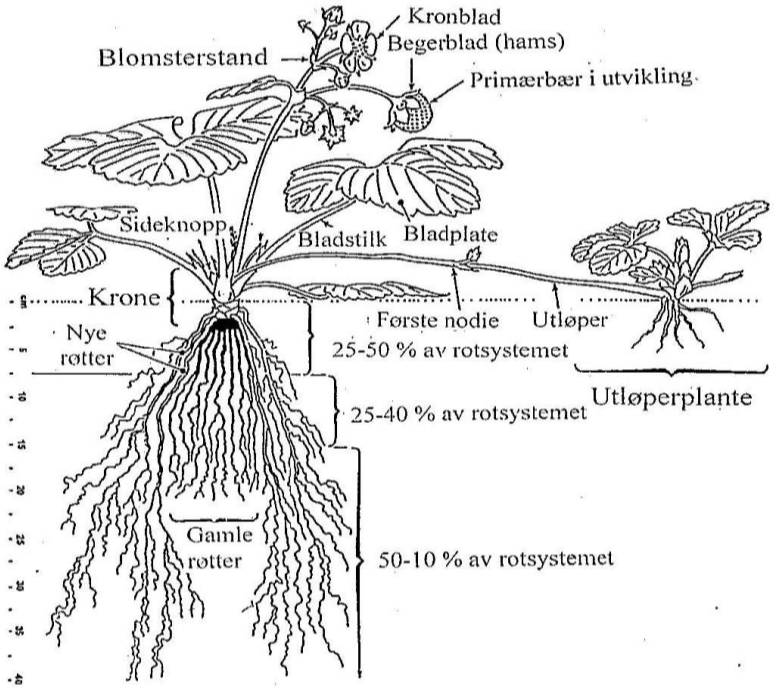

Figure 1. *The structure of a strawberry plant (Strand 2008).*

Inflorescences develop at the terminal point of the shoot, differing from stolons and side crowns, which develop from axillary buds. The structure of an inflorescence (Fig. 2) consists of a primary flower, with two or three, sometimes four secondary flowers, developing terminally on branches of the main axis (Anderson & Guttridge 1982). As the inflorescence develops at the terminal growth point, the apical dominance shifts to the nearest axillary bud. As the growing point has been shifted, the previously developed inflorescence is pushed to the side. The new shoot then develops leaves in the same 2/5 pattern before developing a terminal inflorescence. The newly developed inflorescence is again pushed to the side and a new axillary bud develops in the same pattern. This is called a sympodial growth pattern (Heide 2000). There are generally 4-5 inflorescences developed from the meristem of a crown.

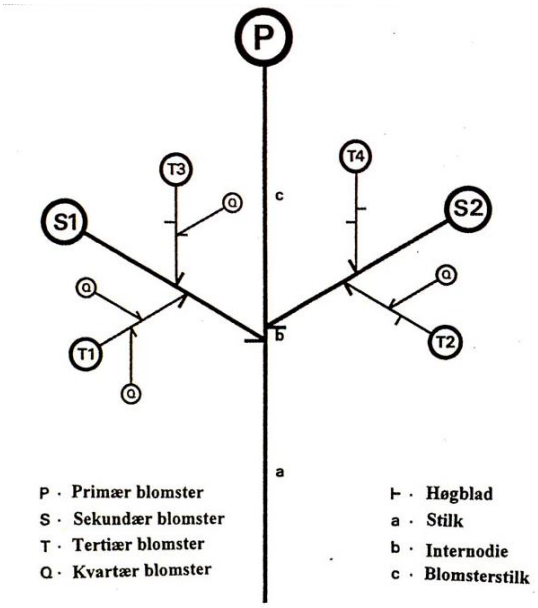

Figure 2. *The flower branching system of a strawberry plant (Anderson & Guttridge 1982).*

The basic floral whorl number is five. The flower usually contains ten sepals, five petals and 20 anthers and numerous carpels situated on a fleshy receptacle (Heide et al. 2013). The primary or terminal flower is the first to differentiate and will be the first to flower in spring, and become the largest berry in the trusses (Heide 2000). Following the primary flower, secondary and tertiary flowers and berries are also produced on the main floral axis (Fig. 1).

The plant will begin flower induction (generative growth) in August-September, depending on geographical latitudinal and altitudinal location. These flower buds will then differentiate to form the different parts of the flower. In late autumn, the plants will enter semi-dormancy. This is not a true dormancy, as the plants are always ready to resume growth (Heide

1977). Strawberry plants are able to grow and flower without a period of chilling. However, this leads to small and compact plants, with short petioles and flower stems, and small leaf area with decreased yield potential (Heide 1977; & Heide 2006). Dormancy initiation is dependent on the sensing and signaling of seasonal environmental changes, especially the decreasing day-length in autumn (Jonkers 1965). Exposure to long days act as a vegetative growth promoter as well as flower inhibitor (Guttridge 1959). The dormancy is usually broken early in winter, but low temperatures prevent growth resumption. Flowering and growth occurs in the spring to develop and mature fruits in the summer (Fig. 3). Both flower induction and breaking of dormancy are controlled by climatic factors, especially temperature and day length.

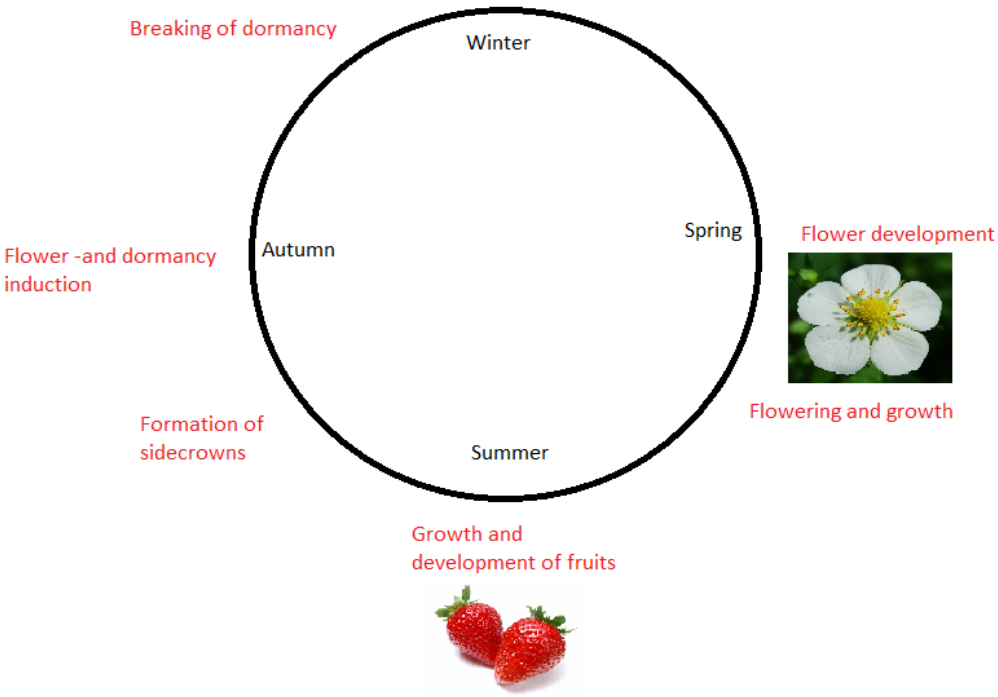

Figure 3. *The yearly life cycle of single-cropping SD strawberry plants Adapted from https://innlandet.nlr.no*

2.2. Interaction between temperature and photoperiod

The growth and development of the strawberry plant are intimately controlled and synchronized with the seasonal changes in temperature and photoperiod (Heide 2000). Long days (>14 hours day light) with higher temperatures (>15 °C) favors the development of stolons. As the days get shorter (>14 hours day light) and temperatures decrease, branch crowns are developed (Strand 2008). Most single cropping cultivars are facultative SD plants requiring short days and temperatures between 18-20 °C to induce flowers. At high latitudes with short photoperiods, temperature is often the limiting factor in floral induction (Darnell et al. 2003). The minimum number of required SD cycles ranges from 7 to 24 days, depending on cultivars and temperature (Heide 1977).

The interaction between SD and temperature has been studied extensively. For a review see (Guttridge (1959) and Heide et al. (2013). For many SD cultivars, low temperatures can override the photoperiod requirements (Guttridge 1985; Heide et al. 2013). If temperature is unsatisfactory (<12 °C or >21 °C), flower induction is reduced even in optimal SD conditions (Heide et al. 2013). Hartmann (1947) found that several SD cultivars flowered under long (15 h) or short (10 h) photoperiods if temperatures were maintained at 15.5 °C. However, when temperatures were increased to 21 °C only plants in SD flowered. Heide (1977) found that a temperature of 18 °C and a photoperiod of 12 hours led to optimum flower induction for several SD cultivars. This study also found that at 12 °C, induction occurred in some cultivars even at 16 and 24 h. In general, when temperature rises, the number of SD cycles required also increases (Ito & Saito 1962). Heide (1977) found that the number of flowers produced was significantly less at 24 °C compared to 18 °C. Usually, temperatures over 28 °C tend to inhibit flowering in SD cultivars (Durner & Poling 1988; Ito & Saito 1962).

The duration of SD is also significant as the number of inflorescences increases with the number of inductive cycles (Sønsteby 1997). This was confirmed by Grimstad (1994), where it was observed a 10 % increase in flower trusses when the number of SD cycles were increased from 21 to 28 days.

2.3. Cultivation and commercial use

Cultivation of strawberries in Norway can be traced back to the 1800s when monks brought them into the country from Southern Europe. For a long time, monasteries were the primary growing site (Nes 1998).. Since then, Norwegian strawberry production has progressed rapidly Today, strawberries are one of the most important horticultural crops in the Nordic countries (Nes et al. 2008). It is important for both fresh consumption and industry purposes. Less than 25 % of the production is produced for the processing industry, the rest is used primarily for fresh consume (OFG, 2016)

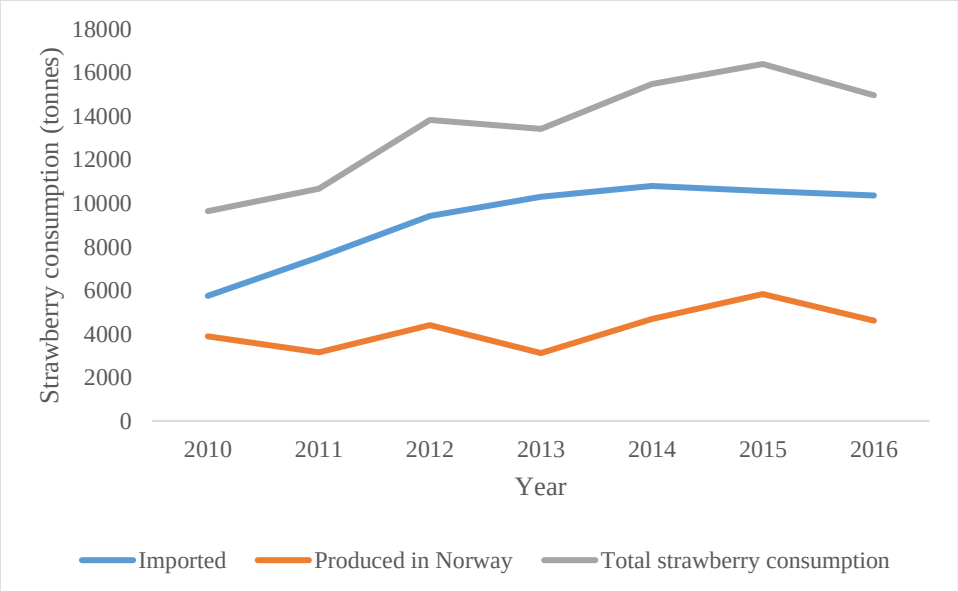

Figure 4. *Strawberry consumption in Norway, registered import and domestic sales (OFG, 2016).*

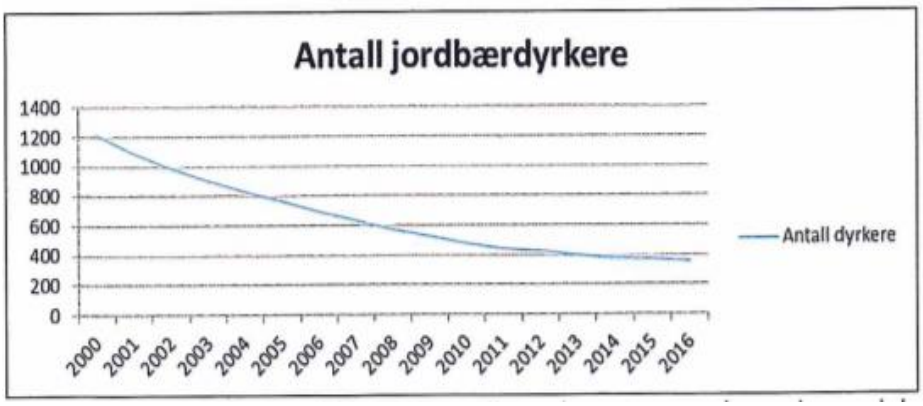

Figure 5. *The number of strawberry growers in Norway from 2000-2016 (Haslestad 2016).*

Norway is a country stretching from 52 ºN-71 ºN northern latitude and therefore has a varying climate. Despite this, strawberries are cultivated in almost all parts of Norway. However, over 50 % of the production is located in mid-Eastern parts of Norway (Haslestad 2006).

The Norwegian strawberry production is characterized by growing cultivars of foreign origin. The Dutch cultivar 'Korona' is the most important cultivar for fresh consumption. It was initially favored for its aroma and resistance to powdery mildew. However, the fruits are soft, and shelf life therefore very short. In the recent years, new cultivars are sought to replace Korona. 'Senga Sengana' (Germany) and 'Polka' (Holland) are favored for the processing industry.

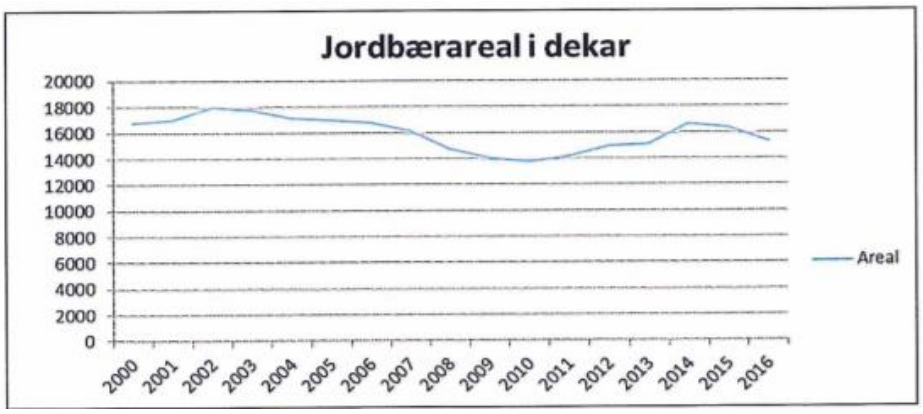

Figure 6. *The acreage employed for strawberry production in Norway from 2000-2016 (Haslestad 2016).*

The demand for fresh strawberries in Norway has increased significantly over the last decade (Fig. 4). From 2010 to 2016, the total consumption increased by 5326 tons (OFG, 2016). However, it is a trend that whilst strawberry consumption is increasing, the Norwegian production remains stable, meaning that imports cover this market. The number of Norwegian growers has faced a rapid decline over the last decade (Fig. 5). In 2000, there were approximately 1200 growers in Norway, but in 2016, this number was reduced to about 400 (Haslestad 2016). On the other hand, the production area has not decreased as dramatic as the number of growers (Fig. 6) (Haslestad 2016). From 2015-2016, the acreage of strawberry production decreased with 6.5 %. This means that each grower has increased their production area and is investing more in the production. Imports have become gradually more important

as can be seen in Figure 4 and has had almost a linear growth pattern. As of 2016, the percentage of strawberries produced in Norway was 31 %.

According to numbers from OFG (2016), the amount of strawberries consumed seems to be closely connected to the Norwegian production. From 2010 to 2015, strawberry sales increased from 2.2 kg to 3.2 kg per capita (Fig. 7). In 2016, the volume had decreased to 2.8 kg per capita. The years 2013 and 2016 were marked with low sales and this is in accordance with the poor strawberry seasons in Norway these years.

Compared to other European countries, Norway has a limited market for fresh berries, and the strawberry industry is therefore rather small. Still, the high number (64%) of imported strawberries encourage the Norwegian growers to take some of the market from import, especially by programmed production in high tunnels, and by prolonging the season of strawberry production.

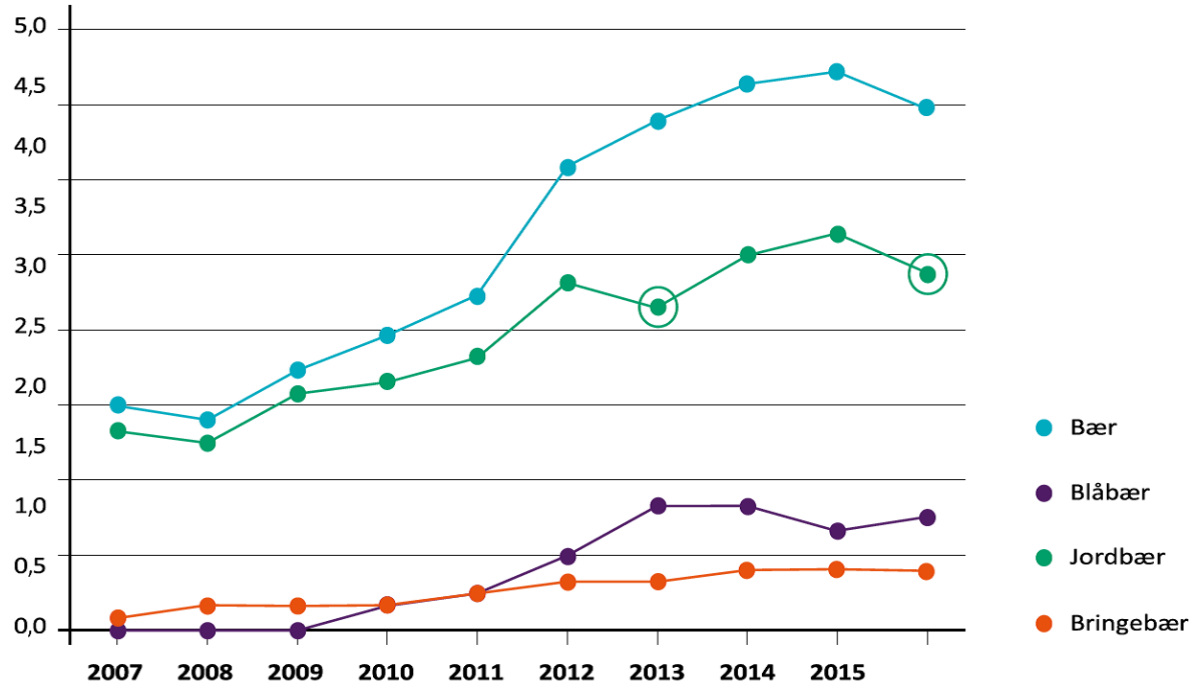

Figure 7. *Berry sales in Norway from 2007 to 2016 (in Norwegian) (OFG, 2016).*

2.4. The strawberry breeding program in Norway

There have been Norwegian breeding traditions of strawberry cultivars since the 1960s. Initially, it was located at the Norwegian University of Life Sciences (NMBU) and led by Professor Johannes Øydvin. Several commercially successful cultivars were achieved such as 'Jonsok' (1964), 'Glima' (1969) and 'Frida' (2001) (Alsheikh et al. 2009). The breeding program was for a period led by Bioforsk, until 2002, when the Norwegian breeding company Graminor Breeding Ltd. was established. The major goal of this breeding program is to develop new cultivars that can withstand harsh and varietal winters and maintain superior berry qualities as well as giving profitable yields. In addition, susceptibility to diseases is emphasized.

As of 2010, around 28000 seed plants were evaluated where 135 advanced lines was further tested (Alsheikh et al. 2010). In the same year, two lines showed great potential regarding high and early fruit yield as well as good berry quality. These lines were later released and named 'Nobel' (GN1196.15) and 'Saga' (GN1189.3).

2.5. Protected production

Protected production is the modification of the natural environment to achieve optimum plant growth (Jensen & Malter 1995). Over the last decades, strawberry cultivation in greenhouses and high tunnels has gained increased interest in Norway (Sønsteby et al. 2006). In controlled environments, crops can be produced year-round and off-season (June-September).

Greenhouse and tunnel production

High tunnels are a greenhouse-like unit, but without mechanical ventilation or a permanent heating system (Jensen & Malter 1995). Greenhouses are usually framed structures often covered by a transparent material, enabling light to transmit optimally and also protecting the plant from unfavorable climatic conditions. They may also include mechanical equipment for heating and cooling. Greenhouse producers aim for year-round production, whereas those

using plastic extend the growing season at both the beginning and end of the main production season (Davik et al. 2000). Tunnels are constructed with arch ribs covered by polyethylene. There is no system for artificial heating or cooling. Ventilation occurs by rolling up the sides or opening in the front or back (Waterer 2003).

Substrate and table top system

Cropping in substrate culture is becoming increasingly popular (Lieten et al. 2004). Substrate systems includes peat bags, containers and pots. This method has been used for over twenty years in several central European countries. The Netherlands have developed the table top system for cropping in substrate under unfavorable climatic conditions (Lieten 2002b). This system involves raising the plants above the ground in plastic trays or gutters. The substrates used are usually peat moss or a mix of peat moss and coir. Cropping in soilless systems offers several advantages. The use of soil fumigants and fungicides may be greatly reduced. However, this system requires expertise regarding nutrition and watering. The nutrient solution must be calculated accurately depending on the soil factors and the needs of the various cultivars (Lieten 2013). Strawberries grown in substrate may be sensitive to pH, supply of macro nutrients (Si) and micro elements (Cl, Fe, Zn, Mn, B) as well as salinity (Lieten et al. 1995). Fertigation systems have developed as a result, meaning fertilizers are injected into an irrigation system. By computer controlling the nutrient status in the substrate, the fertilization is carefully monitored (Lieten 2013). If performed correctly, cropping in substrate can extend the harvesting season eight to ten months.

Cropping in protected environments require high input investments and thus high yields are needed in order for the production to be profitable (Sønsteby et al. 2009). Thus, production of plants with high yield potential is of essential value in such a system.

2.6. Programmed production

Background and plant types

The forcing of production-ready plants is one of several systems used to extend the growing season (Strik 2012). These are plants produced under controlled environments to give harvest the same year as planting. These plants develop flower buds in the autumn by controlling the flower-inducing temperature and photoperiod. They are cold stored for long or short periods, depending on the desired planting time (Sønsteby et al. 2013). Three types of plant material are used in this system: 1) graded, cold stored bare-rooted runner plants from normal field propagation (A+), 2) plants grown in waiting beds outdoors, lifted and cold stored or 3) plants rooted in trays before cold stored (Durner et al. 2002; Hancock & Simpson 1995).

The plants are de-runnered during the raising period so the plant can incorporate more energy into crowns and roots. Waiting-bed plants are graded into waiting-bed little (WBL), medium (WBM) heavy or (WBH) depending on crown size. The plants usually produce 4-7 inflorescences and 40-65 fruits per plant (Lieten 1998). In the Netherlands, an early cropping in May is achieved by planting waiting bed plants in December. A second crop is achieved in the autumn by planting waiting bed plants or A+ graded runners from end of June to mid of July (Lieten 2002b).

Plants that have been cold treated are referred to as frigo plants. Frigo plants are runner plants dug in December-January and are stored in boxes. They are sorted based on the crown diameter: A++ are the largest with diameters of >20 mm, A+ with diameter 15-18 mm and A with diameters of 9-12 mm (Lieten 2014).

Tray plants are the most common plant type to use for substrate production (Lieten 2014). Tray plants are produced from runners of mother plants, which are rooted in trays containing 8-9 cells in a peat-based mixture. Runner tips are usually planted in the middle of July and develop during the summer/autumn. In December, they are put in cold-storage (Lieten 2014).These are cultivated in protected waterlogged environments allowing them to root properly, followed by a strict fertilization program. It takes about five months from they are rooted until they can be cold stored. This plant type has a crown diameter of 12 to 18 mm and usually produces 35 to 50 fruits per plant. According to (Lieten 1998), tray plants produce 10 to 20 % more large fruits than bare-rooted waiting bed plants. He also found that tray plants obtain higher yields than A+ graded runner plants.

Over the past two decades, tray plants have been replacing waiting bed plants for long-term storage (Durner et al. 2002; Lieten 1998; Yoshida & Morimoto 2010). Tray plants offer several advantages compared to bare-root plants. In the Netherlands, tray plants are preferred mid-season as well as late season as they handle warmer temperatures better than waiting-bed plants (Lieten 2002b). As tray plants are cultivated in substrate, they are less susceptible to soil borne pathogens (Durner et al. 2002). Norway has a strict control regime regarding soil-borne pathogens in certified plant material. Thus, tray plants are preferred (A. Sønsteby pers. comm.). Mechanical transplanting is possible, reducing costs of labor (Durner et al. 2002). By controlling photoperiod and temperature, tray plants flower and fruit earlier than traditional transplants. Tray plants handle transplanting well as their roots remain intact. This leads to

greater survival in cold storage and quicker establishment after planting. Compared to bare-root plants, tray plants have a greater buffer against drought as the roots are covered (Lieten 1998).

2.7. Climate variations

Norway has a colder and more varying climate than the leading strawberry producing countries in the temperate regions, such as the Netherlands and Belgium (Davik et al. 2000). Winters are especially harsh and freezing injury is a common problem. The snow cover can also have seasonal variations. In certain regions, the temperatures may lie between -20 and -30 °C for several weeks. Most plants cannot survive these temperatures with no protection from snow or cover (Davik et al. 2000).

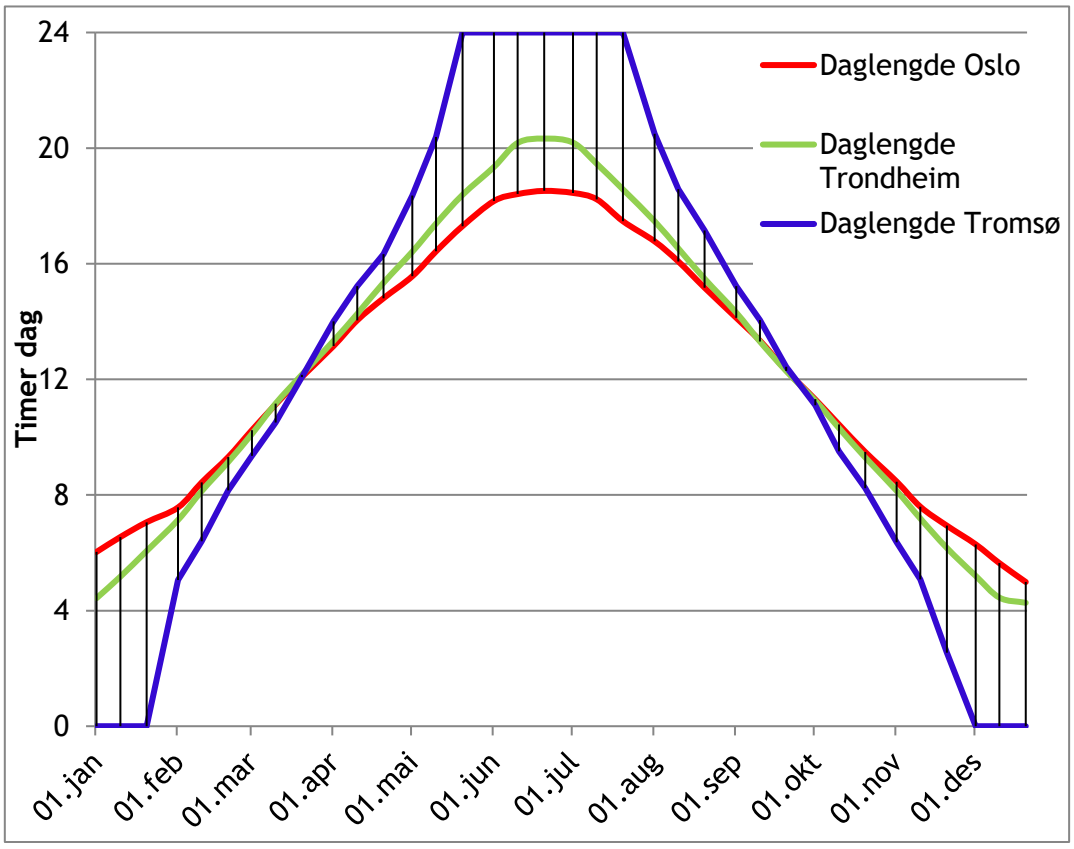

Figure 8. *The day length variations in three locations in Norway. (Adapted from https://www.wikipedia.com)*

As Norway is elongated, the climate also varies with altitude and latitude. Tromsø has for instance, extreme day length conditions in the summer, with 24 hours day length from mid-

May to mid-August (Fig. 8). The average temperature also varies across the country. Figure 9 shows the annual average temperatures in Norway. The annual temperature in the south is considerably higher in the south than in the north of the country.

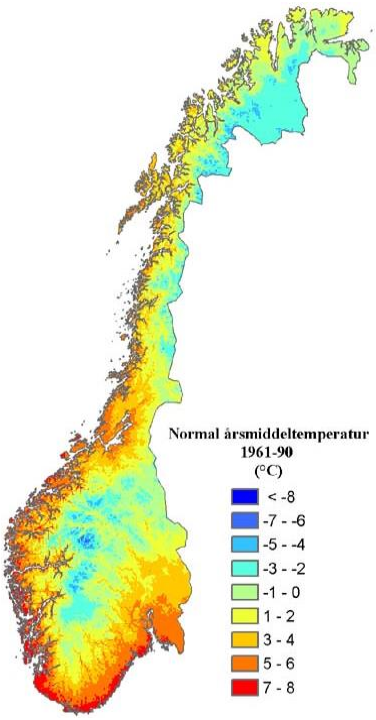

Figure 9. *Annual average temperature in Norway (Adapted from https://www.wikipedia.com)*

SD cultivars have challenges producing flowers in areas of high latitude and altitude. Opstad et al. (2011) found that floral initiation was increasingly delayed with increasing altitude and latitude. For instance, 'Korona' has critical photoperiod of 15 h and this was reached at Ås on August 23, at Steinkjær on August 29 and at Kvæfjord on September 1. In regular outdoor conditions in Norway, rooting runners in late-July will not give satisfactory time to induce a good crop potential. As days get shorter in September, temperatures need to be between 15-18 °C for SD cultivars (Heide 1977). Plants need to be exposed to these conditions for an extended period (5-10 weeks). However, the temperatures tend to drop too quickly in September-October in our climate (A. Sønsteby. pers. comm.).

2.8. Possibilities of programmed production in Norway

The Norwegian climate does not coincide with production methods that have long been used in the Netherlands and Belgium (Sønsteby et al. 2013). Temperatures in these regions are still high enough during October compared to Norway to keep the flower differentiation going (Lieten 2014). Belgium and Holland also have optimal photoperiod for strawberry flower initiation already from early August. Combining a long period of SD and favorable temperatures, a full flowering potential in the plant can be obtained.

Alternative cultivation strategies for producing strawberry forcing plants with high yield potential in Norway have been studied. Sønsteby et al. (2013) discovered that raising the temperature in the autumn in addition to adding pulses of nitrogen to the flower buds after SD conditions, significantly enhanced flowering in the cultivars 'Korona', 'Sonata' and 'Polka'. They concluded that producing tray plants is possible in Norway with these cultivars, and it opens for testing of other cultivars as well.

2.9. Strawberry fruit quality

The typical strawberry-flavor with a balance of sweet and sour is important to the Norwegian fresh market (Haffner & Vestrheim 1997). In addition to satisfying traditional quality parameters and sensory analyses, fruits and berries should be high in vitamins and other health-related components.

The traditional quality parameters in fruits and berries include dry matter, sugars and organic acids (Skrede 1980). Soluble solids indicate the sugar level in the fruits. Together with titratable acidity and pH, soluble solids contribute to sweetness and acidity of fruits and berries (Hulme 1971; Viljakainen et al. 2002). Health-related parameters include vitamin C, which is a water-soluble compound found in fruits, berries and vegetables and is essential for humans. Depending on the cultivar, strawberries can contain more L-ascorbic acid than oranges (Haffner & Vestrheim 1989). It has two forms: dehydroascorbic acid and L-ascorbic acid, where the latter is the biologically active form. It is an unstable compound, which is often affected by its surroundings (Bode et al. 1990), e.g. fertilizers, air humidity, temperature and processing. Due

to the knowledge of this health-related compound, the level of vitamin C is often used as an indicator of quality of the berries.

Anthocyanins (classified as both antioxidants and pigments) (Kähkönen & Heinonen 2003), total phenolic compounds (Moyer et al. 2002) and total antioxidant activity (determined by various assays) (Halvorsen et al. 2002) are also important health-related parameters. Together with vitamin C, these are important free radical scavengers in plants, animals and humans (Wang & Lin 2000). Fruit color is due to the presence of anthocyanins and this is a major determinant of quality in strawberries (Patras et al. 2009).

These qualities may differ depending on cultivars, some differing substantially (Pellegrini et al. 2003). Location and weather conditions as well as production methods also influence the nutritional and biochemical constituents of the plant material (Poll et al. 2003; Wold & Opstad 2012; Zheng & Wang 2003).

3. Materials and methods

3.1. Plant material and cultivation

Plants of four strawberry cultivars were produced at two locations in 2015. Plants of the cultivars 'Nobel', 'Saga' and 'Korona' were produced at NIBIO Apelsvoll, Kapp in Oppland, in the central part of South-East Norway (60° 40' N; 10° 52' E; 250 m altitude), while plants of 'Nobel', 'Korona' and 'Sonata' where produced at Hodne Gartneri, Bryne in Rogaland, in the South-West part of Norway (58° 44' N; 5° 37' E, 31 m altitude). Table 1 summarizes key characteristics of the cultivars used in the study.

At NIBIO Apelsvoll (called 'Oppland'), the plants were raised using a method developed and described by Sønsteby et al. (2013). Certified runner tips were achieved from NORGRO, and were rooted directly in plastic trays of 0.25 l volume (Bato Strawberry Tray 9-holes, Bato Plastics B. V., The Netherlands) on July 1, using a peat-based soil mixture (Gartnerjord, LOG, Oslo, Norway) with pH 6.0 and the following soluble nutrient contents in mg per litre soil: 850 N, 35 P and 170 K + micronutrients. Except for the nutrients contained in the potting soil, the plants received only limited fertilizer during propagation, but were watered with a weak fertilizer solution (EC 1.0) six times in the period August 1 to August 24. After thorough rooting in a water saturated atmosphere in the greenhouse maintained at 20 h photoperiod and a minimum of 20 °C, the plants were moved outdoors on August 1, and grown under ambient out-door conditions until September 1 (Fig. 10). The plants were then moved into a greenhouse compartment kept at elevated temperature (>15°C) and ambient photoperiod until October 5. During this period, all plants received a pulse of fertilization for a 3-week period, starting on September 7. The fertilizer solution used was a mixture of 1:1 mixture of Superba^{TM} Rød (7-4-22% NPK + micronutrients) and Calcinit^{TM} (15.5% N, 19% Ca) (Yara International, Oslo, Norway) with electric conductivity (EC) 3.0 mS cm^{-1}. Plants were fertilized manually three times per week for the three weeks period.

During the propagation and treatment period, pest and diseases were controlled by using predator mites (*Amblyseius cucumeris*), and by spraying with pesticides two times. Runners were removed throughout the raising period. After completion of the fertilization and temperature treatments in early October, all plants were gathered out-doors, covered with one layer of fiber cloth, and hardened under ambient out-door conditions until November 16 when

they were moved into a cold store maintained at -1.5 °C. Caution was taken to ensure that the pots were thoroughly frozen before being stored in a wooden box covered with plastic on November 23.

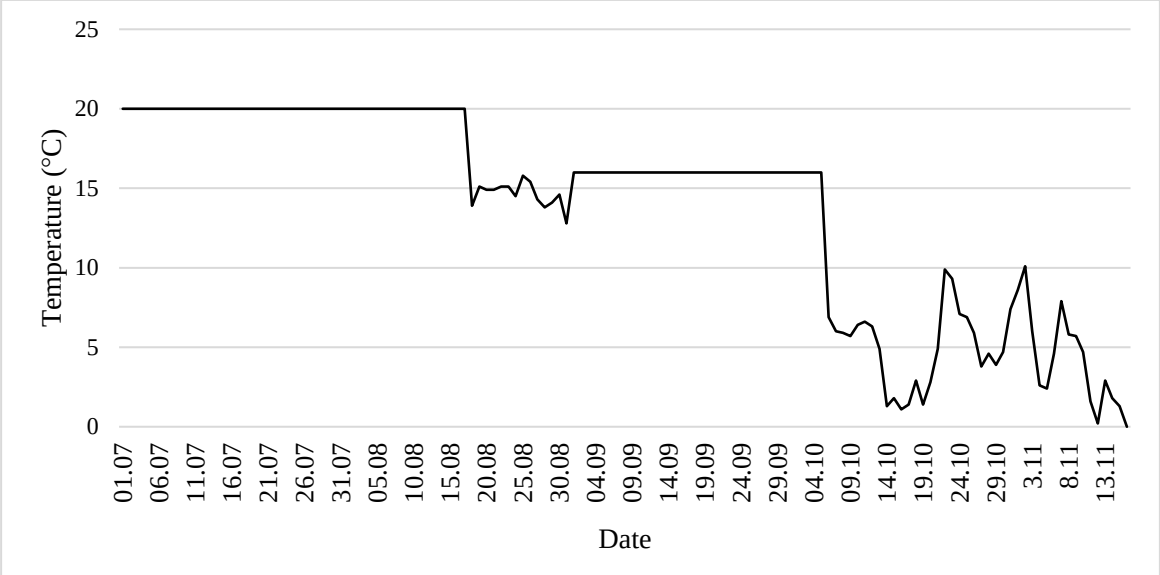

Figure 10. *Temperature during the raising period of the cultivars in Oppland 2015. From July 1 –July 31, the plants were kept in a greenhouse. The plants were held outside from Aug. 1 to Sep. 1. Then the plants were moved back into the greenhouse (>15 °C) until Oct. 5 when they were hardened under out-door conditions. On Nov. 16, the plants were moved to the cold storage.*

At Hodne Gartneri (Rogaland), rooting of plants took place on July 30, 2015. Certified runners achieved from NORGRO were rooted in a peat-based soil mixture (Gartnerjord, LOG, Oslo, Norway) in peat trays in a greenhouse. The runners were rooted for four weeks (July 30 – August 30) at a temperature of 18-20 °C. During rooting, the plants were covered with a plastic sheet until fully rooted. Following this, the plants received SD treatment, consisting of 10-hour days, at 16 °C at night and 20 °C in the day. High pressure sodium lamps (SON-T, ca 150 W/m^2) were installed. The plants were kept in SD until October 1 when they were moved to a cooler department with temperature 15 °C. The plants were placed out-doors with ambient temperature to harden from November 1 to December 1. The plants were sprayed against grey mold four times during the raising period until December 1, when they were moved to NIBIO Særheim for storage at -1.5 °C. The EC remained constant throughout the entire cultivation period (EC 1.5). Predator mites were present at all times until the cultivars were set outside. Sulphur evaporators were used a couple of hours during the night from August 15 until October 15.

Table 1. General description of the cultivars studied in this experiment.

Cultivar	Origin, year	Parentage	Fruits	Yield	Resistance	Comments	References
'Korona'	The Netherlands, 1978	'Tamella' x 'Induka'	Large well-tasting berries. Needs to be handled carefully.	Good yield, but decreases with the age of the plant.	Exposed to powdery mildew and leather crown rot.	Mainly produced for fresh consumption. Poor keepability after harvest. Main cultivar in Norway since the 1990s	(Alsheikh et al. 2009; Eikemo et al. 2000; Nes 1997) (Norgro – available at http://norgro.no/index.php?objectId=909&method=contents)
'Nobel'	Norway, 2016	'Korona' x 'Diamante'	Consistent small, berry size, even coloration and shiny berries. Very good taste.	Usually same yield size as 'Korona' and 'Sonata', but can be harvested five days earlier.	Seems to be resistant to powdery mildew. Susceptible to leather rot. Needs further testing.	Fresh consumption. Presumed stronger keepability after harvest than 'Korona'.	(Graminor – available at http://www.graminor.no/sorter/baer/jordbaer/nobel/) (Eikemo & Stensvand 2015)
'Saga'	Norway, 2016	'Korona' x 'Kimberley'	Large well-tasting berries with good coloration. Firmer fruit than 'Korona'	Good yield. Can be harvested a couple of days before 'Korona' and 'Sonata'.	Moderate resistance to powdery mildew and leather rot. Needs to be tested further.	Fresh consumption and industry (combination berry)	(Eikemo & Stensvand 2015) (Graminor – available at http://www.graminor.no/sorter/baer/jordbaer/saga/)
'Sonata'	The Netherlands, 1998	'Elsanta' x 'Polka'	Large, well-tasting berries with an even size throughout the season.	Lower yield than 'Korona', but bigger fruits and a longer harvesting season.	Strong against powdery mildew but exposed to crown rot.	Winter-hardy. Increased planting in Scandinavia.	(Masny & Żurawicz 2009) (Norgro – available at http://norgro.no/index.php?objectId=909&method=contents)

3.2. Forcing of the plants in 2016

NIBIO Apelsvoll (called 'Oppland' throughout the thesis) received the plants from NIBIO Særheim on May 19, 2016. All plants were carefully thawed and acclimatized before being potted into 3.5 l plastic pots with one plant in each pot, and moved to a table-top system in an unheated Haygrove plastic tunnel on May 25 for cropping. The pots contained a mix of Gartnerjord (LOG, Oslo, Norway) and perlite.

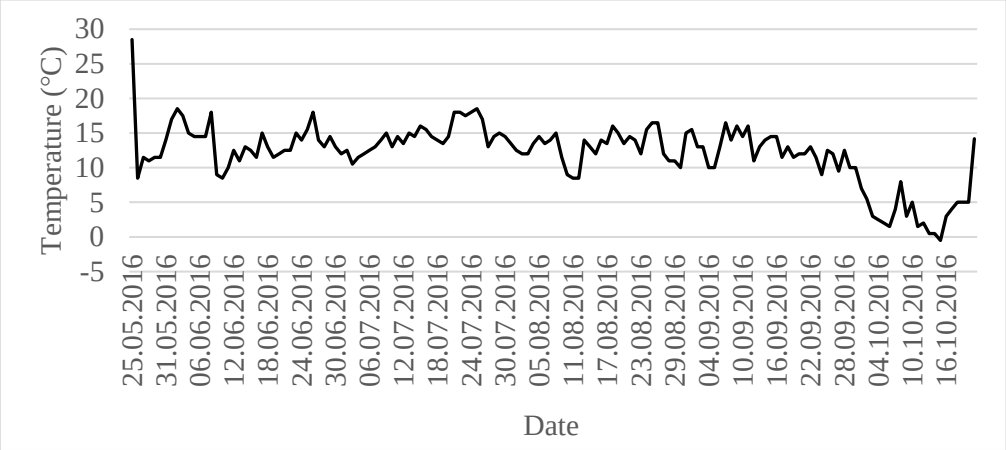

Figure 11. *Average daily mean temperature during forcing in Oppland during the period May 25 - Oct. 16, 2016.*

3.3. Experimental design, data observations and analyses

In the plastic tunnel, the pots were organised in three randomized blocks, each with 10 pots of each cultivar from each location. This design gave 18 experimental plots in total. The plants were fertigated through an automatic fertigation system in each watering according to irrigation needs, from June 1 throughout the cropping period with a complete fertilizer solution with EC 1.5 mS cm^{-1}. The fertilizer solution used was the same as described above. Temperature conditions in the tunnel during the forcing period are shown in Figure 11. Powdery mildew was controlled by using an automatic over-head sprinkling system, together with spraying with Thiovit 3 times. Pests were controlled using predators (LOG).

This investigation consisted of three parts: plant phenotyping (recordings of days to flowering, number of flowers and crowns), fruit yield registrations and fruit quality analyses. Phenotyping of the plants was done on July 13 and October 20, and included registrations of days to anthesis, total number of flowers, crowns and inflorescences per plant. All the registrations were measured per plant, and five out of ten plants were phenotyped for each experimental plot.

Berries were harvested two to three times a week from July 18 until October 13. In weeks number 40 and 41, berries were harvested only once, because of slow ripening. The number and weight of all berries were recorded. All healthy berries were graded into three size classes according to diameter (< 25 mm, 25-30 mm, and >30 mm).

3.4. Chemical compounds

From August 29 until October 13 (week numbers 35-41), berries from the three cultivars raised at Oppland were frozen at -20˚C for later analysis. Berries from the three replicated plots were kept separate, so berries from nine plots where frozen for each harvest every week. Analyses were carried out in the laboratory at NMBU, Ås. Analyses conducted were DM (dry matter), SS (soluble solids) content, TA (titratable acidity), pH, and O.D. (optical density). In addition, L-ascorbic acid content was measured. Some results are missing due to low berry yields towards the end of the season. All results were later calculated on a dry weight (DW) basis.

Figure 12*. Preparation of samples for SS, TA, pH and O.D.*

Preparation of samples:

Soluble solids (SS), titratable acidity (TA), pH, optical density (O.D.) and dry matter (DM)

For determination of soluble solids (SS), titratable acidity (TA), pH, optical density (O.D.) and dry matter (DM), berries (~50 g) were manually crushed to obtain juice. The samples were filtered (Whatman 125 mm, Schleicher & Schuell, Dassel, Germany). Then, 10 ml of each filtered sample was pipetted into a beaker (Fig. 12). Following, 5 µl of each sample was diluted to a 5 % solution (5 µl sample + 9.5 ml distilled water. This solution was used to measure O.D. The remaining specimen was used to measure SS, TA and pH,

L-ascorbic acid

For analyses of L-ascorbic acid 25 g of frozen material was weighed. Then, 1 % oxalic acid was added to a total of 75 g. The material was then homogenized for one minute, before it was filtered through a Whatman filter (B 1/2, folded, Schleicher & Schuell, Dassel, Germany). After this, the sample was filtered through an activated Sep-Pak C-18 cartridge

(Waters Corp., Milford, MA, USA) where the first 2 ml of the sample was discarded. The Sep-Pak filters were activated by applying 5 ml methanol and then 5 ml water, removing pigments, salts and organic acids that may affect the analysis. Finally, the sample was filtered through a 0.45 μm Millex HA filter (Millipore, Molsheim, France).

Figure 13. *The samples in an ultransonic bath (Bandelin SONOREX RK 100, Bandelin Electronic GmbH & Co., Berlin, Germany)*

Antioxidant capacity (AOC), total monomeric anthocyanins (TMA) and total phenolic compounds (TP)

First, 50 g berries were homogenized with a blender (Baun MR400, Karlsruhe, Germany). Following, triplicates of 3 g of homogenate was extracted with 30 ml acidic methanol (Methanol + 0,085 % HCl (32 %)). Nitrogen was added to the samples and immediately capped to prevent oxidation of the sample. After this, the samples were vortexed (Vortex-T Genie 2, Scientific Industries Inc., Bohemia, NY, USA) for 30 seconds, before placed in an ultrasonic bath (Bandelin SONOREX RK 100, Bandelin Electronic GmbH & Co., Berlin, Germany) (Fig. 13) at 0 °C for 15 min, agitating the particles of the sample and removing of eventual gases. The samples were stored at -20 °C prior to analysis.

Chemical analyses

Soluble solids (SS), titratable acidity (TA), pH, optical density (O.D.) and dry matter (DM),

Soluble solids (%) was determined by the use of a refractometer (Atago Palette, Japan). Juice was filled on the measuring surface of the refractometer. The value obtained from the refractometer is an expression for soluble solids in the berry juice and gives an indirect measurement of the sugar content.

TA (%) was measured with an automatic titrator (Methrom 716 DMS Titrino and 730 sample changer (Herisau, Switzerland). The titrator was pre-calibrated with the use of buffer pH 4 and 7 (Titrisol pH 4/pH7, Mereck, Germany). Prior to the titration, 7 beakers filled with 10 ml filtered sample material and distilled water, were placed into the sample changer before titrated with lye to pH 8.5

pH was measured with a pH-meter (Methrom 691, Herisau, Switzerland) calibrated at pH 4 and 7 (Titrisol pH 4, Mereck, Germany).

O.D. was measured with a spectrophotometer (Shimadzu UV mini-1240, Kyobashi, Japan) with absorbance at 515 nm.

DM (%) content was determined by drying 6-7 g of berry homogenate at 100 °C for 24 h in a drying oven (Termaks, Bergen, Norway). After drying was completed, the homogenate was stabilized in a dessicator before weighing.

L-ascorbic acid

To determine L-ascorbic acid, samples were analyzed by an Agilent Technologies 1100 Series HPLC system (Waldbronn, Germany) as described by Williams et al. (1973). This system consists of a quaternary pump, an inline degasser, an autosampler, a column oven and an ultraviolet (UV) light detector (Fig. 14). With the use of a 4.6 mm × 250 mm Zorbax SB-C18 5 Micron column (Agilent Technologies, Palo Alto, CA, USA), separation was achieved. Chemstation software was used to monitor chromatography and data processing. The

mobile phase was 0.05 M KH_2PO_{4-} at 1 mL min^{-1}. The injection volume was 5 µl. L-ascorbic acid was measured at 254 nm. The results are given in mg/ 10 g, dry weight (DW).

Figure 14. *An Agilent 1100 Series HPLC system (Agilent Technologies, Waldbronn, Germany) equipped with an auto-sampler (4 °C), a quaternary pump, an in-line degasser, a column heater and a photodiode array detector.*

Antioxidant capacity (AOC), total phenolic compounds (TP) and total monomeric anthocyanins (TMA)

For analysis of AOC, TMA and TP a Konelab 30i (Thermo Electron Corp., Vantaa, Finland) analyzer was used. The analysis is based on spectrophotometry. The antioxidant capacity was measured by the Ferric Reducing Antioxidant Power (FRAP) assay as described by Benzie and Strain (1996). The FRAP reagents (200µl) were acetatebuffer (3.0 mM, iron trichloride (20 mM) and TPTZ (2, 4, 6- tripyridyl-s-triazin- 10 mM in 40 mM HCI (ratio 10:1:1), pipetted separately and mixed in cuvettes. The reagents were added to the testing material (8µl) before incubated for 10 minutes at 37 °C. The absorbance was measured at 595 nm. The AOC was calculated on the basis of E-vitamin analog Trolox (control). The reagents and standard solutions were prepared as decribed by (Benzie & Strain 1996). The results are presented as mmol Fe^{2+} per 10g DW.

TP were measured according to the Folin-Ciocalteu method as described by Singleton et al. (1999). The Konelab 30i (Thermo Electron Corp., Vantaa, Finland) performed all steps. The material (20 µl) was diluted to concentrations within the linear absorbic range of the analyzer, mixed with Folin Ciocalteu reagent (100µl, diluted 1:10 with distilled water) and incubated for 60 seconds before extracted with 80µl sodium (7,5 % w/v). The samples were remixed and incubated for another 15 minutes before absorbance at 765 nm. Then the concentration of phenolic compounds were calculated based on gallic acid standard (3, 4, 5-trihydroxybenzoacid, Sigma G-7384) for all samples. The results are presented as mg GAE (gallic acid equivalents) per 10g (DW).

TMA was performed by the pH differential method based on the spectral characteristics of anthocyanins (Giusti & Wrolstad 2001). To determine TMA, the samples (20 µl) were first diluted by the analyzer before pH 1 buffer (KCl – 0.025 M) and pH 4.5 buffer ($NaC_2H_3O_2$ – 0.4 M) was added. The buffers were added separately. The samples were then incubated at 37 °C for five minutes. The absorbance for both solutions were measured at 520 and 700 nm. The reagents were prepared as described by Giusti and Wrolstad (2001). The TMA content is presented as mg/g cyanidin-3-glucoside equivalents (CGE).

3.5. Statistical analysis

All statistical analyses were performed using Minitab (version 17.3.1, Minitab Inc., 2016). Analysis of Variance (ANOVA) was used to separate the means for the different parameters, with a confidence interval of 95 %. Two-way analysis of variance (ANOVA) was performed to test the effects of cultivars, location and their interactions. Grouping information was obtained using Tukey's test to compare means.

Pearson's correlation coefficient was used to determine the strength of correlations, where $P<0.05$ is significant.

4. Results

4.1. Growth and flowering performance

The plants were separated according to location of raising. Phenotyping of plants of the different cultivars raised in Oppland and Rogaland are shown in Table 2 and Table 3, respectively.

There was no difference in time to flowering for either cultivar or location (Tables 2-4). All cultivars flowered after 18 - 22 days, as counted from start of forcing, until first open flower.

There was a highly significant effect on the amount of flowers in plants of the different cultivars raised in Oppland. ‘Korona’ and ‘Nobel’ had almost twice as many flower trusses per plant as ‘Saga’, when recorded on July 13. ‘Korona’ had more flowers in total per plant, due to a higher number of flowers per truss (Table 2). ‘Korona’ and ‘Saga’ developed more crowns per plant than ‘Nobel’, when recorded early in the season, with an average of 4.7, 4.3 and 4.0 crowns per plant for ‘Korona’, ‘Saga’ and ‘Nobel’, respectively. The number of inflorescences and crowns per plant increased during the season, so that at the end of the experiment, the number of inflorescences per crown had increased from 0.8 to 1.4 and 1.1 for ‘Korona’ and ‘Nobel’, respectively. ‘Saga’ had also developed on average one more inflorescence per plant at the end of the season, but also the number of crowns were increased, so the number of inflorescences per plant was the same (data not shown).

There was also a highly significant effect on the amount of flowers in plants of the different cultivars raised in Rogaland. When recorded on July 13, ‘Korona’ and ‘Nobel’ had on average 0.6 to 1 flower truss more per plant than ‘Sonata’ (Table 3). ‘Korona’ had the highest number of flowers per truss with an average of 12.1, but this was not significant different from ‘Nobel, with 9.1 flowers per plant (Table 3). Due to the high number of flowers per truss, ‘Korona’ also had the highest total amount of flowers per plant with an average of 38 flowers per plant. In comparison, ‘Nobel’ and ‘Sonata’ had 21.1 and 15.7 flowers per plant, respectively. ‘Korona’ had developed significantly more crowns at the first registration with an average of 4.1 compared to ‘Nobel’ and ‘Sonata’ that had 2.9 and 1.9 (Table 3).

On the last registration date, on October 20, plants of all cultivars from Rogaland had developed more flower trusses and crowns, than plants raised in Oppland (Table 3 and 4). ‘Nobel’ had the highest increase with 3.9 trusses developed between the two registration dates.

Both ‘Nobel’ and ‘Sonata’ had nearly doubled the number of crowns with an average of 5.2 and 3.4, respectively. ‘Korona’ had increased the number of crowns per plant by 2.3. ‘Nobel’ was the only cultivar that experienced an increase in inflorescences per crown, from 0.9 to 1.2, on the last registration. In fact, ‘Sonata’ had a decrease as it went from 1.1 to 0.8, meaning it has developed more crowns throughout the season, but not flower trusses.

Plants of ‘Korona’ and ‘Nobel’ were raised at both locations. There was a trend that ‘Korona’ produced in Oppland, flowered later than ‘Korona’-plants raised in Rogaland, but this difference was not statistical significant (Table 4). There were significant ‘Cultivar x Location’ interactions for flowers per inflorescence recorded on July 13, and number of crowns per plant recorded on October 20 (Table 4). ‘Korona’ had initiated more flowers per truss in plants raised in Oppland, when recorded on July 13, but had developed fewer crowns per plant on October 20 (Table 4).

***Table 2**. Growth and flowering performance of three strawberry cultivars in 2016, after raised at the location 'Oppland' in 2015*

		Days to anthesis (after May 25)	No. of infloresc. plant^{-1} (July 13)	No. of flowers plant^{-1} (July 13)	Flowers infloresc.$^{-1}$ (July 13)	No. of crowns plant^{-1} (July 13)	No. of infloresc. crown^{-1} (July 13)	No. of infloresc. plant^{-1} (Oct. 20)	No. of crowns plant^{-1} (Oct. 20)
Cultivar effect	'Korona'	21.4	3.6 a[y]	62.2 a	17.3 a	4.7 a	0.8 a	6.8 a	5.0 b
	'Nobel'	18.9	3.4 a	34.3 b	10.0 b	4.0 b	0.8 a	6.7 a	5.9 a
	'Saga'	20.5	1.9 b	20.3 b	10.9 b	4.3 ab	0.4 b	2.8 b	6.7 a
	Mean	*20.3*	*3.0*	*39.0*	*12.7*	*4.3*	*0.7*	*5.4*	*5.9*
	Significance	n.s.	***	***	***	**	***	***	***

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. * = 0.05; ** = 0.01; *** = 0.001

n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

***Table 3**. Growth and flowering performance of three strawberry cultivars in 2016, after raised at the location 'Rogaland' in 2015*

		Days to anthesis (after May 25)	No. of infloresc. plant^{-1} (July 13)	No. of flowers plant^{-1} (July 13)	Flowers infloresc.$^{-1}$ (July 13)	No. of crowns plant^{-1} (July 13)	No. of infloresc. crown^{-1} (July 13)	No. of infloresc. plant^{-1} (Oct. 20)	No. of crowns plant^{-1} (Oct. 20)
Cultivar effect	'Korona'	17.8	3.0 a[y]	38.0 a	12.1 a	4.1 a	0.7 b	4.3 b	6.4 a
	'Nobel'	18.8	2.5 ab	21.1 b	9.1 ab	2.9 b	0.9 ab	6.4 a	5.2 b
	'Sonata'	21.7	1.9 b	15.7 b	7.9 b	1.9 c	1.1 a	2.7 b	3.4 c
	Mean	*19.4*	*2.5*	*24.9*	*9.7*	*3.0*	*0.9*	*4.5*	*5.0*
	Significance	n.s.	*	***	**	***	*	***	***

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. *= 0.05; ** = 0.01; *** = 0.001

n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

***Table 4**. Comparison of growth and flowering performance of two strawberry cultivars in 2016, after raising at the locations 'Oppland' and 'Rogaland' in 2015*

		Days to anthesis (after May 25)	No. of infloresc. plant^{-1} (July 13)	No. of flowers plant^{-1} (July 13)	Flowers infloresc.$^{-1}$ (July 13)	No. of crowns plant^{-1} (July 13)	No. of infloresc. crown^{-1} (July 13)	No. of infloresc. plant^{-1} (Oct. 20)	No. of crowns plant^{-1} (Oct. 20)
Cultivar effect	'Korona'	23.4	3.3	50.1 a	14.7 a	4.7 a	0.8	5.4	5.7
	'Nobel'	20.0	3.0	27.7 b	9.5 b	3.5 b	0.9	6.6	5.6
	Significance	n.s.	n.s.	***	***	***	n.s.	n.s.	n.s.
Location effect	Oppland	20.2	3.5 a[y]	48.2 a	13.7 a	4.4 a	0.8	6.8 a	5.5
	Rogaland	18.3	2.8 b	29.6 b	10.6 b	3.5 b	0.8	5.3 b	5.8
	Significance	n.s.	*	***	**	***	n.s.	*	n.s.
Interactions	Cult*Loc	n.s.	n.s.	n.s.	*	n.s.	n.s.	n.s.	***

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. * = 0.05; ** = 0.01; *** = 0.001

n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

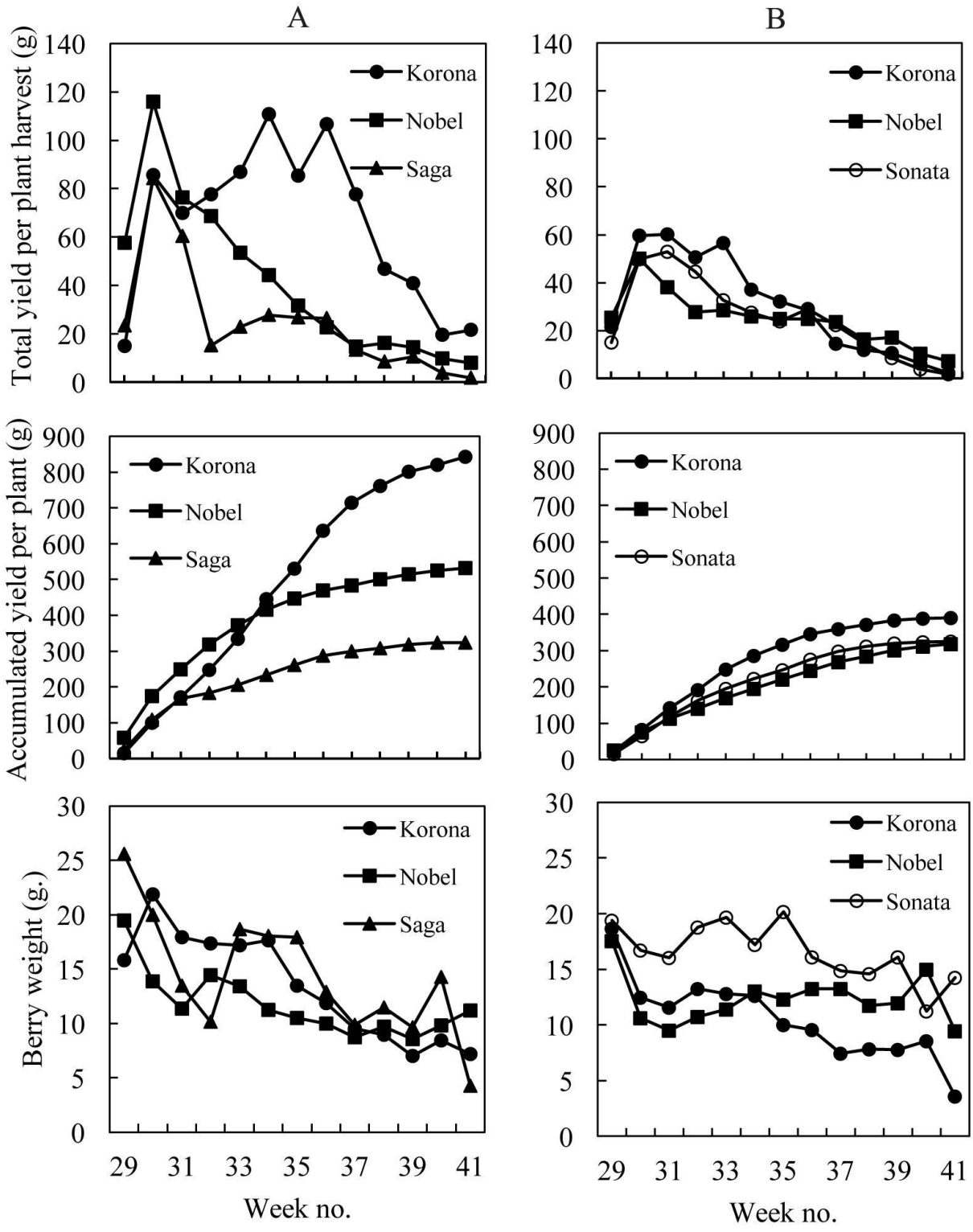

Figure 15. *Total yield per plant per harvest (g), cumulative yield per plant (g) and berry weight (g) for Oppland (A) and Rogaland (B).*

4.2. Yield and berry weight

Yield results from plants raised in Oppland and Rogaland are presented in Table 5 to 7. 'Nobel' was the earliest cultivar, with ripe fruits 53 to 55 days after planting, in both raising locations. For Oppland, 'Nobel' was harvested six and five days earlier than 'Korona' and 'Saga', respectively. For Rogaland, there were no differences in ripening time between the cultivars (Table 6).

There was a highly significant effect on the total yield in plants of the different cultivars raised in Oppland. 'Korona' stands out with 843 g plant^{1} compared to 'Saga' that had 323.7 g plant^{-1}. This was due to a high number of harvested berries per plant and not as much total berry weight as this was not significant different for the two cultivars (Table 5). The weight of the berries decreased steadily throughout the harvest period for all cultivars (Fig. 15). The berry weight of 'Nobel' was also quite small with an average of 12.6 g. However, the berries held a more even size throughout the season with no peaks with larger berries, like 'Korona' and 'Saga' (Fig. 15). 'Nobel' (Fig. 16) and 'Korona' (Fig. 17) did not differ in berry weight or grading at Oppland, although in 'Korona', 9.6% of the total harvested fruits was graded as smaller than <25 mm in diameter, compared to 6.0% of the fruits from plants of 'Nobel'. Even though 'Saga' had the lowest yield, it had significantly larger berries with an average berry size of 15.4 g, and also had the highest percentage of berries graded as being larger than <30 mm with 83.7 % (Fig. 18).

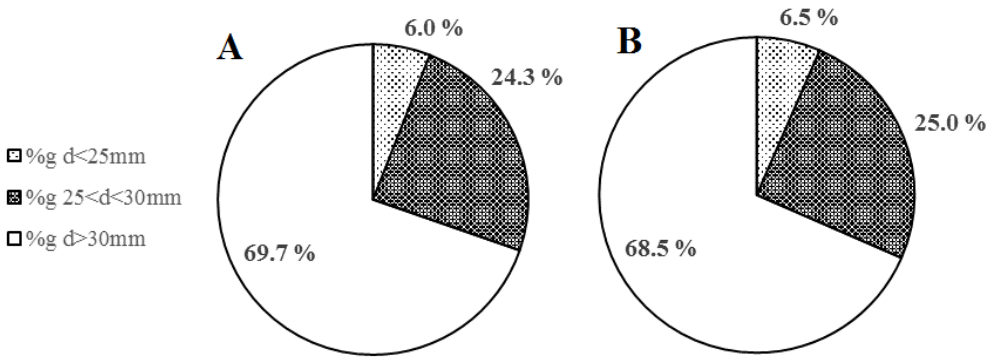

Figure 16. *Berry size gradings for 'Nobel' raised in Oppland (A) and Rogaland (B).*

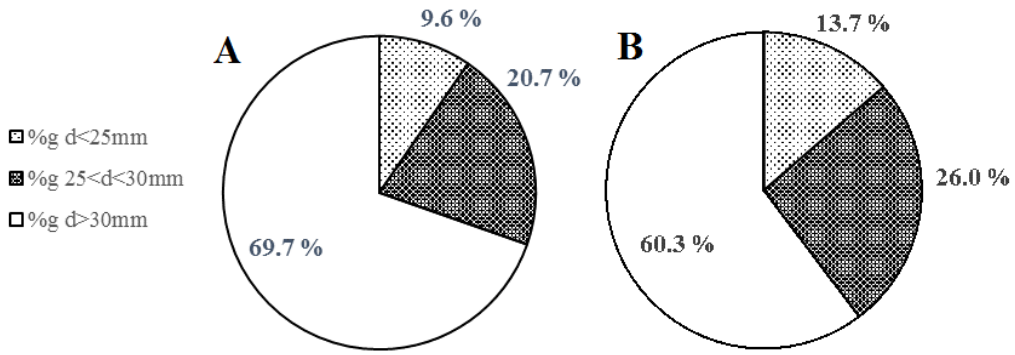

Figure 17. *Berry size gradings for 'Korona' raised in Oppland (A) and Rogaland (B).*

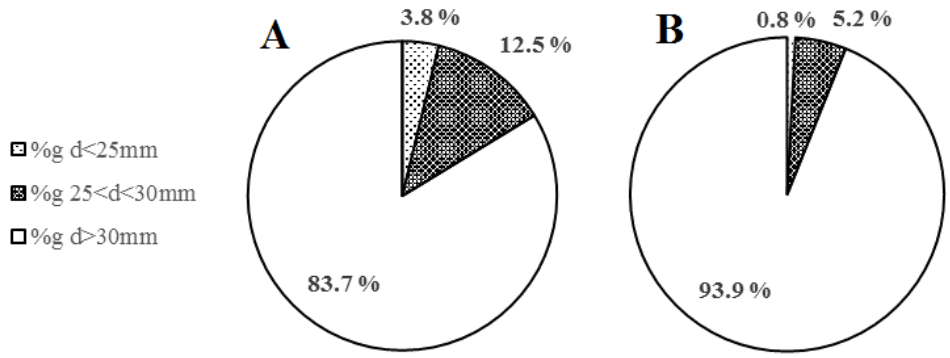

Figure 18. *Berry size gradings for 'Saga' from Oppland (A) and 'Sonata' from Rogaland (B).*

Table 5 shows that there was a significant difference between 'Korona' and the other cultivars from Oppland regarding the total number of fruits and flowers not harvested when recorded on October 13. 'Korona' had the highest number with 112.9 flowers and fruits per plant and this was significantly higher than for 'Nobel' and 'Saga' that had 35.5 and 10.4 unharvested flowers and fruits, respectively. As 'Korona' had the highest number of 'Harvested berries' and 'Flowers and berries not harvested', it also had the highest total amount of flowers and fruits per plant. 'Korona' had 177.1 followed by 'Nobel' and 'Saga' with 77.8 and 31.6, respectively.

Unlike for plants from Oppland, there were no significant differences between the cultivars regarding total yield per plant from Rogaland (Table 6). All cultivars yielded

approximately 350 g per plant. However, ‘Sonata’ had significantly larger berries, with an average of 17.1 g, compared to ‘Korona’ and ‘Nobel’ with 11.4 and 11.8 g per berry, respectively. ‘Sonata’ also had the highest percentage of berries graded larger than >30 mm in diameter with 93.9 % (Fig. 18, Table 6). ‘Korona’ had the lowest berry weight in addition to having the highest percentage of small berries. ‘Sonata’ and ‘Nobel’ held quite stable berry weight throughout the season (Fig. 15). Of all the cultivars, ‘Korona’ had the largest decline in berry weight towards the end of the season. There were also significant differences between plants of cultivars from Rogaland regarding fruits and flowers not harvested. Again, ‘Korona’ had the highest number of 43.2, followed by ‘Nobel’ with 27.6 and ‘Sonata’ with 10.7 (Table 6). The total number of flowers and fruits per plant from ‘Korona’ was 77.7, followed by ‘Nobel' and ‘Sonata’ with 54.8 and 29.6 flowers and berries per plant, respectively.

The yield per harvest for ‘Nobel’ and ’Saga’ from plants raised in Oppland had a steady decrease (Fig. 15). ‘Korona’ had three peaks with the last one in week 36. This was different for the plants of the cultivars from Rogaland, that all had a steady decrease in total yield per week, with no peaks. Total fruit yield was highest in Oppland for both ‘Korona’ and ‘Nobel’ having an average of 450.4 g and 212.3 g more yield per plant than from Rogaland (Table 5 and 6).

There was a significant interaction between cultivar and location regarding percentage of berries d <25 mm (Table 7). Rogaland had the highest number of small berries. There was also an interaction between cultivar and location for total number of fruits and flowers per plant, with ‘Korona’ having the highest number when raised in Oppland.

Table 5. *Berry yield and size gradings for three strawberry cultivars forced in an open plastic tunnel at NIBIO in 2016. The plants were raised at 'Oppland' in 2015.*

		Days to first harvest	Berry yield (g/plant^{-1})	Yield (%) <25 mm	Yield (%) 25-30 mm	Yield (%) >30 mm	Berry weight (g)	Harvested berries plant^{-1}	Flowers and berries not harvested	Total no. of berries and flowers
Cultivar effect	'Korona'	58.3 a[y]	843.0 a	9.6 a	20.7 a	69.7 b	13.2 b	64.2 a	112.9 a	177.1 a
	'Nobel'	52.7 b	533.6 b	6.0 b	24.3 a	69.7 b	12.6 b	42.4 ab	35.5 b	77.8 b
	'Saga'	57.0 a	323.7 b	3.8 b	12.5 b	83.7 a	15.4 a	21.2 b	10.4 b	31.6 c
	Mean	*56.0*	*566.8*	*6.7*	*19.2*	*74.4*	*13.7*	*42.6*	*52.9*	*95.5*
	Significance	***	**	**	**	***	**	**	***	***

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. * = 0.05; ** = 0.01; *** = 0.001. n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

Table 6. *Berry yield and size for three strawberry cultivars forced in an open plastic tunnel at NIBIO in 2016. The plants were raised at 'Rogaland' in 2015.*

		Days to first harvest	Berry yield (g/plant^{-1})	Yield (%) <25 mm	Yield (%) 25-30 mm	Yield (%) >30 mm	Berry weight (g)	Harvested berries plant^{-1}	Flowers and berries not harvested	Total no. of berries and flowers
Cultivar effect	'Korona'	57.7 a[y]	392.6 a	13.7 a	26.0 a	60.3 c	11.4 b	34.5 a	43.2 a	77.7 a
	'Nobel'	55.0 a	321.3 a	6.5 b	25.0 a	68.5 b	11.8 b	27.2 ab	27.6 b	54.8 b
	'Sonata'	58.7 a	326.1 a	0.8 c	5.2 b	93.9 a	17.1 a	18.9 b	10.7 c	29.6 c
	Mean	*57.1*	*346.7*	*7.0*	*18.7*	*74.2*	*13.4*	*26.9*	*27.2*	*54.0*
	Significance	n.s.	n.s.	***	***	***	***	*	***	***

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. * = 0.05; ** = 0.01; *** = 0.001. n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

Table 7. *Comparison of berry yield and size for two strawberry cultivars from two different locations.*

		Days to first harvest	Berry yield (g/plant^{-1})	Yield (%) <25 mm	Yield (%) 25-30 mm	Yield (%) >30 mm	Berry weight (g)	Harvested berries plant^{-1}	Flowers and berries not harvested	Total no. of berries and flowers
Cultivar effect	'Korona'	58.0 a[y]	617.9 a	11.6 a	23.4	65.0	12.3	49.4 a	78.0 a	127.4 a
	'Nobel'	53.8 b	427.5 b	6.3 b	24.7	69.0	12.2	34.8 b	31.5 b	66.3 b
	Significance	**	*	***	n.s.	n.s.	n.s.	*	***	***
Location effect	'Oppland'	55.5	688.4 a	7.8 b	22.5	69.7 a	12.9 a	53.3 a	74.2 a	127.5 a
	'Rogaland'	56.3	357.0 b	10.1 a	25.5	64.4 b	11.6 b	30.9 b	35.4 b	66.3 b
	Significance	n.s.	**	*	n.s.	*	**	**	***	***
Interactions	Cult*Loc	n.s.	n.s.	*	n.s.	n.s.	n.s.	n.s.	***	**

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. * = 0.05; ** = 0.01; *** = 0.001. n.s. – not significant.

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

Table 8. *Berry quality parameters of three strawberry cultivars forced in an open plastic tunnel at NIBIO in 2016. Data are the means of quality analysis of berries harvested weekly from August 29 until October 13. Data are the means of three replications.*

Abbreviations: DM = dry matter, SS= Soluble solids, TA= (titratable acidity), L-asc = L-ascorbic acid. AOC = antioxidant capacity, TMA = total monomeric anthocyanins and TP = total phenolic compounds.

		DM (%)	(SS) (%)	(TA) (%)	SS/TA	pH	Color (515 nm)	L-asc. (mg/ 10 g DW)	(AOC) (mmol/10 g DW)	TMA (mg CGE/10 g DW)	TP (mg GAE/10 g DW)
Cultivar effect	'Korona'	9.1	9.7	0.9	10.9	3.5 a[y]	0.07 b	47.1 b	2.1	14.6 b	276.5
	'Nobel'	8.8	9.2	1.0	10.3	3.5 a	0.08 ab	58.3 a	2.3	21.0 a	304.1
	'Saga'	9.3	9.6	1.0	9.5	3.4 b	0.1 a	51.2 ab	2.3	18.6 ab	312.7
	Mean	*9.1*	*9.5*	*1.0*	*10.2*	*3.5*	*0.08*	*52.2*	*2.2*	*18.1*	*297.8*
	Significance	n.s.	n.s.	n.s.	n.s.	**	*	*	n.s.	*	n.s.

The data are means of three replicate plots, each with 5 plants per plot of each cultivar. *=0.05, **= 0.01, ***=0.001. n.s. – not significant

[y] Mean values within each column followed by different letters are significantly different at $P < 0.05$ by Tukey's test.

4.3 Chemical compounds

No significant differences were found between the cultivars regarding dry matter (DM), soluble solids (SS), titratable acidity (TA), SS/TA ratio, antioxidant capacity (AOC) or total phenolic compounds (TP) (Table 8). There was however, a significant difference in pH between 'Saga' and the two other cultivars 'Korona' and 'Nobel' ($P \leq 0.01$). 'Saga' had lower and insignificant pH (3.4) than the two other cultivars (3.5). Regarding color, 'Saga' and 'Nobel' had the highest O.D.-value, with 0.1 and 0.08, respectively, while 'Korona' had a slightly lower value than 'Nobel' (0.07).

Figure 19 shows weekly changes in the measured chemical compounds in berries harvested weekly from August 29 until October 13 (week 35-41). The SS/TA ratio had a steady increase for all cultivars throughout the harvest season (data not shown). From week 35 this increase was quite rapid for 'Nobel' and 'Saga', but the same was not observed for 'Korona'.

'Nobel' had significantly higher amount of L-ascorbic acid, with 58.3 mg/10g than 'Saga' and 'Korona' which had 51.2 and 47.1 mg/10g, respectively. The L-ascorbic acid content decreased in all cultivars throughout the harvest season (Fig. 20). From week 35 to 40, the amount of L-ascorbic acid in 'Nobel' went from 57.4 to 47.1 mg/10g DW. 'Saga' had too low harvest from week 39, resulting in insufficient amount of berries for these analyses.

'Korona' had the lowest amount of TMA (14.6 mg CGE/10 g DW) and 'Nobel' the highest (21.0 mg CGE/10 g DW). This difference showed to be significant for these two cultivars. The amount of TMA decreased throughout the season for all cultivars. The greatest reduction was in berries of 'Nobel', where the TMA level decreased from 22.5 to 15.9 mg CGE/10 g DW from week 35 to week 41. In comparison, berries of 'Korona' decreased from 14.0 to 10.1 mg CGE/10 g DW. No results were obtained from 'Saga' due to lack of berries from week 39.

In general, the different quality parameters decreased slightly only at the end of the harvesting season (Fig. 19 and 20).

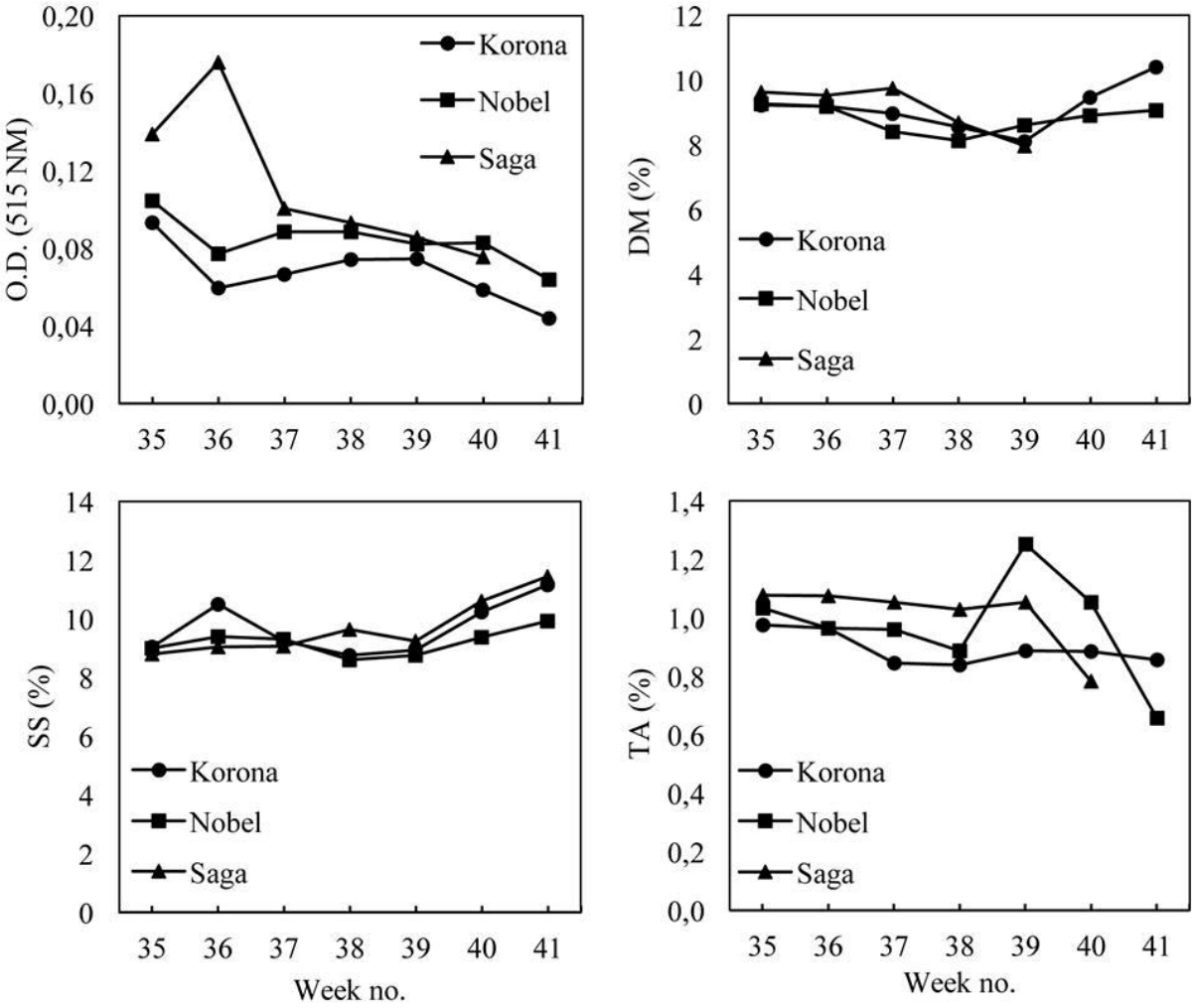

Figure 19. *Weekly changes in chemical compounds. Optical density = O.D, dry matter = DM, soluble solids = SS and titratable acidity = TA.*

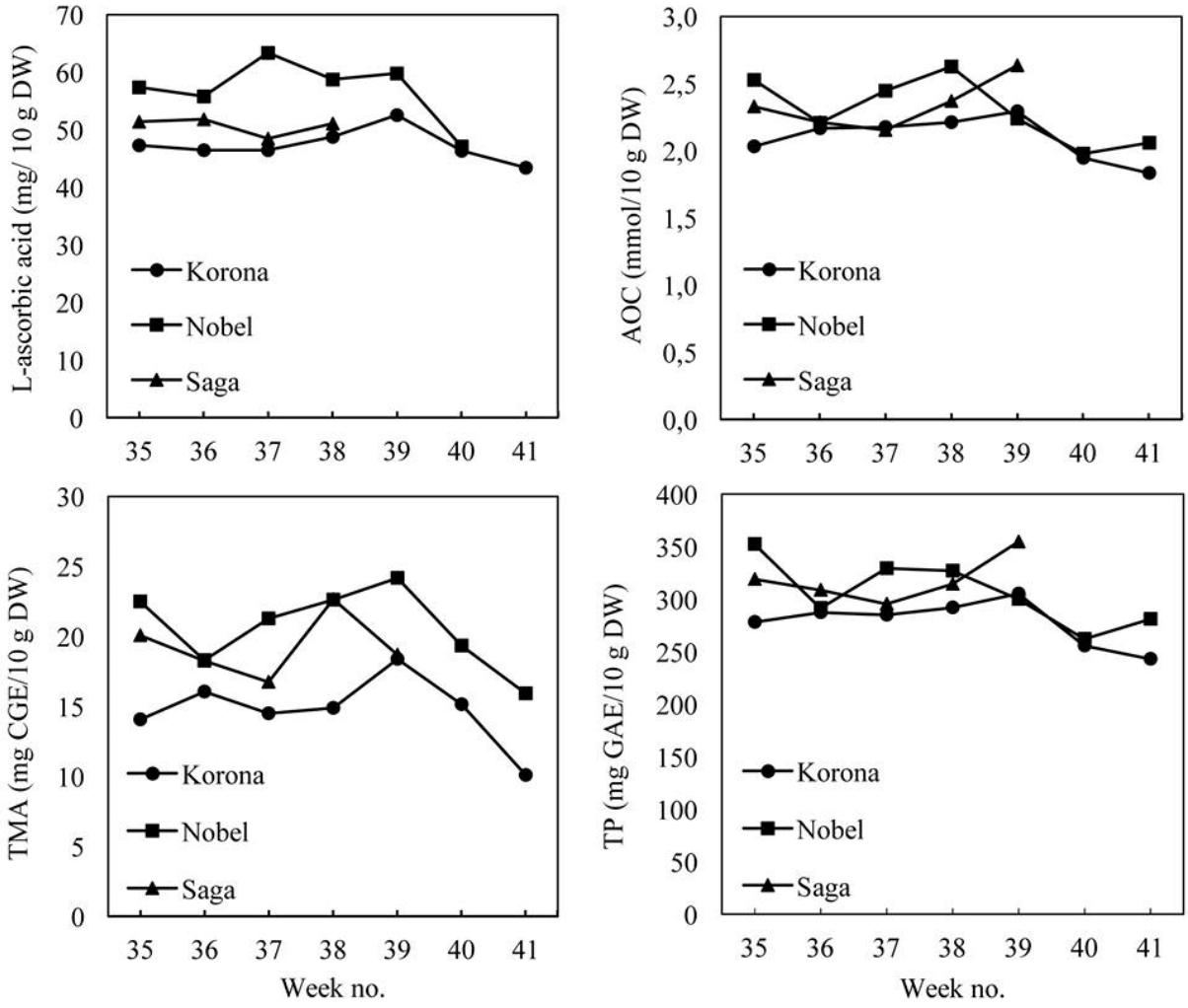

Figure 20. *Weekly changes in chemical compounds. Antioxidant capacity = AOC, total monomeric anthocyanins = TMA and total phenolic compounds = TP.*

Sensory analysis

Both cultivars obtained high scores in an unofficial quality test performed by Graminor Breeding Ltd (Alsheikh et al. 2010). Out of the two, berries of 'Saga' won this test. It had a stronger skin and better firmness compared to 'Korona'. 'Nobel' also achieved high scores in this test. According to Alsheikh et al. (2010), the taste of 'Nobel' was as good as 'Korona'. In addition, it obtained better scores for firmness, skin strength and appearance. These results can be compared to an unofficial test of berry characteristics performed by Anita Sønsteby and myself on September 22, 2016 (week 38) (Table 9-10). The results concluded that 'Saga' (Table 10) had nice and even berries, with a good taste. However, it fell through on texture. 'Nobel' (Table 9) obtained slightly higher scores than 'Saga'. These berries also had a good taste and were evenly sized. These obtained almost maximum score for evaluation of outside coloration. However, 'Nobel' also was given low scores for texture.

***Table 9**. Berry quality test of the cultivar 'Nobel' performed by Anita Sønsteby and Synne Olsen on September 22, 2016.*

Berry characteristic	Score (scale 1-10)	Comments
Appearance	8	Even and nicely shaped.
Outer coloration	9	Deep and shiny red color.
Skin strength	7	The skin does not get marks or bruises easily.
Fruit firmness	3	A 'sponge'-like texture.
Taste	8	Nice balance between sweet and sour.
Inner coloration	6	Quite good coloration throughout. Somewhat pale in the center.

The test was based on a scale from 1-10, where 10 is the maximum points (best) that can be obtained. A score below 5 is evaluated as not acceptable.

Figure 21 and 22 give an indication of quality in the berries. The color appears to have faded slightly for 'Sonata' and 'Nobel' from week 37 to week 40. This can also be seen in Figure 19. In addition, the shape of 'Saga' is not ideal. This can be seen especially in Figure 22 where the berries were small and misshaped.

***Table 10**. Berry quality test of the cultivar 'Saga' performed by Anita Sønsteby and Synne Olsen on September 22, 2016.*

Berry characteristic	Score (scale 1-10)	Comments
Appearance	8	Conically shaped, even sized and shiny berries.
Outer coloration	9	Nice deep red color.
Skin strength	6	A bit weaker than 'Nobel'.
Fruit firmness	4	Sponge-like texture.
Taste	8	Quite sweet. Nice balance between sweet and sour.
Inner coloration	7	Quite even.

The test was based on a scale from 1-10, where 10 is the maximum points (best) that can be obtained. A score below 5 is evaluated as not acceptable.

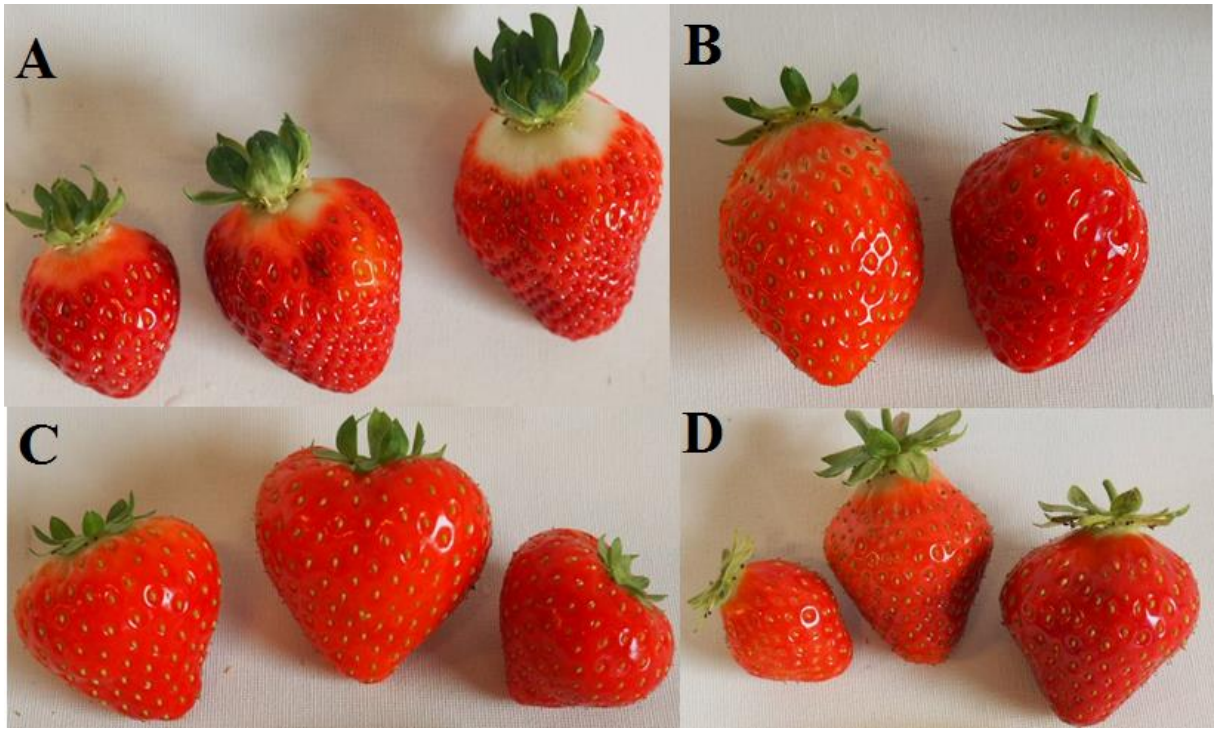

***Figure 21.** Harvested berries from week 37. A: 'Nobel', B: 'Korona', C: 'Sonata', D: 'Saga'.*

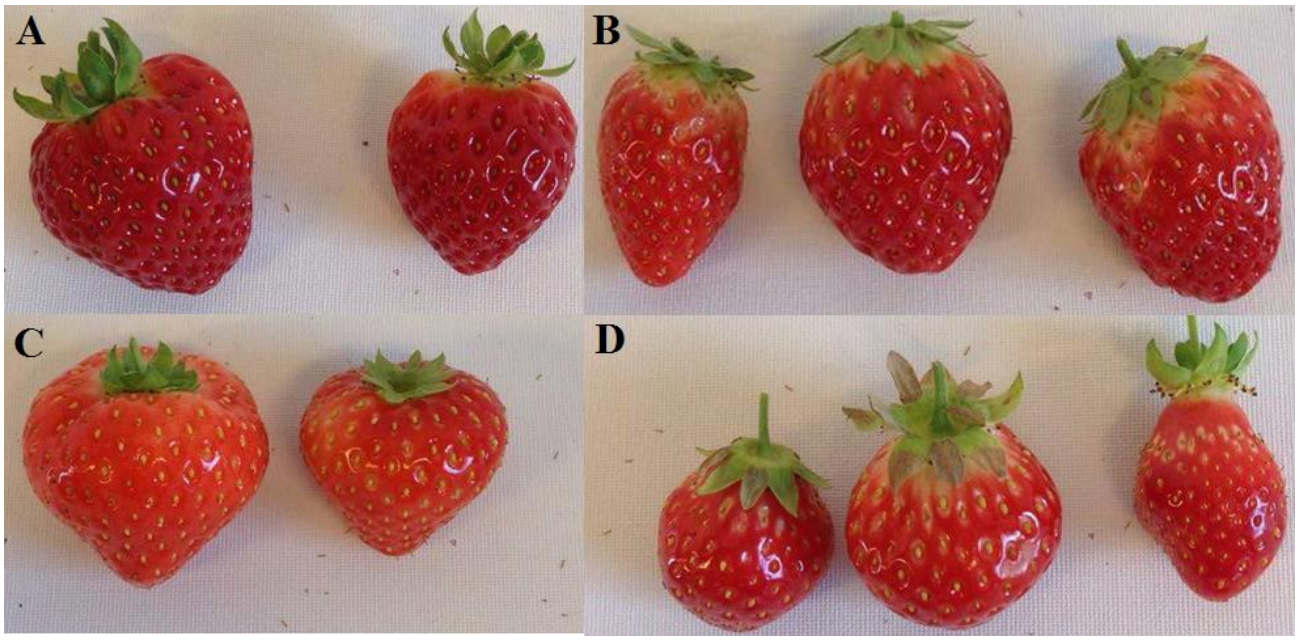

Figure 22. *Harvested berries from week 40. A:' Nobel', B: 'Korona', C: 'Sonata', D: 'Saga'.*

5. Discussion

5.1. Plant development and yield

There were high expectations for ‘Nobel’ and ‘Saga’ when starting this experiment. Both cultivars received good evaluations from earlier field trials, where flowering and yield were evaluated (Myrstad 2014; Sønsteby & Heide 2017). ‘Saga’ and ‘Nobel’ were tested in southern Troms in 2014, where ‘Saga’ achieved the highest yield of all cultivars tested (‘Zephyr’, ‘Korona’, ‘Sonata’, ‘and Nobel’). Sønsteby and Heide (2017) raised plants of ‘Nobel’ and ‘Saga’ together with ‘Malwina’, ‘Rumba’, ‘Florence’ and ‘Sonata’ under different SD and temperature combinations. ‘Nobel’ and ‘Saga’ showed broad temperature adaptations as flower initiation occurred across the entire temperature range (9 °C to 27 °C). This was true especially for ‘Nobel’, where all the plants (100 %) flowered in all temperatures. In addition, ‘Nobel’ showed early flower induction, flowering after 29.3 days with 9 °C and 10 h photoperiod. It is a SD cultivar, but has been reported to flower also in LD (Sønsteby & Heide 2017). These qualities combined, suggest that ‘Nobel’ has a wide adaptability to a varying climate and is ideal for the Nordic environment.

This adaptability may be explained by its pedigree, where one of the parents (‘Diamante’) is an ever-bearing (LD) cultivar (Eikemo & Stensvand 2015). It seems that the combination of genes from a SD and a LD cultivar has made ‘Nobel’ more or less day-neutral (Sønsteby et al. 2016). Despite of this, however, the cultivar is not ever-bearing, but behaved as a regular single cropping cultivar in the field. These qualities may explain why ‘Nobel’ was the earliest cultivar in regards to flowering and harvesting. Despite the good qualities of ‘Nobel’, the cultivar had low yield and berry weight. Similar results were also obtained in recent study (Sønsteby & Heide 2017). ‘Saga’, however, had larger berries, but lower yield. This cultivar did also show variation in temperature requirements (Sønsteby et al. 2017). Therefore, the reason for the cultivars’ unsatisfactory yield in this study is most likely due to other factors related to the raising methods used here.

In the study of Sønsteby and Heide (2017), it was found that overwintering of ‘Nobel’ and ‘Saga’ in open field had deteriorating effects on the number of flower trusses. After chilling, the plants had lost 2/3 of the inflorescences developed in the autumn. For ‘Nobel’ this might be explained by its early flowering. It is likely that the advanced inflorescences had already started to elongate prior to winter, thus rendered themselves vulnerable to winter kill (Sønsteby &

Heide 2017). However, the authors concluded that this theory could not explain the same results for 'Saga', which flowered rather late. The flower buds were not dissected prior to cold storage in this study, and plants were not forced without cooling, thus it cannot be concluded that the results obtained in our study are comparable.

Despite low yield and berry weight, 'Nobel' was the most stable cultivar during the entire harvesting period. There were no harvest peaks, like for the other cultivars (Fig. 15). This is most likely due to its many inflorescences and a low amount of flowers per inflorescence, but it also confirms that small fruit size is a negative trait for this cultivar.

There was a general trend that the cultivars, 'Korona' and 'Nobel', raised in Oppland achieved most flowers and berries per plants. The plants of 'Korona' from Oppland (843 g plant^{-1}) yielded over twice as much as the plants of 'Korona' raised in Rogaland (392.6 g plant^{-1}). A high yield was also found by Sønsteby et al. (2013) where 'Korona' had a yield of 507.8 g plant^{-1}, using the same raising method as here, but with the cultivars 'Korona', 'Polka' and 'Sonata'. Even though the same method was applied in both studies, this study obtained a significant higher yield for 'Korona'. A potential reason for this might be differences in ambient temperature in the periods the plants were kept outside. Another reason might be that the fertilization pulses in our study were better timed in relation to the plants generative development, as there are yearly variations within plants. In our study, 'Nobel' from Oppland achieved a total yield of 533.6 g plant^{-1} and from Rogaland the yield was significantly lower with 321.3 g plant^{-1}. The different raising methods might be the reason for this.

One major point with the method used in Oppland, is to raise temperature during the SD induction period. In the common seasonal flowering strawberry cultivars, it is well documented that a pronounced interaction of photoperiod and temperature, with SD of 10–12 h length and temperatures of 15–18 °C being optimal for flower initiation control flowering (Darrow & Waldo, 1934; Ito & Saito, 1962; Heide, 1977; Verheul et al. 2007). When the plants in Oppland were moved into the greenhouse on September 1, temperature was raised to >15 ºC. In Rogaland, the plants received a four-week SD treatment with >15 ºC. This means that temperature itself cannot explain the varying results. The importance of warm temperatures also during the flower differentiation period was demonstrated by Le Mière et al. (1996) who reported that elevated temperature (18.3 °C vs. 14.8 °C) during flower differentiation doubled the number of flowers in the secondary and tertiary inflorescences of 'Elsanta' strawberry. This might mean that the plants could have benefited from a longer duration of SD with optimal

temperature. However, the plants in Oppland received an extra week of SD conditions. In addition, the plants raised in Rogaland received less light (10 h) than the plants raised in Oppland (11.5-14 h). This might also give reduced flowering as the plants received less light energy (A. Sønsteby pers. comm.).

'Korona' has been the most important cultivar grown in Norway since the early 1980's. Therefore, its physiology has been widely studied (Sønsteby & Heide 2008; Verheul et al. 2006; Verheul et al. 2007). It is acknowledged to be an obligate SD cultivar, and only initiates flowers when exposed to photoperiods of 10-12 h lasting 21 days or longer, with temperatures between 12-18 °C (Verheul et al. 2006). However, the physiology of cultivars is a complicated field of research, as minor modifications may significantly alter the plant's response. Continuing with 'Korona' as an example; Verheul et al (2006), showed that the highest number of inflorescences and flowers were produced in plants exposed to 28 SD, while if exposed to 21 SD, the highest numbers of flowers per inflorescence were produced. Optimal temperature and SD requirements for floral induction remain to be established for 'Nobel' and 'Saga'. They have been somewhat tested in terms of cultivation, but few physiological studies of the cultivars have been conducted.

Nitrogen fertilization immediately after plants enter SD has been shown to enhance the floral induction effect of SD in SD cultivars (Guttridge 1985; Sønsteby et al. 2009). This is also supported by Lieten (2002a), where it was found that withholding nutrition until SD promoted flower induction and increased yield. However, if nutrition was low during differentiation of the primary flower bud, the plant responded with phyllody-like symptoms, where the floral parts develop into leaf-like structures. Thus, correct timing of N application is crucial to be effective. In Oppland, pulses of nitrogen were added to the flower buds shortly after the plants had entered SD (on September 7), while the plants raised in Rogaland did not receive this treatment.

Still, the results show significant variation among the cultivars raised in Oppland with the method used. This may be related to the cultivars different temperature x photoperiod patterns related to timing of their floral induction in autumn. Geographical location also has an importance. Opstad et al. (2011) showed that when growing four cultivars in five different localities in Norway, timing of flower induction varied as much as 36 days for instance for 'Korona', when grown at 59 °N and 68 °N, respectively. There was also a strong difference in timing of floral initiation between the cultivars at each location, with 13 days between the

earliest and latest cultivar tested (Steinkjær, 64 °N). In order to optimize the effect of adding extra nitrogen, the timing of fertilization should be customized accordingly (Opstad et al. 2011). As 'Nobel' and 'Saga' are new cultivars, this interaction is not extensively studied. To determine the time of flower induction in these cultivars, a dissection of the plant before the fertilization pulse with EC 3 should have been done.

An interesting result was that 'Korona' was still flowering at the end of the experiment, in October. Being a SD-cultivar, it is peculiar that it was continuing inducing flowers during LD conditions the preceding summer. This might be a result of the fertilizer pulses of nitrogen during raising in September the year before. This assumption is made, as it was only 'Korona' from Oppland that was flowering continuously. One can speculate if the N pulse affected the plant's floral repressor, FaTLF1. It has previously been demonstrated in *F. vesca* that the silencing of FvTFL1 eliminates the SD requirement for flowering (Koskela et al. 2012). Koskela et al. (2016) also showed by transgenic approach that the silencing of the floral repressor FaTFL1 in the octoploid short-day cultivar 'Elsanta' was sufficient to induce continuous flowering under long days without direct changes in vegetative reproduction. If nitrogen could have the possibility to also silence the same repressor is yet to be researched. However, it is difficult to compare the effect of an N pulse, as in our experiment, no control plants were raised without fertilizer pulses and elevated temperature.

The plants' size before autumn treatments might be a potential reason for the high yields from Oppland compared to Rogaland. The runners were rooted as late as July 30 in Rogaland, compared to July 1 in Oppland. A rooting as late as July 30, might not have given the plants sufficient time to root, and develop enough branch crowns. Rooting time might also partially explain the excessive flowering of 'Korona' from Oppland. While rich flowering is a prerequisite for high yield, excessive flowering can also be a problem since it is associated with reduced fruit size. This was the case with 'Korona' both in this study and in a study by Sønsteby et al (2013). It has been shown that 'Korona' responds to a short induction period by producing more flowers per truss, as means of compensating for fewer inflorescences. In a study by (Verheul et al. 2006; Sønsteby & Heide 2008) it was found that 'Korona', on average, had half the number of inflorescences as the other cultivars studied. However, it had more flowers per truss and so the total yield was nearly the same as for the other cultivars. This can explain the instability in berry weight throughout the season for this cultivar (Fig. 15), considering that trusses with more flowers gives more small berries. Due to the results of the current study,

‘Korona’ might need to be rooted even earlier than July to have time to produce more crowns, in order to produce more trusses and so avoid over-induction of flowering (Sønsteby et al. 2013).

The cultivars also differ in their rate of growth and development, in addition to how fast they develop a solid root system at rooting. Coherently, ‘Sonata’ is very susceptible to root diseases, such as crown rot (*Phytophthora cactorum*). Resulting from a weak root systems, ‘Sonata’ tends to establish itself slower than ‘Korona’. Sønsteby et al (2013) showed that the cultivars ‘Korona’ and ‘Polka’ had a significantly ($P \leq 0.001$) earlier harvest by timely autumn fertilization. This significance was not seen in ‘Sonata’ in their study. A reason might be that ‘Sonata’ was not yet generative. Therefore, this cultivar might need to have been rooted earlier in the season (June). This might regard plants of ‘Saga’ as well, as these plants were also rather late to flower, and was approximately one day earlier than ‘Sonata’. Because of incorrect rooting time, the plant size for ‘Nobel’ and ‘Saga’ might not have been optimal at the time of fertilization (EC 3). It is known that large plants have a greater number of branch crowns and inflorescences. A higher number of inflorescences give a larger yield as the number of primary berries increases (Verheul et al. 2006; Sønsteby & Heide, 2008).

However, this is only a speculation, as to be certain, a dissection of the apical meristem would have been needed. This may be important information also regarding the optimal runner rooting date. In order to get a full yield potential in all cultivars, different rooting times may be an alternative.

5.2. Chemical compounds

Results showed that the chemical compounds slightly decreased towards the end of the harvest season (Fig. 19 and 20). Between July 3 and July 17, SS decreased by 0.09 %. TA remained approximately the same, and so did color. L-ascorbic acid decreased significantly from 61.4 on July 3 and 39.7 mg/ 10 g DW on July 17. AOC also decreased with one mmol/10 g DW between the two dates. However, the decrease in L-ascorbic acid was not as marked for ‘Korona’ in this study as it the content had been reduced by 3.87 mg/ 10 g DW compared to 21.7.

The results from this study seem to conform to the results of Remberg et al. (2006), where chemical compounds of 'Korona' was tested in a laboratory at NMBU. Some values, such as O.D, DM, and AOC varied quite a bit. However, the berries from the NMBU study were harvested at a much earlier time (July 6-17) compared to July 18 – October 13. This could mean that the limited amount of light has affected the berries in our study.

Table 11. *Strawberry quality content from analysis done at NMBU, Ås, for the strawberry cultivar 'Korona' in July 2006 (Remberg et al. unpublished data)*

Date	**SS (%)**	**TA (%)**	**Color (515 nm)**	**DM (%)**	**L-ascorbic acid (mg/ 10 g DW)**	**AOC (mmol/10 g DW)**
3.7.06	10.15	0.87	0.1	10.1	61.4	3.3
17.7.06	10.06	0.89	0.12	12.4	39.7	2.3

It may seem that these results show that berry quality kept quite well, even in late harvests, which is not common in commercial production in Norway today.

In 2009, Josuttis et al. (2012) studied the quality of 'Korona' in an open field in a location in mid-Norway (63°36 N). They found that DM varied between 10.3 to 12.0 %, SS varied from 9.3 to 10.4, TA varied from 0.8 to 0.85. The content of TP was 164.1 – 217.8, L-ascorbic acid was 41.8- 63.2 and AOC was 25.2 – 32.4. This is an accordance with the results from this study, as all the values are comparable.

Comparing results from the chemical analysis of berries of 'Nobel' and 'Saga' with previous results obtained from 'Korona', these cultivars are of decent quality. This assumption can be made as the values obtained are within the values of 'Korona', which are accepted as good quality berries. 'Nobel' and 'Saga' also achieved good scores on taste in the berry quality test from this study. However, both cultivars fell through on firmness and texture, reducing the hopes of these cultivars. A remark to be drawn from this test is that it was performed quite late in the season. This might be the reason for the drawback in consistency of the berries. A similar test performed at the start of the harvest would have confirmed or rejected this.

6. Conclusions and further investigations

The results of this study have given increased insight into the production-ready strawberry plant production in Norway. Varying results were obtained with the methods used. The plants that were raised and propagated in Oppland achieved the highest yields and so it seems that raising temperature and fertilization as the plants enter a generative stage increases total yield per plant.

So far, the method seems to be best adapted for 'Korona'. However, due to excess flowering, the berries were too small. Therefore, the method needs to be further developed to see if a larger plant, a longer SD treatment, or higher fertilization concentration pulse for a longer period may give a better result.

For 'Nobel' and 'Saga', the results were not satisfactory, as plants did not reach the expected large yield potential using the same method as for 'Korona'.

As cultivars differ in their temperature x photoperiod response as signals for phase changes, floral initiation occurs at different times. Knowing this, the method applied must be adjusted accordingly. As the point of this method is to raise temperature (15-18 °C) and fertilizer (EC 3) as the plant initiates flowers, it is crucial to know the timing when this occurs for each plant/cultivar. The only way to know for sure is to perform a dissection of the apical meristem. This should be done with selected plants for each specific cultivar.

The results from the chemical analyses display good berry quality in late ripening fruits of all cultivars tested, even in a late growing season. The plants received less light towards the end of the experiment. However, this did not seem to have an impact on the quality of the berries. This implies that an extended season with good yield and berry quality is possible is Norway.

For further investigations, it could be valuable to elongate the period of elevated temperature as well as fertilizer quantity (EC). It would also have been interesting to test imported plants together with Norwegian produced plants, as well, as it is these qualities these plants need to compete with in the market.

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