Journal of Berry Research 7 (2017) 179–194
DOI:10.3233/JBR-170155
IOS Press

Effect of plant type and delayed planting on growth and yield parameters of two short day strawberry (*Fragaria x ananassa* Duch.) cultivars in open field

Rolf Nestby* and Anita Sønsteby
NIBIO-Norwegian Institute of Bioeconomy Research, Ås, Norway

Received 2 November 2016; accepted 16 March 2017

Abstract.
BACKGROUND: It is questioned if Norwegian nurseries can compete with the continental nursery industry in an open market.
OBJECTIVE: Investigated how quality of certified Norwegian strawberry transplants, developed and yielded from planting to first cropping year.
METHODS: Plant qualities of Norwegian fresh and cold stored bare root- and plug-plants of 'Korona' and 'Sonata' were examined for establishing and yield parameters in the open, after three intervals of planting. Fresh plug-plants were delivered when available. Trials were established at NIBIO Research Station Kvithamar, Norway. Growth and yield parameters were registered in the establishing and cropping years.
RESULTS: Plant establishment was poor in 2013 compared with 2014. Bare-root plants stored at 2–4°C generally developed poorly. Plug-plants established well at all delivery dates, except fresh plug in one year. Development of runner plants depended on plant type, cultivar and year. Plug- and bare root-plants planted immediately after first delivery generally developed best crowns. Primary flower primordia reached a more developed stage for 'Sonata' than for 'Korona'. Fruit yield of bare root was low in the establishing years. Plant-types differed in yield and fruit weight between cropping years.
CONCLUSIONS: Bare-root and plug- plants planted one day after delivery generally yielded best. Storage of bare-root plants generally reduced yield. Fresh plug plants had low yield when planted late. Fruit yield of A15 and A13 in the establishing year was not satisfactory.

Keywords: Plug plants, bare-root plants, plant storage, crown parameters, stolon

1. Introduction

The quality of transplants used for establishment of grower's field is of high importance [1, 2]. In Norway, until year 2015, when the borders were opened for import of strawberry plants, transplants had to be propagated in Norway under a strict control regime to avoid virus, pest and disease infection of plants. This situation reduced the availability of transplant types for Norwegian growers compared to growers of other European countries. Also, the production of advanced ready-to-flower planting material with an established yield potential, has proven

*Corresponding author: Rolf Nestby, NIBIO-Norwegian Institute of Bioeconomy Research, 1431 Ås, Norway. Tel.: +47 9598 8530; Fax: +47 7482 2008; E-mail: rolf.nestby@nibio.no.

difficult to produce on a reliable and regular basis in Norway, because of marginal climatic conditions [3]. Before 2015, available plant types in Norway were bare-root plants lifted directly from the field with a mixed crown size generally below 15 mm, and overwintered plug plants for early spring delivery, or fresh plug plants for late delivery in the planting year.

It has been shown in short day strawberry that in A-grade transplants with crown diameters 10–20 mm, yields were directly related to crown diameter [4]. Later, several authors have shown that increasing crown diameter from 6 to15 mm led to more flowers and higher yield and increased leaf area and ascorbic acid content in the fruit [2, 5–7]. However, in the cooler climates of the Nordic countries, where the transition to inductive short day conditions is delayed compared with lower latitudes, even plants with large crown diameter has not given plants with satisfactory flowering and yield potential (Sønsteby, unpublished results). A similar effect was demonstrated between Scotland and the south of England. [8].

Besides, in a two year harvest cycle, which is normal for short day cultivars in the Nordic countries, the fruit yield is dependent on planting date in the vegetative year to develop a full yield potential in the first fruiting year. In addition, the planting date for developing a full yield potential is cultivar dependent [9]. Early planting will also lead to more runners [10], and improved yield and berry size in the first cropping year [11]. In autumn, floral initiation and differentiation is depending on temperature, photoperiod and cultivar. It is well documented that flowering is controlled by a pronounced interaction of photoperiod and temperature, with short days of 10–12 h length and temperatures of 15–18°C being optimal for flower initiation [12–14]. The importance of warm temperatures also during the flower differentiation period was demonstrated by Le Miére et al. [15] who reported that elevated temperatures (18.3°C vs. 14.8°C) during flower differentiation doubled the number of flowers in the secondary and tertiary inflorescences of 'Elsanta' strawberry. In Norway, the optimal temperature for flower development in 'Korona' and 'Sonata' was estimated to18°C, and 15–18°C for three other cultivars [16, 17]; conditions which can be a challenge to obtain under Norwegian conditions depending on cultivar, year, altitude and longitude. Bochud [18], also showed that plant types differed in overwintering capacity; fresh runner plants overwintered better the following winter even though they were planted later than the cold stored runner plants. For frost susceptible cultivars, cold stored runner plants should be avoided. However, plants of 'Korona' lifted in December and cold stored at –2.0°C, gave better yield than fresh lifted plants when planted 27 June, while fruit quality improved when planting was postponed to 11 July. Also, 'Elsanta' and 'Bogota' gave highest yield using fresh lifted plants [19]. The reproductive induction of bare root transplants is also dependent on growing conditions like fertilization, time of planting and other conditions that influence the growth rate of the apex [20].

These experiments were initiated to investigate how certified Norwegian strawberry plants of different qualities, planted immediately after lifting or delayed planting after cool storage at the farm, developed and yielded in a single crop cycle (planting year and crop year); with a view to similar plant types propagated in Central Europe.

2. Material and methods

Transplants were delivered from a nursery situated in southwest Norway (58°19′N, 8°13′E). This area is much earlier and with lighter soil than the research site in Mid-Norway. The field where the bare-root plantlets where lifted, and where runner plants started to root in June/July, was covered with fleece in late autumn to secure good over-wintering. The fleece was removed in spring when snow had melted or the eventual frozen soil had thawed. Immediately after lifting, the bare root transplants were cooled down to 3°C, before transport to the planting site. The August potted runner transplants were stored outdoors covered with several layers of fleece during winter to avoid freezing injury.

Two field trials with 'Korona' and 'Sonata' were planted in 2013 and 2014 with eight and ten plant-types, respectively (Table 1). The trials were planted at NIBIO's research station Kvithamar in Mid-Norway (63°46'N; 11°16'E) in open field on a silt clay loam. The plants were planted on raised beds covered with brown polyethylene

Table 1
Plant types, management of plant types (B = bare root; P = plug; Pf = Plug of the year; A = Large bare root) and planting dates in field in two years in Norway

Plant type	Management	Planting Date (dd.mm) 2013	2014
B1	Early lifting and planting within two days	22.05	07.05
B2	Late lifting and planting within two days	Not applied	14.05
B3	Later lifting and planting within two days	Not applied	21.05
B7	Lifted similar to B1, and cold stored 7 days before planting	Not applied	14.05
B14	Lifted similar to B1, and cold stored 14 days before planting	04.06	21.05
B28	Lifted similar to B1, and cold stored 28 days before planting	18.06	
A[a]	A15 and A13; lifting and planting similar to B1	22.05	07.05
P1	Plug overwintered; planted at same date as B1	22.05	07.05
P2	Plug overwintered; planted at same date as B2	29.05	14.05
P3	Plug overwintered; planted at same date as B3	04.06	21.05
Pf	Plug of the year; planted as soon as available (Fresh plug)	26.06	28.07

[a]diameter ≤15 mm in 2013 and diameter ≤13 mm in 2014.

mulch equipped with drip irrigation. At planting, plots were watered manually with a sprinkler can, for two weeks, when necessary. We fertilized with 50 g m^{-2} of a multi mineral fertilizer (YaraMila Fullgjødsel 12-4-18 micro™, YARA Norway) before bedding and mulching, which is standard recommendation for a silt clay loam in the region. In September of the planting year and in the cropping year of each of the two field trials we fertilized by fertigation. We used two nutrient stock solutions (7.5 kg YaraLiva™ Calcinit per 100 l of water and 7.5 kg per l of Kristalon™ Indigo per 100 l of water) in September in the planting year and in May and June in the cropping year. In July and later in the cropping year, we changed the solution of Kristalon™ Indigo to 9.0 kg per 100 l of water to balance the nutrient solution to a generative plant development stage. In the planting year fertigation in September was equivalent to 0.2 g N m^{-2}. The amount of fertilizer in the cropping year was equivalent to 6 g N m^{-2}, giving 3.5 g from two weeks before harvest and during harvest. Planting was on 20 cm high bed in double row 20 cm apart, with 25 cm plant space. The distance between bed-centres was 150 cm, equivalent to 5.33 plants m^{-2}. Weed, disease and pest protection were done according to standard recommendations for the region.

Each trial was a block design with four replications. Each cultivar occupied two blocks by random. The plant-type treatments were random within each block. Plot length was 2.25 m, and 1.50 m of the plot centre was harvested (12 plants). The extra border plants were available for lethal harvest.

Because of late spring and frozen soil in 2013, plant delivery was delayed, and the first delivery of bare-root and plug transplants (B1, A15 and P1) was 22 May. Late thawing of the soil and cold weather after thawing, gave sub-optimal conditions at the research site as well. However, transplants were planted according to the schedule shown in Table 1. Early lifted bare root plants (similar to B1) B14 and B28, were planted after 14 or 28 days of cold-storage at 2°C, respectively. There were a few changes in trial 2 (2014) compared with trial 1 (2013). B2 and B3 were delivered and planted at delivery date 7 and 14 days later than B1 (7 May), respectively; some plants of B1 delivered was planted as B14 after 14 days of storage at 4°C, twelve days earlier than the latest planting (Pf) in trial 1. A new treatment B7 was introduced; delayed planting till after 7 days of storage at 4°C. Fresh plug plants (Pf) was delivered and planted 32 days later in 2014 than in 2013.

Recordings on plant survival and runner parameters in the planting year were undertaken in both fields in September. In October 24, crowns from four plants per treatment were examined for floral development stage of the primary flower, according to the six-stage scale used by Heide [14] and Opstad et al. [16]:

Stage 1 = Vegetative apex with only leaf primordia.

Stage 2 = Sepal primordia visible in terminal flower.

Table 2
Effect of plant type and storage on plant establishment in % of full establishment, as a mean of two cultivars recorded in early September 2013 and 2014. B = Bare root; P = Plug; Pf = Fresh plug; A = large Bare root, of diameter ≤15 mm in 2013 and ≤13 mm in 2014

Plant type	Establishment (%)		
	2013	2014	Mean
B1	89.6	100.0	94.8
B2	–	95.8	95.8
B3	–	100.0	100
B7	–	97.9	97.9
B14	48.8	2.5	25.5
B28	27.1	–	27.1
A	91.7	97.9	94.8
P1	100.0	95.8	97.9
P2	95.8	97.9	96.9
P3	–	95.8	95.8
Pf	97.9	83.3	90.6
Mean	78.3	86.7	82.5
Se	17.1**	3.5***	8.4***

ns,*,**,***indicate levels of no, 5%, 1% and 0.1% significance, respectively.

Stage 3 = Petal primordia visible in terminal flower.
Stage 4 = Stamen primordia visible in terminal flower.
Stage 5 = First carpel primordia visible in terminal flower.
Stage 6 = All flower parts differentiated.

For bare root A-plants (A15 and A13), fruit yields were recorded both in the planting year and in the following year. All other plant types were harvested the year after planting, only. For these plant types flower stalks were removed in the planting year.

For statistics, tables and graphs SAS procedures were used [21].

3. Results

3.1. Plant establishment

Since there was no significant interaction between plant-type and cultivar concerning plant establishment, an average of the two cultivars is presented in Table 2. The first planting date in 2013 was one day after lifting for both bare root plants and plug-plants (Table 1). The plant establishment was close to or higher than 90% for B1, A15, P1, P2 and Pf. Bare root plants stored at 2°C for 14 or 28 days before planting had poorer establishment than the other treatments. Especially 'Korona' stored for 28 days was decayed, while most 'Sonata' plants survived (data not shown). In 2014, B14 and Pf had poorer establishment than the other plant-types. Storage for 14 days gave poorer establishment than in 2013, probably because the storage temperature was 2°C higher. Again the establishment of 'Korona' was much poorer than for 'Sonata'. Lifting of bare root plants B2 and B3 was undertaken in 2014, but not in 2013, and the establishing was similar to B1. Storage for seven days at 4°C, gave a good result (Table 2). All plug plants established well. However there was poorer establishment for Pf, probably because of warm and dry weather during planting and the following two weeks.

Table 3
Development of runners per plant (R/p) and propagules per runner (Pg/r) as an effect of plant type and storage for two strawberry cultivars in in late September in the establishing years. B = Bare root; P = Plug; Pf = Fresh plug; A = large Bare root of crown diameter ≤15 mm in 2013 and ≤13 mm in 2014

Plant type	2013				2014			
	'Sonata'		'Korona'		'Sonata'		'Korona'	
	R/p	Pg/r	R/p	Pg/r	R/p	Pg/r	R/p	Pg/r
B1	6.66	0.79	10.37	0.88	8.13	2.03	13.29	2.35
B2	–	–	–	–	12.07	1.48	9.88	2.50
B3	–	–	–	–	9.88	1.35	15.13	2.37
B7	–	–	–	–	7.83	1.41	8.96	2.37
B14	4.73	0.70	1.67	0.60	0	0	0	0
A	5.54	0.53	7.63	0.60	12.14	1.40	9.96	2.36
P1	5.09	0.85	10.50	1.00	17.08	1.25	26.32	1.90
P2	4.75	0.58	8.77	1.02	13.08	1.36	16.83	1.98
P3	–	–	–	–	11.56	1.72	15.83	1.88
Pf	2.09	0.81	4.38	0.63	0	0	0	0
Mean	4.76	0.68	6.53	0.68	10.20	1.33	13.27	1.97
Se	0.49^{**}	0.10^{ns}	0.93^{**}	0.11^{**}	1.67^{**}	0.15^{***}	2.10^{***}	0.15^{***}

^{ns,*,**,***}indicate levels of no, 5%, 1% and 0.1% significance, respectively.

3.2. *Runner development*

Plant type, cultivar and year had influence on runner development, and there was interaction between plant type and cultivar considering number of runners per plant (R/p) and number of propagules per runner (Pg/r) for each establishing year. The main effects of R/p and Pg/r were significant, except for Pg/r for 'Sonata' in 2013 (Table 3). A striking effect was the large differences between the two years, with much poorer development in 2013 than in 2014. In 2013, R/p and Pg/r as an average for all plant types, were half the amount or less than in 2014, for both cultivars.

In 2013, R/p for 'Korona' was highest for B1, A15 and P1 and lowest for B14, P2 and Pf. Pg/r followed the same pattern to some extent, and were highest in P1,Pf and B1 and lowest in A15 and P2. 'Sonata' acted differently and had the highest R/p in B1 and P1, while Pf had the lowest number. Pg/r in 'Sonata' was highest in P1 and P2 and B1 and lowest in A15 and B14 and Pf. Plants of B28 died during storage or shortly after planting, resulting in no runners (not tabulated). The average of Pg/r was similar for the two cultivars in 2013, while 'Korona' produced more runners than 'Sonata.

In 2014 the highest number of runners per plant for 'Sonata' was on plant type P1, P2, P3, B2 and A13, while B1 and P3 had the highest numbers of propagules per runner; B14 and Pf developed no runners and Pg/r. 'Korona' developed in average of plant types, more runners per plant than 'Sonata', similar to 2013. Bare-root plants of 'Korona' developed the highest number of runners on B1 and B3, but the numbers were highest for P1. The bare-root plant types developed more Pg/r than the plug plants. However, B14 and Pf plants developed no runners or propagules, similar to 'Sonata'.

3.3. *Crown-development*

There was a trend in 2013, that the 'Sonata' B14 plants had crown diameter a little larger than P1 and larger than A15, B1, P2 and Pf (Fig. 1). There were small differences between number of crowns per plant and number

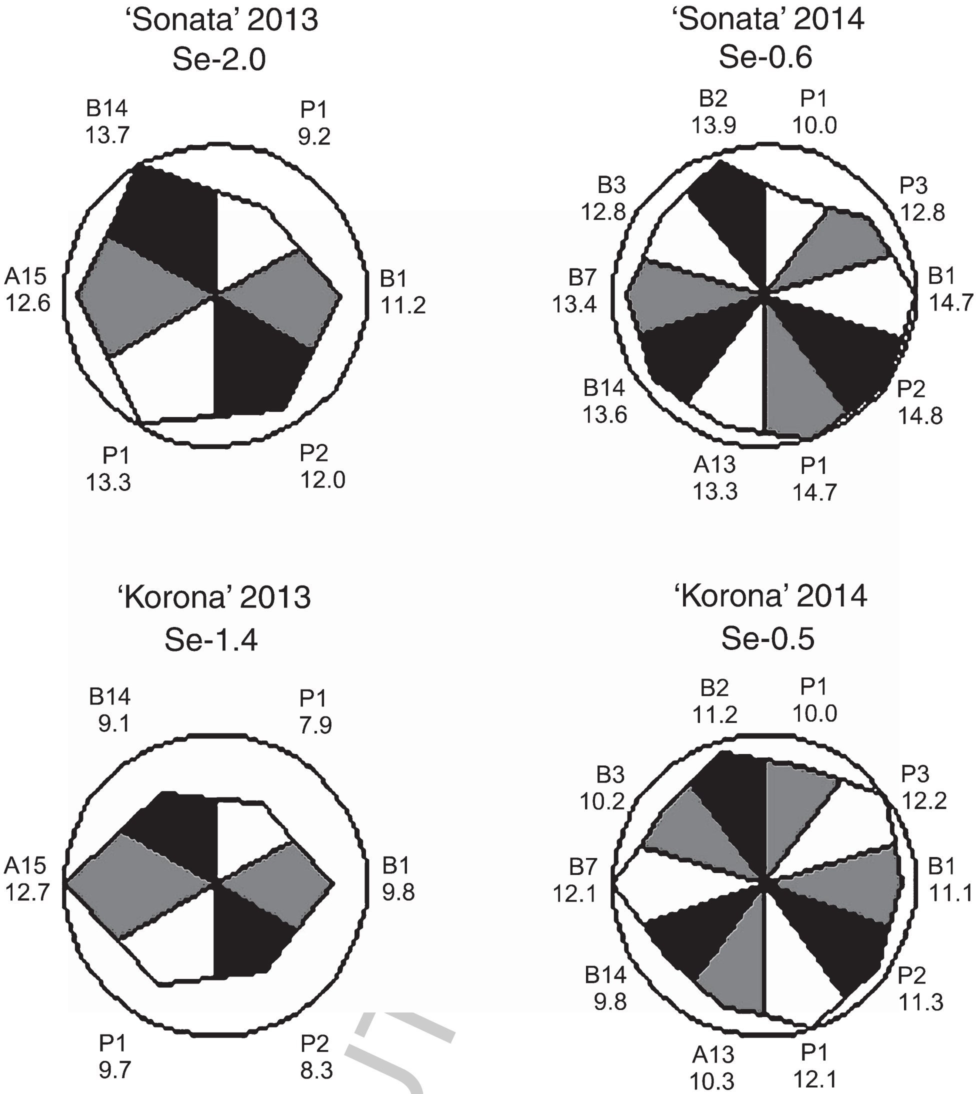

Fig. 1. Mean crown diameter (mm) and standard error (Se), for plant types of two short day strawberry cultivars in October of two establishing years. B = Bare root; P = Plug; Pf = Fresh plug; A = large bare root (≤13 or ≤15 mm crown diameter in 2014 and 2015, respectively).

of leaves per crown (Table 4). 'Korona' had as a trend largest crowns for A15. The plant types B1, P1 and B14 had approximately 3 mm smaller crown diameters than A15, while P2 and Pf had the smallest crowns. However, as a trend B1, P1 and P2 had more crowns than A15, while B14 had only one crown per plant.

In 2014, P2, P1 and B1 of 'Sonata' had largest crowns closely followed by B2, B7 and B14 and A13 (Fig. 1). Crowns of P3 and B3 had approximately 1 mm smaller diameter, while Pf had the smallest crowns. There was a trend that plug plants had higher crown numbers than bare root plants except for B7 and B14; Pf had one crown per plant. For 'Korona', P3, B7 and P1 had the largest crowns, while A13 and Pf had the smallest. The Pf plants were planted nearly 3 months after B1, A13 and P1, and had 4.7 mm and 1.1 mm smaller diameters than B1 of 'Sonata' and Korona', respectively. There were some differences in number of crowns in 'Korona' (Table 4),

Table 4

Effect of plant type and treatment on average crown number (Cn) per plant and number of leaves (Ln) per crown in October, for two cultivars in two years. B = Bare root; P = Plug; Pf = Fresh plug; A = large bare root;[a] diameter ≤15 mm in 2013 and ≤13 mm in 2014

Type	2013				2014			
	'Sonata'		'Korona'		'Sonata'		'Korona'	
	Cn	Ln	Cn	Ln	Cn	Ln	Cn	Ln
B1	2.8	4.9	3.1	6.6	2.4	7.7	3.3	8.0
B2	–	–	–	–	2.0	8.7	3.5	7.5
B3	–	–	–	–	2.4	7.7	3.4	7.3
B7	–	–	–	–	3.0	7.8	4.7	7.6
B14	2.3	6.3	1.0	6.3	3.0	7.8	4.7	7.6
A[a]	2.5	6.2	2.5	8.5	2.5	7.9	2.5	7.6
P1	2.8	6.3	3.8	6.3	3.1	7.8	3.4	8.1
P2	2.5	5.3	4.1	5.8	2.6	7.7	4.6	7.9
P3	–	–	–	–	3.3	7.1	3.1	8.1
Pf	2.1	5.0	3.4	4.3	1.0	6.0	1.0	6.0
Mean	2.4	6.0	2.6	6.3	2.5	7.6	3.4	7.5
Se	0.3^{ns}	0.8^{ns}	0.5^{ns}	0.7^{ns}	0.6^{ns}	0.5^{ns}	0.5*	0.3*

^{ns,*,**,***}indicate levels of no, 5%, 1% and 0.1% significance, respectively.

and B7, B14 and P3 and P1 had the highest numbers, while Pf had only one crown per plant. There were small differences in number of leaves per crown, but Pf had fewest leaves per crown.

Development stage of the primary flower revealed differences between years. The floral development stage was on average 3.3 on 24 October 2013, but 4.1 on the same date in 2014. There was a treatment x cultivar interaction, but no significant difference between cultivars in 2013, but a difference in 2014 (Fig. 2).

In 2013 B1, P2 and Pf of 'Korona' had poorer development than all other treatments. B28 did not develop any crowns in 2013 and the good development of B14 is a result of poor establishment giving better growth conditions for the remaining plants (Table 2). A15 and P1 had had best development for 'Korona'. For 'Sonata' B1, B28, A15, P1 and Pf had the highest flower stage development, while B14 and P2 achieved a lower development stage.

In 2014 B14 of 'Korona' did not survive the storage and was not planted, and as a result of that had zero crowns. All other plant types except B7 and Pf reached a development stage close to 4.5, which mean that some of the eight crowns per treatment had development stage 5 (Sepal primordia elongated). For 'Sonata', B1, B3, B7 and A13 had the most developed crowns, while B2, P2 and Pf had the poorest development of the plant types. Pf reached only a vegetative growth stage, most likely because it was planted one month later then in 2013.

3.4. Fruit yield of bare-root transplants A15 and A13 in the planting year

'Sonata' A15 tended to give larger total yield and had larger fruit-weight than 'Korona' A15 in 2013, and the percentage of berries larger or equal to 35 cm diameter was higher for 'Sonata' than for 'Korona' and the opposite for the grade below (Table 5). However, fruit weights were generally low. The percentages of discarded fruit were about equal for the two cultivars, and a little more than 30%. A relative large part of the yield for both cvs was misshapen fruit. One medium strong to small inflorescence was developed per plant (Fig. 3). In 2014, the fruit yield was lower than in 2013. However, the plant type classified as A13 was smaller than in 2013. Similar as to 2013, 'Sonata' had higher fruit yield than 'Korona', but yields were generally very low. However, there was no difference in fruit weight, although it was also low. Sorting in fruit size classes revealed no differences

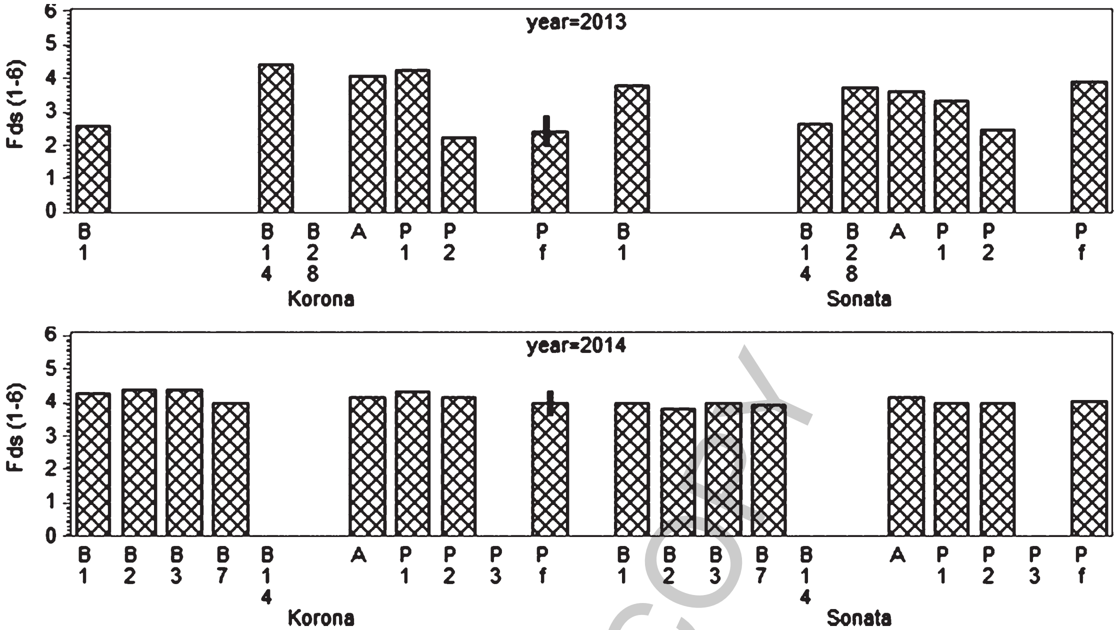

Fig. 2. Development stage of primary flower in the apex in different plant types of 'Korona' and 'Sonata' 24 October 2013 and 2014. The standard error bar can be used comparing plant types within and between cultivars. B = Bare root; P = Plug; Pf = Fresh plug; A = large bare root (≤13 or ≤15 mm crown diameter in 2014 and 2015, respectively).

Table 5

Total strawberry fruit yield of two cultivars (kg m^{-2}), marketable yield (Mark) and different size classes in %, and fruit weight (g $fruit^{-1}$) in the planting years 2013 and 2014, for A15 and A13 respectively

Cv	Year	Yield Total	Mark	>35	35–30	30–25	25–22	<22	Fw
Sonata	2013	1.21	67.5	22.2	22.3	18.2	4.3	0.5	14.1
Korona		0.48	69.4	11.7	37.1	18.5	1.2	0.9	12.4
Mean		0.85	68.5	17.0	29.7	18.4	2.8	0.7	13.2
Se		4.6^{ns}	6.8^{ns}	2.6^{ns}	4.1^{ns}	8.6^{ns}	0.2*	0.6^{ns}	0.2*
Sonata	2014	0.42	89.3	45.5	31.2	7.0	3.2	1.5	12.3
Korona		0.21	74.1	20.5	12.8	20.8	7.4	11.3	12.0
Mean		0.31	81.7	33.0	22.0	13.9	5.3	6.4	12.2
Se		0.05^{ns}	2.1^{ns}	11.7^{ns}	8.5^{ns}	5.0^{ns}	1.6^{ns}	5.0^{ns}	3.7^{ns}
Sonata	Mean	0.81	78.4	34.3	26.7	12.6	3.8	1.0	13.2
Korona		0.34	71.8	16.1	25.0	19.7	4.3	6.1	12.2
Mean		0.58	75.1	25.2	25.9	16.2	4.1	3.6	12.7
Se		0.11*	4.8^{ns}	6.0^{ns}	4.7^{ns}	4.9^{ns}	0.8^{ns}	2.5^{ns}	1.8^{ns}

^{ns,*,**,***}indicate levels of no, 5%, 1% and 0.1% significance, respectively.

between cultivars. There were, however, a significant or close to significant interaction for cultivar vs. year for all classes. In average of the two years, 'Sonata' had higher yield than 'Korona'.

Fig. 3. Open field flowering in 2013 of ‘Sonata’ bare root A15 plants in Mid–Norway. Photo: Rolf Nestby.

3.5. *Effects on fruit yield of plant-types and delayed planting the year after planting*

Fruit yield the year after planting, was recorded for trial 1 in 2014 and for trial 2 in 2015. There was a striking difference in yield and fruit weight between the years. Trial 1 had lower fruit yield and fruit weight than normal, while trial 2 developed normally. Additionally, there was a significant plant-type vs. year interaction for total yield and fruit weight.

In 2014, there was no difference in total yield between treatments for ‘Sonata’, though B28 tended to have lower yield and larger fruits than the other treatments; ‘Korona’ plant types B1, A15 and Pf yielded more than the other plant types, while the stored plants B14 and B28 had no yield (Table 6). In 2015, ‘Sonata’ B14 yielded less than all other treatments; Pf yielded more than B14, but lower than the other treatments. Plants stored for 7 days (B7) had good yield compared to B14 and Bf, and had larger fruits, but lower yield than B1, B2, A13, P1, P2 and P3. In ‘Korona’, B14 had no yield, while B7 with seven days shorter storage, had similar yield as P1, P2 and P3, but could not be significantly separated from B1. For ‘Korona’, as for ‘Sonata’, Pf had lower yield than all other plant types except for B14.

4. Discussion

In a situation where Norwegian nurseries since 2015 have had to compete with imported strawberry transplants from mainly The Netherlands, it is detrimental for the success of the Norwegian nursery industry that they can produce high quality transplants of cultivars wanted by the growers. The plant quality of bare root and plug transplants of Norwegian origin were evaluated in two years, and it was shown that a good establishment was dependent on the freshness of especially bare-root plants. The bare root transplants in these trials were delivered the day after lifting. When the plants were planted the same day as they arrived, within a timespan

Table 6

Effect of strawberry plant type on total and marketable (Market) fruit yield in kg m^{-2} and fruit weight (Fw) in g fruit^{-1} in two years, of two short day strawberry cultivars grown in open field in Norway. B = Bare root; P = Plug; Pf = Fresh plug; A = large bare root (≤13 or ≤15 mm crown diameter in 2014 and 2015, respectively)

Plant type	Year	Cultivar					
		Sonata			Korona		
		Total	Market	Fw	Total	Market	Fw
B1	2014	0.59	0.43	15.6	0.70	0.67	13.6
B14		0.40	0.36	15.6	0.00	0.00	–
B28		0.29	0.27	17.1	0.00	0.00	–
A15		0.55	0.48	15.2	0.70	0.62	14.0
P1		0.50	0.44	13.7	0.45	0.39	16.6
P2		0.51	0.41	14.4	0.46	0.40	12.0
Pf		0.50	0.37	12.0	0.83	0.69	14.5
Mean		0.48	0.39	15.0	0.45	0.40	14.1
Se		0.12^{ns}	0.13^{ns}	1.3^{ns}	0.09**	0.10*	1.2^{ns}
B1	2015	1.81	1.55	22.3	1.99	1.70	17.8
B2		1.73	1.51	19.9	1.79	1.52	16.5
B3		1.67	1.37	17.9	1.76	1.42	17.7
B7		1.24	1.02	21.1	2.17	1.95	19.1
B14		0.15	0.12	29.1	0.00	0.00	–
A13		1.84	1.53	22.9	1.87	1.62	16.3
P1		1.80	1.61	19.8	2.17	1.80	18.4
P2		1.88	1.58	21.8	2.09	1.84	16.5
P3		2.23	1.96	20.1	2.19	1.94	17.3
Pf		0.46	0.35	14.6	1.21	0.88	16.1
Mean		1.48	1.26	20.5	1.72	1.45	17.4
Se		0.13***	0.14***	1.6**	0.29*	0.25*	1.7^{ns}
Mean$_{2y}$		1.01	0.83	14.7	1.09	0.93	14.4
Se$_{2y}$		0.12***	0.06***	1.2^{ns}	0.11*	0.10*	1.17**

^{ns,*,**,***}indicate levels of no, 5%, 1% and 0.1% significance, respectively.

of lifting dates of three weeks in May, the establishment varied from 90% in 2013 to 96–100% in 2014. The poor establishment in 2013 vs. 2014 was because soil conditions at the planting site were not ideal due to late spring with frozen soil into May (Table 7). In 2014 the situation was different with a soil of good structure. In a situation like this where the nursery is situated at a much earlier location than the planting site, it is necessary that the nursery delays the lifting of transplants until the planting conditions are optimal. The experiments also showed that transplants could be stored at 4°C for 7 days by the grower without loss of yield for 'Korona' while 'Sonata' was down in yield. Storage for 14 and 28 days even at 2°C reduced the quality of transplants strongly, because of rot, and more for 'Korona' than for 'Sonata'. The plug plants had a much larger buffer and had good establishment (96–100%) at all planting dates in a time span of three weeks from delivery to planting, for both cultivars.

The bare root transplants delivered in 2013 were sorted in A15 and in a mix with smaller crown diameters (5–14 mm). In 2014, all bare root plants were delivered as a mix of crown sizes, and the largest size A13, was sorted at the research site, as well as a mixed grade (5–12 mm) for all other bare-root plant types. This is not beneficial since it is shown that the crown diameter has large influence on fruit yield. A regression analysis

Table 7
Mean temperatures in °C at NIBIO Kvithamar Research Station, Mid-Norway

Month	Year		
	2013	2014	2015
January	–3.9	–1.6	0.4
February	–2.9	4.3	1.9
March	–2.9	3.6	3.9
April	4.0	6.1	4.9
May	12.5	10.0	8.4
June	13.3	12.8	10.3
July	14.7	19.5	13.4
August	14.4	15.6	17.1
September	11.3	11.7	–
October	6.4	8.1	–
November	2.6	3.6	–
December	2.9	–0.1	–

of yield components versus initial crown diameter revealed a positive relationship between total fruit numbers produced per plant and initial crown size for two cultivars. Also total weight of marketable fruit produced per plant was positively associated with initial crown diameter of transplants [5]. Later it was shown that a mix of crown diameters larger than 10 mm resulted in 23% higher yield on average over two seasons than a mix of bare root transplants with crown diameters below 10 mm [7]. Also crown diameters 5–8 mm and 8–12 mm were compared, and the group with larger diameters had the highest increment of leaf area, total yield and ascorbic acid in the fruits over two seasons [6].

4.1. Runner development

The number of runners of all plant-types was about the double in 2014 than in 2013, and similar for the number of propagules per runner (Table 3). The reason for this could be the cold winter 2012/2013 at the transplant production site, which had the following number of days with minimum temperatures below –10.0°C [22]:

Month	Days	Temperature range °C
December	7	–11.2 to –16.9
January	10	–10.3 to –18.8
February	6	–10.7 to –14.2
March	5	–10.4 to –12.7

The lowest temperature in April was –8.2°C (1 April). In addition, the minimum temperatures in the winter period were rarely above zero degrees before 15 April. These freezing conditions could have caused injury of the transplant crowns and roots and reduced crown growth and development of runners in the summer season of 2013 [23]. Another factor that would increase number of runners in 2014 compared to 2013 was the high July and August temperatures in 2014 (Tab. 7). Conditions that would stimulate formation of runners [14].

Additionally, the soil conditions at the planting site in 2013 were not optimal for establishment and growth of the transplants. The plant type of 'Sonata' that developed most runners in 2013 was B1, while Pf developed the fewest runners. The situation was similar for 'Korona', except that B14 had very few runners, but the cultivar had more runners than 'Sonata'. In 2014 the situation was different. Both cultivars developed much more runners than the year before, but 'Korona' still more than 'Sonata' except for the B2 and A13 plants. 'Korona' had more propagules per runner than 'Sonata', except for B14 and Pf in 2013. For B14 probably because 'Korona' B14 was more weakened during storage than 'Sonata' B14. The post-delivery stored transplant B14 did not develop any runners in 2014 for either cultivar, probably because they were weakened during the storage period which was 2°C warmer than in 2013.

4.2. Crown development

There were differences between transplant types of 'Korona' and 'Sonata' in crown development at the end of the first growing season. In 2013, average crown size of plants developed from A15 of both cvs were equal and larger than for plants developed from B1which was planted at the same date. This is reasonable since transplants with large crowns are shown to give a better plant development evaluated by several parameters like leaf area, fruit yield etc. [4–6], and in this case the strong A15 transplants resulted in better plant development than the mixed standard of B1 transplants (6–14 mm). However, B1 of 'Sonata' developed better than similar transplants of 'Korona'. If the grower wants to delay the planting, our results in 2014 show that cold storage of bare root plants (2–4°C) for 7 days (B7) after lifting gave a good result for 'Korona' with good establishment after planting and development of a high number of crowns with large diameter at the end of the growing season. In average of treatments 'Korona' had smaller crowns than 'Sonata' but a higher number, especially in 2014. Some bare root transplants (B2 and B3) were lifted two or three weeks later than B1 in 2014. These plants developed just as well as B1. This indicates that if the grower knows that the planting will be delayed, it is a better option to ask for late delivery instead of storing the transplants at the farm. Late delivery of fresh plug transplants (Pf) like in 2014 when number of crowns was strongly reduced, indicates that fresh plug plants should be planted early in this region.

4.3. Flower development in the crown

'Korona' and 'Sonata' are both considered as facultative short day cultivars, meaning that flower initiation in principle starts when the day is shorter than 15 hrs at temperatures above 18–20°C, while at lower temperatures, some initiate flowers also in long day [24, 25]. The flower-inducing effect of short day is also highly temperature dependent, and at temperatures <12°C and >21°C floral induction is increasingly reduced also under short day conditions [25]. For the cultivars grown in the region of the research station, initiation normally starts in late August [16]. However, just as important as initiation is flower development that depends on temperature in September and October. It is shown that flower bud development increases with higher temperatures [26]. At the latitude of our trials the temperature in September and in October is a minimum factor for development of inflorescences, and was lower in 2013 than in 2014, especially in October (Table 7). Van Delm et al. [27] planted runner tips of 'Elsanta' on 23 July for growing tray plants in Belgium. This is at least a month later than in our experiments (except for plant type Pf in 2014) using bare-root plants, and the apical meristem was visible 8 September. On 6 October the apical inflorescence turned into development stage 7. This is much higher than in our experiments, where crowns were examined 24 October, indicating that 'Elsanta' is better adapted to a Belgian climate, when it concerns flower initiation and differentiation, than our 'Sonata' and 'Korona' plants, showing a higher yield potential in late autumn. Therefore, to be able to compete with imported tray plants and waiting bed plants, Norwegian propagators needs to develop a system to improve climate (increase temperature) in autumn [3, 28].

4.4. Yield of A15 and A13 plants

The influence of differences in crown size between A plants in 2013 and 2014, is reflected in the yield of A15 and A13 bare root plants (Table 5), with low yields and fruit weights especially for A13 (2014). Even if bare root transplants larger than A15 is produced in Norway with a security of annual delivery, the development of flower buds would be much slower than in Belgium, especially with obligate short day cvs like Korona and Elsanta. Even at the south part of Norway crowns with diameter larger than 15 mm is hard to produce without using artificial means (production in tunnels etc. to increase temperature). The field trials showed that we achieved a total yield in 2013 of more than a kilogram per m^{-2} (0.227 kg $plant^{-1}$) of ‘Sonata’, but only 40% of that for ‘Korona’, and the fruit weight was low. In 2014, the crown diameter was 13 mm and the difference between the cvs was much the same, but yields were disappointingly low; in spite that the average temperature for September and October in 2013 was 10.8°C compared to 9.2°C in 2012 [22], conditions that should favour (but still too cold for optimal development) better flower bud development in late autumn 2013 and higher yield in 2014. The low yield especially in 2014 was partly because the average fruit weight was low, but also because the plants produced only one small sized inflorescence per plant with 5–12 flowers (Fig. 3). Nurseries further south in Europe delivered A+ (11–13 mm) plants with approximate 18 flowers per plant and A++ (16–18 mm) with 43 flowers per plant [2]. At Norwegian nurseries they normally remove the first runners because they are few, and therefore produce transplants on later developing runners to secure a large crop of transplants that they sell as a mixed plant size. If they start to produce transplants from the first runners and move plants into polytunnels, it could be possible to deliver A+ plants or preferably A++ plants at a quality of interest to Norwegian growers. However, they would have to compete with a high quality plant from nurseries further south in Europe, delivering a defined transplant quality.

4.5. Yield influenced by plant-type treatment

In the traditional concept of growing short day strawberry plants, as in our experiments, with an establishing year and a cropping year, fruit yield parameters were influenced by year, plant-type and cultivar and there was interactions year vs. plant-type concerning total and marketable yield (Table 6). In trial 1 (2014), total and marketable yield were much lower than normal. Plant types of ‘Sonata’ did not react much different from ‘Korona’, except that the cold stored plant types B14 and B28 of ‘Sonata’ gave some yield in contrast to ‘Korona’ that did not yield any fruits, and had roughly 66.8% and 60%, respectively, of the yield compared with the other treatments. This is a result of poor plant establishment in 2013 especially of ‘Korona’ (Tables 2 and 6). And there was not a significant effect on fruit weight by treatment for both cvs. However, in ‘Sonata’, B28 tended to have the largest fruits, and the reason for this is probably that each plant had less competition than in a fully established plot; and Pf tended to have the smallest fruits probably because of a smaller crown diameter (Fig. 1). ‘Korona’ reacted differently and produced higher yields for B1, A15 and Pf than for the other plant-types, and higher yield than ‘Sonata’. The plug plants of ‘Korona’ yielded similar to ‘Sonata,’ except for Pf which had the highest yield in trial 1 for ‘Korona’ in spite of small crown diameter in the autumn of establishment (Fig. 1). The reason of the relative high yield of Pf is probably that Pf-transplants were healthy and without winter injury, the planting date 26 June was also early enough to secure a relatively high yield potential [23]. The relatively low yield of P1 and P2 plants is probably caused by freezing of the plants in spite several layers of fleece covering the plugs at the nursery during winter. The roots and the crown of the bare root transplants are better protected than for plug plants since they grow in soil and are covered by fleece. Freezing injury at the nursery in addition to poor planting conditions in 2013, are probably the reason of the low fruit weights.

In trial 2 (2015), the conditions for growth were normal, with the highest yields beyond two kg m^{-2} for both cultivars. For ‘Sonata’, plant type P3 gave highest yield, but with the data available it is not possible to fully understand the reason why it produced more than P1 and P2 in spite of later planting date and smaller crowns, but the number of fruits per m^{-2} was higher. The relatively low yield of plant-type Pf, however, must be related to the late planting and the small crown diameter (Table 1, Fig. 1), which is expected to give lower yield than earlier planting [23]. The three bare root transplant treatments B1, B3 and A13 had equal yields, but much higher than for B1 transplants stored for 14 days (B14). The reason is weakening of the plants and rotting at storage, and therefore poor establishment (Table 2). The bare root transplants stored for 7 days (B7) at 4°C established well, but yielded lower for 'Sonata' than all other bare root transplants except B14. It is obvious that storage even for seven days under the actual conditions is not recommendable for 'Sonata'. 'Korona' bare root transplants produced yields comparable to 'Sonata'. However, B14 produced no yield while B7 produced yields equal to or higher than mixed bare root transplants and A13. This suggests that 'Korona' could be stored for seven days at the given conditions without yield reduction. The Pf-transplants gave low yield, though not as low as for 'Sonata', but lower than for normally treated bare root and plug transplants because of late planting date. There were differences in fruit weight between 'Korona' plant types, and Pf, B2, A13 and P2 had the smallest fruits, while B7 and P1 had the largest fruits. The effect on Pf is explainable because of small crown diameter and P2 had many crowns competing which could explain reduction in fruit size. For 'Sonata', there was (because of a much larger variation within treatment than for 'Korona') low fruit weight of Pf plants and high fruit weight of B14. The effect on Pf plants is probably connected to relatively poor crown development shown by small crown diameter, few crowns per plant and few leaves per crown compared with the three other plug plant-types. (Tables 4 and 6, Fig. 1).

5. Conclusion

The survival of the Norwegian strawberry plant nursery industry in an open market situation is dependent on the plant quality that can be delivered. The practise in Norway of storing plug transplants outdoors covered by fleece is risky. In our experiments potential freezing temperatures in one of two years in the nursery, probably reduced the quality of plug plants and to some extent bare-root transplants. This weakened the establishment in the production field and the ability to develop a decent amount of flowers during autumn. In addition, a late spring with frozen soil at the production site, forced us to prepare the soil when sub-optimal, this added extra stress to the plants. To avoid this, plug transplants should be in controlled storage during winter to avoid freezing injury. This may be a challenge under Norwegian conditions, because of a potential long storage period weakening the plants [29]. The bare-root transplants should be graded in defined crown sizes at the nursery to secure uniform development of the production fields, and to make it possible to offer a differentiation in price. It was shown here that bare root A15 and A13 transplants can be developed at Norwegian nurseries situated in the best climate zones of Norway. However, to achieve better plant quality it is essential not to remove the early runners for bare root production which is the practice today, and to sort grade A+ or better A++ for special delivery. To secure good quality every year closer to the standard of nurseries further south in Europe, transplant production should be moved into polytunnels, although this will increase the nursing costs. We have shown that by using A15 and A13 transplants for harvest in the planting year, yield will not suffer in the second harvest year. Larger A plants could add an extra possibility for Norwegian growers.

When bare root transplants are established as fresh plants, they produce yield and fruit size at similar levels as plug transplants. In a situation of outdoor winter storage, which is normal in Norway, they yielded even better, at least for 'Korona'. However, except being more vulnerable for freezing injury by outdoor storage, the plug plant is a more secure transplant than bare root and can be stored for a long period before planting in the production field without reduction of yield, if watered and fertilized optimally. Unless they are planted later than early July in a region with similar growing conditions as our research site, they will produce a full yield. However, late planting in our climate will reduce plant crown and flower development in the establishment year, and thus reduce the first crop [9].

Storage of bare root transplants after lifting is risky, and storage at temperatures of 2–4°C was not successful even for a short time, except 7 days of storage for 'Korona'. The storage conditions could be improved by lowering the temperature closer to zero. But not many growers have such facilities available. It can be concluded that bare root transplants are a fresh product and should be treated like that.

Acknowledgments

This work was supported by the Norwegian Agricultural Agreement Research Fund/Foundation for Research Levy on Agricultural Products (grant number 225154/E40). The authors thank Product manager fruit and berries Tor Kjetil Kongsrud in NORGRO AS for important assistance in planning the field trials, and technicians Sigrid Alstad for thorough experimental field management and Unni M. Roos for investigations of the apical flower development stages.

Conflict of interest

None to report.

References

[1] Bartczack M, Lisiecka J, Knaflewski M. Correlation between selected parameters of planting material and strawberry yield. Folia Horticulturae. 2010;22:9-12.

[2] Massetani F, Neri D. Strawberry plant architecture in different cultivation systems. Acta Hortic. 2016;1117:291-6.

[3] Sønsteby A, Opstad N, Roos MU, Heide OM. Environmental manipulation for establishing high yield potential of strawberry forcing plants. Scientia Horticulturae. 2013;65-73.

[4] Wijsmuller J, Dijkstra J. Strawberries. Cold stored waiting-bed plants are also the best choice on peat bales. Groenten en Fruit. 1990;45:52-3.

[5] Johnson C, Raiford T, Whitley K. Initial crown diameter of transplants influences marketable yield components of two strawberry cultivars in annual hill production system. International Journal of Fruit Science. 2005;5:23-9.

[6] Ragab ME, El-Yazied AA, Al-Sherif M, Hassani NM, Mohamed HH. Response of cold stored drip-irrigated strawberry to root trimming and transplant crown diameter. Acta Hortic. 2012;926:431-4.

[7] Torres-Quesada EA, Zotarelli L, Whitaker VM, Santos BM, Hernandez-Ochoa I. Initial crown diameter of strawberry bare-root transplants affects early and total fruit yield. HortTecnology. 2015;25:203-8.

[8] Mason DT. Effects of initial plant size on the growth and cropping of the strawberry (*Fragaria x ananassa* Duch.). Crop Research. 1987;27:31-47.

[9] Nestby R. Effect of planting date and defoliation on three strawberry cultivars. Acta Agriculturae Scandinavica. 1985;35:206-2012.

[10] Lareau MJ, Lamarre M. Late planting of strawberries using bare root or plug plants. Acta Hortic. 1993;348:245-8.

[11] Hansen P. Summer planting of fresh runners of heavy-cropping strawberry cultivars. Frugt og bær. 1992;21:131-3.

[12] Darrow GM, Waldo GF. Responses of strawberry varieties and species to duration of the daily light period. US Department of Agriculture Technical Bulletin. 1934;453:1-31.

[13] Ito H, Saito T. Studies on the flower formation in the strawberry plant I. Effects of temperature and photoperiod on the flower formation. Tohoku Journal of Agricultural Research. 1962;191-2013.

[14] Heide OM. Photoperiod and temperature interactions in growth and flowering of strawberry. Physiologia Plantarum. 1977;40:21-6.

[15] Le Miére P, Hadley P, Darby J, Battey NH. The effect of temperature and photoperiod on the rate of flower initiation and the onset of dormancy in the strawberry (*Fragaria x ananassa* Duch.). Journal of Horticultural Science and Biotechnology. 1996;71:361-71.

[16] Opstad N, Sønsteby A, Myrheim U, Heide OM. Seasonal timing of floral initiation in strawberry: Effects of cultivar and geographic location. Scientica Horticulturae. 2011;129:127-34.

[17] Sønsteby A, Heide OM. Flowering performance and yield of established and recent strawberry cultivars (*Fragaria x ananassa* L.) as affected by raising temperature and photoperiod. Journal of Horticultural Science and Biotechnology. 2016. (submitted).

[18] Bochud P. Strawberry planting. Relative advantages of freshly-lifted and cold-stored runners. Revue Suisse de Viticulture, d'Arboriculture et d'Horticulture. 1983;15:213-6.

[19] Wijsmüller J. Cold-stored plants show promise. Fruittelt. 1988;78:22-3.

[20] SAS Institute Inc., Cary, NC, USA. NOTE: SAS (r) Proprietary Software 9.4 (TS1M3). Procedures GLM, GRAPH and Tabulate. 2012.

[21] Massetani F, Savini G, Neri D. Effect of rooting time, pot size and fertigation technique on strawberry plant architecture. Journal of Berry Research. 2014;4:217-24.

[22] NMI-Norwegian Meterological Institute. Free access to weather- and climate data. From historical data to real time observations. 2015; Web page: http://sharki.oslo.dnmi.no/portal/page?_pageid=73%2C39035%2C73_39049&_dad=portal&_schema=PORTAL

[23] Nestby R, Bjørgum R, Nes A, Wikdahl T, Hageberg B. Reactions of strawberry plants to long-term freezing and alternate freezing and thawing. Journal of Horticultural Science & Biotechnology. 2001;76:280-5.

[24] Guttridge CG. *Fragaria x ananassa.* In: *CRC Handbook of Flowering.* (Halevy, AH, Ed.). Volume III. CRC Press Inc., Boca Raton, FA, USA. 1985:16-33.

[25] Heide OM, Stavang JA. Sønsteby A. Physiology and genetics of flowering in cultivated and wild strawberries – a review. Journal of Horticultural Science and Biotechnology. 2013;88(1):1-8.

[26] Battey NH, Le Miére P, Theranifar A, Cekic C, Taylor S, Shrives KJ, Hadley P, Greenland AJ, Darby J, Wilkinson MJ. Genetic and environmental control of flowering in strawberry. In: Cockshull KE, Gray D, Seymore GB, Thomas B. (eds). Genetic and environmental manipulation of horticultural crops, CAB Innternational, Wallingford, UK. 1998.

[27] Van Delm T, Melis P, Stoffels K, Van De Vyver F, Baets W. Strawberry Plant Architecture and Flower Induction in Plant Production and Strawberry Cultivation. Acta Hortic. 2014;1049:489-97.avini

[28] Bosc JP, Neri D, Massetani F, Bardet A. Relationship between plant architecture and fruit production of the short-day strawberry cultivar 'Gariguette'. Acta Hortic. 2012;926:229-36.

[29] Lieten F, Kinet J-M, Bernier G. Effect of prolonged cold storage on the production capacity of strawberry plants. Scientica Horticulturae. 1995;60:213-9.