This is an Accepted Manuscript of an article published by Taylor & Francis in Acta Agriculturae Scandinavica, Section B — Soil & Plant Science on 14/12/2016, available online: https://doi.org/10.1080/09064710.2016.1261933

Phenology, flowering and yield performance of thirteen diverse strawberry cultivars grown under Nordic field conditions

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Running title: '*Phenology of strawberry cultivars in the North'*

Phenology, flowering and yield performance of thirteen diverse strawberry cultivars grown under Nordic field conditions

As part of an overall assessment of the commercial suitability of strawberry cultivars for the Nordic environment, we studied growth, flowering and yield performance of thirteen diverse strawberry cultivars in an experimental field at the Apelsvoll Experimental Center in South East Norway (60°40'N- 10°50'E, 250 m a.s.l.). The results are discussed together with practical experiences and market preferences in an attempt to provide overall cultivar recommendations for Norway. Early-maturing cultivars of Scandinavian origin, such as 'Glima', 'Zefyr', and 'Blink' and their common American progenitor 'Valentine' were characterized by early initiation of floral primordia and early flowering and fruit maturation, while the English cultivar 'Florence' was particularly late. High temperatures in July and early August delayed floral initiation in the early cultivars, resulting in more synchronous initiation of early and late cultivars. The recent Norwegian cultivar 'Nobel', which has an everbearing parent, differed from the other cultivars by early initiation also at elevated summer temperature. The recently released Norwegian cultivar 'Blink' had superior yield and earliness, but regrettably, failing market acceptance limits the promise of this cultivar. Inadequate yield and berry size were identified as important causes for outdating of older cultivars such as 'Senga Sengana' and 'Glima' and others. Over all, the high-yielding and large-fruited 'Sonata' was judged as the best fresh consumption cultivar in Norway, and market trends indicate that it will continue to expand its market share at the expense of 'Korona', mainly because of inadequate fruit firmness and shelf life of the latter. Adequate yields and berry quality justify the use of the late maturing 'Florence' for prolongation of the fresh market season.

Keywords: berry size and yield; earliness; floral initiation; *Fragaria*; phenology; strawberry

Introduction

The flowering physiology of the cultivated strawberry (*Fragaria x ananassa* Duch.) has been extensively researched and communicated (Guttridge 1985; Heide et al. 2013). Since the early work by Darrow and Waldo (1934) it has been known that flowering in seasonal-flowering (June-bearing) strawberry cultivars is controlled by a pronounced interaction of photoperiod and temperature. Generally, these plants are facultative short day (SD) plants, requiring SD at temperatures above approximately 18-20°C, while at lower temperatures they are more or less day neutral and flower also under long day (LD) conditions. However, both the critical photoperiods and the temperature thresholds for change of the photoperiodic mode vary greatly among cultivars (Ito & Saito 1962, Heide 1977), so that each cultivar has its own specific photoperiod x temperature response curve (Heide et al. 2013). The flower-inducing effect of SD is also strongly modified by temperature, so that at temperatures <12°C and >21°C floral induction is increasingly reduced also in SD (Heide et al. 2013). Furthermore, cultivars such as 'Abundance', 'Senga Sengana', 'Elsanta', 'Korona' and 'Sonata' behave as obligatory SD plants and do not induce flowering under LD conditions even after extended exposure to temperatures as low as 9°C (Sønsteby & Heide 2006) or 12°C Heide 1977; Sønsteby & Heide 2006; Verheul et al. 2006; Sønsteby et al. 2016b).

While the basic physiological responses to photoperiod and temperature is fairly well known for most cultivars grown commercially in Northern Europe (Heide 1977; Heide et al. 2013), their phenological performance and adaptation to the Nordic climate have received less attention. New cultivars are also steadily released, whose physiological responses are only superficially known. In order to provide more information on these issues as well as the yield performance in the Nordic environment, we have carried out a simple experiment with thirteen traditional and new cultivars of diverse origin in an experimental field in South East Norway. Because of the importance of earliness in the cool and short Nordic growing season, the earliness aspects of cultivar performance were given special attention. The results are discussed together with market preferences and experiences from commercial production in an attempt to provide overall cultivar recommendations for the Nordic environment.

Materials and methods

Plant material and growing site

The experiment was carried out in an experimental field at the Apelsvoll Experimental Center in South East Norway (60°40’N-10°50’E, 250 m a.s.l.). The thirteen cultivars used included the Scandinavian early-flowering ‘Glima’ and ‘Zefyr’ and the American ‘Valentine’ that has been an important progenitor of their early-flowering trait. Also the old German cultivar ‘Senga Sengana’ and the traditional Dutch cultivars ‘Elsanta’, ‘Korona’ and ‘Polka’ and the widely grown American cultivars ‘Honeoye’ and ‘Camarosa’ were used together with the more recent Dutch cultivar ‘Sonata’ and the new Norwegian cultivars ‘Blink’ and ‘Nobel’ (Graminor selection no. GN1196.15). Young runner plants of all cultivars were sampled in the field on 1 August 2012 and rooted in plug trays in a water-saturated atmosphere in a plastic enclosure in a heated greenhouse. During rooting and early growth, the plants were maintained at 20°C and 20 h photoperiod established by extension of the natural daylight with low-intensity incandescent light (c. 15 µmol $m^{-2}s^{-1}$ PPF). On 3 September 2012, the plants were planted on raised beds with black polyethylene mulch in double rows, at a spacing of 25cm x 40cm x 160 cm, corresponding to 50,000 plants ha^{-1}. The experiment comprised three randomized blocks, each with 30 plants of each cultivar. Before planting, a basal fertilizer dressing of 75, 20 and 105 kg $ha^{-1}$of N, P and K, respectively, was supplied along the rows. The plants were sprinkle irrigated after planting and later fertigated twice weekly (according to irrigation needs) from early May to late August in both years, with a complete fertilizer solution with an electric conductivity of 1 mS cm^{-1}. Daylength conditions at Apelsvoll and temperatures during the years 2012-2014 are shown in Figure 1.

Growth performance (number of crowns, runner and leaves) were recorded for all plants in September 2013. Flowering phenology data (time of anthesis and number of inflorescences and flowers in each plant) were recorded in spring and early summer of 2013 and 2014. In the same two years, we also sampled three crowns of each cultivar (one from each replicate) at weekly intervals from mid-August to late October for dissection and examination of floral initiation as described by Opstad et al. (2011). Floral development stages were scored according to the scale described and used by those authors:

Stage 1 = Vegetative apex with only leaf primordia

Stage 2 = First sepal primordia visible in terminal flower

Stage 3 = Petal primordia visible in terminal flower

Stage 4 = Stamen primordia visible in terminal flower

Stage 5 = First carpel primordia visible on terminal flower

Stage 6 = All flower parts differentiated in terminal flower

The plants were cropped only in 2014, since all remaining plants were sampled and dissected for floral initiation later that year. Ripe fruits were harvested two to three times a week. The number and weight of all berries, including rotten berries, were recorded and healthy berries graded into three size classes (<25 mm, 25-30 mm, and >30 mm diameter).

All experimental data were subjected to analysis of variance (ANOVA) by standard procedures using a MiniTab® Statistical Software program package (Release 15, Minitab Inc. State College, PA, USA). Percentage values were always subjected to an arc sin transformation before performance of the ANOVA.

Results and discussion

The results in Table 1 show that the cultivars varied significantly in all growth and flowering performance characters recorded. With the exception of the late-flowering cultivars 'Elsanta' and 'Florence', more than 90 % of the plants were flowering in the year after autumn planting. The number of inflorescences and flowers per plant was highest in 'Blink' and 'Glima'. Early in the season, the number of crowns per plant was also highest in these cultivars, while in September, the number had increased to the same level also in 'Zefyr' and 'Florence'. The number of leaves in autumn was particularly high in the early-flowering cultivars 'Blink', 'Zefyr' and 'Glima', while the number of runners formed during the season was highest in 'Glima' and 'Polka', and least in 'Honeoye', 'Elsanta' and 'Blink' (Table 1).

The progress of floral initiation in the various cultivars in late summer and autumn of 2013 and 2014 is shown in Figure 2. With the exception of cultivar 'Nobel', floral initiation took place markedly later in all cultivars in 2014 than in 2013. This was particularly the case in cultivars with early floral initiation, resulting in a more synchronous initiation in early and late cultivars. This was apparently an effect of the high temperature in July and early August in 2014 (Figure 1), which delayed initiation in cultivars such as 'Glima', 'Valentine' and 'Zefyr' which initiate flowers also in LD if the temperature is relatively low (Heide 1977, Heide et al. 2013). It should be noticed that, at difference from the other cultivars, 'Nobel' exhibited more or less the same timing of floral initiation in the two years. The divergent floral initiation response of 'Nobel' is apparently due to the fact that the cultivar originates from a cross between 'Korona' and the everbearing cultivar ‘Diamante’ (Alsheikh et al. 2010). It therefore, seems that the combination of genes from both a SD and a LD cultivar, respectively (cf. Sønsteby and Heide 2007, Heide et al. 2013), has rendered ‘Nobel’ more or less day-neutral (Sønsteby et al. 2016a). Despite of this, however, the cultivar is not everbearing, but behaved as a regular single-cropping cultivar in the field. The early initiation in the field in cultivars ‘Glima’, ‘Zefyr’ and ‘Valentine’ concurs with results in controlled environment experiments (Heide 1977), showing that low temperature is as important as SD for flowering in these cultivars. The similarly early initiation in ‘Blink’ suggests analogous flowering response mechanisms in this cultivar as well.

Flowering phenology data for the cultivars in the years 2013 and 2014 are presented in Table 2. The experiment was established with 30 plants per plot of each cultivar, but after sampling of 20 plants for assessment of floral development stages in 2013, plant number were reduced to 10 per plot in 2014. In both years, flowering and ripening was earliest in cultivars ‘Glima’, ‘Valentine’, ‘Zefyr’ and ‘Blink’, all being cultivars with early floral initiation in the previous autumn (Figure 2). In 2014, ‘Nobel’ was also represented in this early group. On average for all cultivars, flowering and ripening were more than two weeks earlier in 2014 than in 2013, apparently due to higher temperatures in March and April in 2014 (Figure 1). However, the time between anthesis and first harvest did not show the same pattern of variation among cultivars as did flowering and ripening, nor did it vary significantly between the two years (Table 2). In other words, temperature influenced the progress of flowering and berry ripening in different ways.

Also fruit yield and berry size varied significantly between the cultivars (Table 3). The total yield and number of berries were highest in ‘Blink’ and ‘Polka’, followed by ‘Florence’ and ‘Sonata’, whereas ‘Valentine’ had by far the lowest yield. ‘Glima’ and ‘Valentine’ had the smallest berries with one-half of the harvest in the smallest grading class and less than 10% in the largest class. The berries were relatively small also in ‘Senga Sengana’ and ‘Nobel’, while ‘Sonata’, ‘Honeoye’ and ‘Elsanta’ had the largest berries. The proportion of rotten berries infested by grey mold was low in all cultivars except ‘Elsanta’ with nearly 15% (Table 3). The time-courses of yield accumulation for the various cultivars shown in Figure 3, demonstrate and confirm the well-known late ripening of ‘Florence’ (Sønsteby and Heide 2008, Opstad et al. 2011).

The results of the experiment are in general agreement with practical experiences in Norway (Haslestad 2016), and explain why many of the older cultivars are outdated. Small berries have excluded cultivars such as ‘Glima’ and ‘Senga Sengana’ despite their superior processing qualities (Thorsrud 1977, Nes and Hageberg, 2005). Yields and quality are unsatisfactory in ‘Zefyr’, which is currently grown mainly for its early ripening and winter hardiness. ‘Valentine’ has never been grown commercially in Norway but used in breeding for its earliness, while ‘Camarosa’ and ‘Elsanta’ have failed to satisfy taste requirements in Norway. ‘Polka’ is still grown to some extent because of acceptable yield and quality. ‘Korona’, which has been the predominant cultivar in Norway for many years, are now in retreat from competition with the high yielding and large-fruited ‘Sonata’, which is steadily increasing its share of the fresh market (Haslestad 2016). Even though not fully at level with ‘Korona’ in taste quality, ‘Sonata’ is benefitting from its superior fruit size and firmness. While berry size in ‘Korona’ usually is fully adequate in first year crops, many small berries is a common problem in second and third year crops with excessive flowering. Stable yields of berries of good size and quality in ‘Florence’ (Table 3) is justifying its position as a late cultivar for extension of the fresh marketing season. The recently released Norwegian cultivar ‘Blink’ performed well in the Nordic climate with early flowering and fruit maturation as well as an unusually high yield potential (Tables 2, 3). Regrettably, however, the market has not found the fruit quality adequate for either fresh consumption or processing. Similarly, the new cultivar ‘Nobel’ was found to have early floral induction and wide temperature adaptation that are ideal for the Nordic environment, as well as superior taste and good firmness, but inadequate fruit size and yields tend to reduce the promise of this cultivar (Sønsteby et al. 2016). The conclusion is therefore, that for the near future, ‘Sonata’ and ‘Korona’ tend to remain as the predominant cultivars for the fresh market in Norway, together with ‘Florence’ as a late maturing cultivar for prolongation of the marketing season. We also observe the need for a new, high-yielding strawberry cultivar with fruit qualities that will meet the needs of the processing industry.

Acknowledgements

The authors wish to thank Hans Gunnar Espelien for technical assistance with the field work. This work was supported by the Norwegian Agricultural Agreement Research Fund/Foundation for Research Levy on Agricultural Products (grant number 225154/E40), and the Research Council of Norway (grant number 234312/E50).

Disclosure statement

No potential conflict of interest was reported by the authors.

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Table 1. Growth and flowering performance of 13 strawberry cultivars in 2013, after autumn planting in 2012.

Cultivar	Flowering plants (%)	No. of infloresc. plant^{-1}	No. of flowers plant^{-1}	No. of crowns plant^{-1} (July 5)	No. of crowns plant^{-1} (Sept. 10)	No. of leaves plant^{-1} (Sept. 10)	No. of runners plant^{-1} (Sept. 10)
‘Blink’	100	2.9	17.8	4.5	6.8	43.4	12.6
‘Camarosa’	95	1.5	8.1	3.1	4.6	28.9	14.0
‘Elsanta’	70	1.0	12.4	1.3	2.3	19.6	11.2
‘Florence’	82	1.8	14.6	3.7	6.3	34.8	11.6
‘Glima’	100	2.7	16.3	4.1	6.1	38.8	18.8
‘Honeoye’	96	1.0	5.0	1.5	2.6	19.0	10.5
‘Korona’	90	1.0	8.8	1.9	3.4	28.0	13.9
‘Nobel’	90	1.1	9.1	2.8	3.6	20.5	11.1
‘Polka’	100	1.8	11.7	2.8	5.6	35.6	16.6
‘Senga S.’	99	1.7	11.5	3.1	5.5	35.3	13.4
‘Sonata’	96	1.0	7.1	1.6	3.5	22.2	12.7
‘Valentine’	97	1.4	7.6	2.8	4.2	25.6	12.5
‘Zefyr’	92	1.7	8.9	4.1	7.4	42.6	12.9
Mean	*93*	*1.6*	*10.7*	*2.9*	*4.8*	*30.6*	*13.3*
LSD	6.9	0.6	4.3	1.0	0.8	11.5	3.8
P-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001

Data are means of three replicate plots with 20 plants per plot of each cultivar for the data in columns 1 and 4-7, and 10 plants in columns 2 and 3.

Table 2. Flowering phenology observations for 13 diverse strawberry cultivars during two years in the experimental field.

Cultivar	2013			2014		
	Days to anthesis after May 1	Days to first harvest after May 1	Days from anthesis to first pick	Days to anthesis after May 1	Days to first harvest after May 1	Days from anthesis to first pick
‘Blink’	36.7	68.3	31.7	23.2	48.7	25.5
‘Camarosa’	36.0	71.7	35.7	22.8	53.2	30.3
‘Elsanta’	42.3	72.7	30.3	27.4	54.5	27.1
‘Florence’	48.3	74.0	25.7	27.2	57.4	30.2
‘Glima’	34.6	59.7	25.1	20.3	50.0	29.7
‘Honeoye’	40.3	68.7	28.3	25.1	54.3	29.3
‘Korona’	41.2	71.3	30.1	24.7	53.2	28.5
‘Nobel’	38.0	69.9	31.9	22.3	50.8	28.4
‘Polka’	40.7	71.6	30.9	27.0	52.7	25.7
‘Senga S.’	37.3	67.7	30.3	25.3	53.8	28.5
‘Sonata’	40.3	70.0	29.7	23.5	52.5	29.0
‘Valentine’	33.7	58.3	24.7	19.7	50.4	30.8
‘Zefyr’	35.3	63.2	27.9	21.5	51.2	29.7
Mean	*38.8*	*68.2*	*29.4*	*23.8*	*52.4*	*28.7*
LSD	2.8	2.7	3.0	2.6	3.5	4.0
P-value	<0.001	<0.001	<0.001	<0.001	0.003	n.s.

Data are means of three replicate plots with 20 and 10 plants per plot of each cultivar in 2013 and 2014, respectively.

Table 3. Berry yield and size for 13 strawberry cultivars in 2014 after autumn planting in 2012.

Cultivar	Berry yield (g plant^{-1})	No. of harvested berries plant^{-1}	Yield (%) >30 mm	Yield (%) 25-30 mm	Yield (%) <25 mm	Berry weight (g)	Rotten berries (%)
'Blink'	427.0	40.4	63.7	29.0	7.3	10.6	2.0
'Camarosa'	242.5	17.3	75.7	19.9	4.4	13.9	2.2
'Elsanta'	165.5	11.3	81.6	14.8	3.6	14.8	14.6
'Florence'	377.0	34.0	79.1	15.7	5.3	11.8	2.7
'Glima'	153.7	27.7	7.5	39.3	53.2	5.5	3.3
'Honeoye'	129.4	9.9	83.3	8.7	8.1	14.1	0.9
'Korona'	257.9	18.2	79.5	14.8	5.7	14.4	4.7
'Nobel'	141.4	16.6	34.1	42.9	22.9	8.5	0.0
'Polka'	407.0	34.7	68.9	25.3	5.8	11.7	2.1
'Senga S.'	215.2	25.1	48.1	31.4	20.5	8.6	3.2
'Sonata'	300.5	20.5	84.6	13.3	2.1	14.6	7.3
'Valentine'	73.2	12.3	8.8	43.3	47.9	5.8	2.2
'Zefyr'	159.3	18.7	50.1	31.8	18.2	8.6	5.4
Mean	*234.6*	*22.1*	*58.8*	*25.4*	*15.8*	*11.0*	*3.9*
LSD	143.3	14.6	17.8	10.2	11.9	3.1	8.6
P-value	<0.001	0.003	<0.001	<0.001	<0.001	<0.001	0.05

Data are means of three replicate plots with 10 plants per plot of each cultivar.

FIGURE LEGENDS

Figure 1. Normal temperature (1960-1990) and average monthly mean temperatures for the years 2012 – 2014, and the annual course of daylength changes at Apelsvoll. Data from the Norwegian Meteorological Institute, Oslo.

Figure 2. Time courses of floral initiation in field-grown plants of 13 strawberry cultivars at Apelsvoll in the years 2013 and 2014. Each data point represents the mean of 3 plants.

Figure 3. Time courses of cumulative berry yield in 13 strawberry cultivars in the year 2014. Data are the means of three replicate plots with 10 plants per plot of each cultivar.

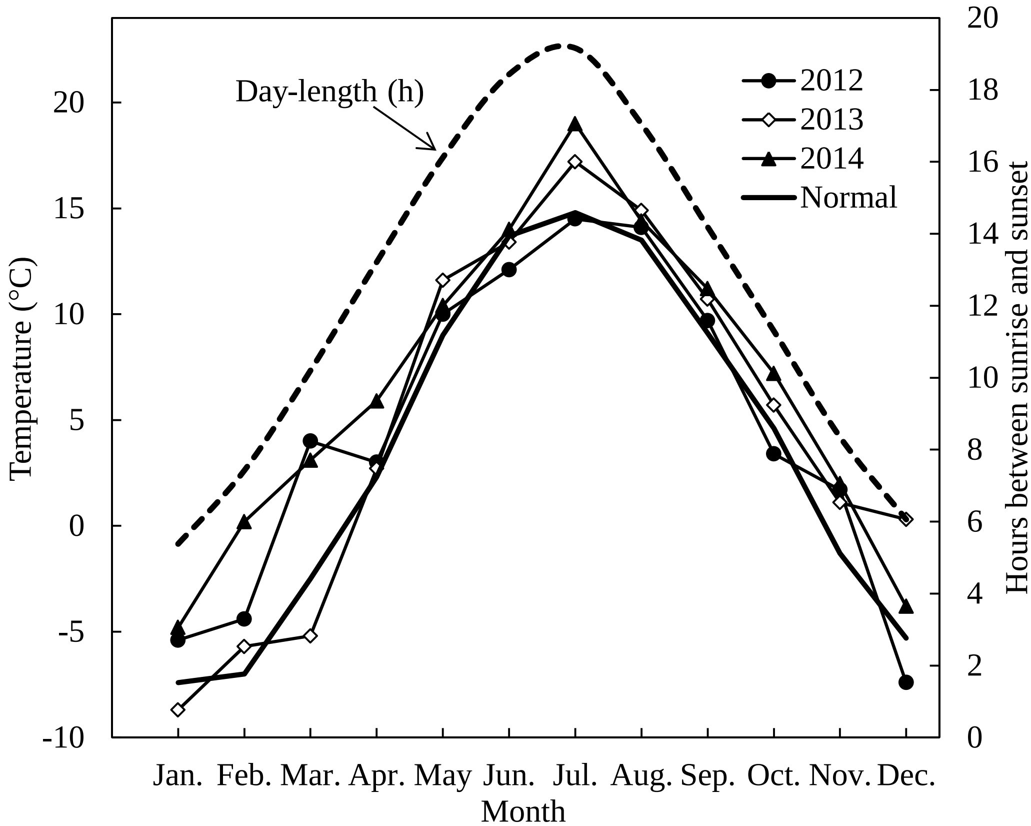
Day-length (h)
2012
2013
2014
Normal
Temperature (°C)
Hours between sunrise and sunset
-10
-5
0
5
10
15
20
0
2
4
6
8
10
12
14
16
18
20
Jan.
Feb.
Mar.
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
Month

Figure 1.

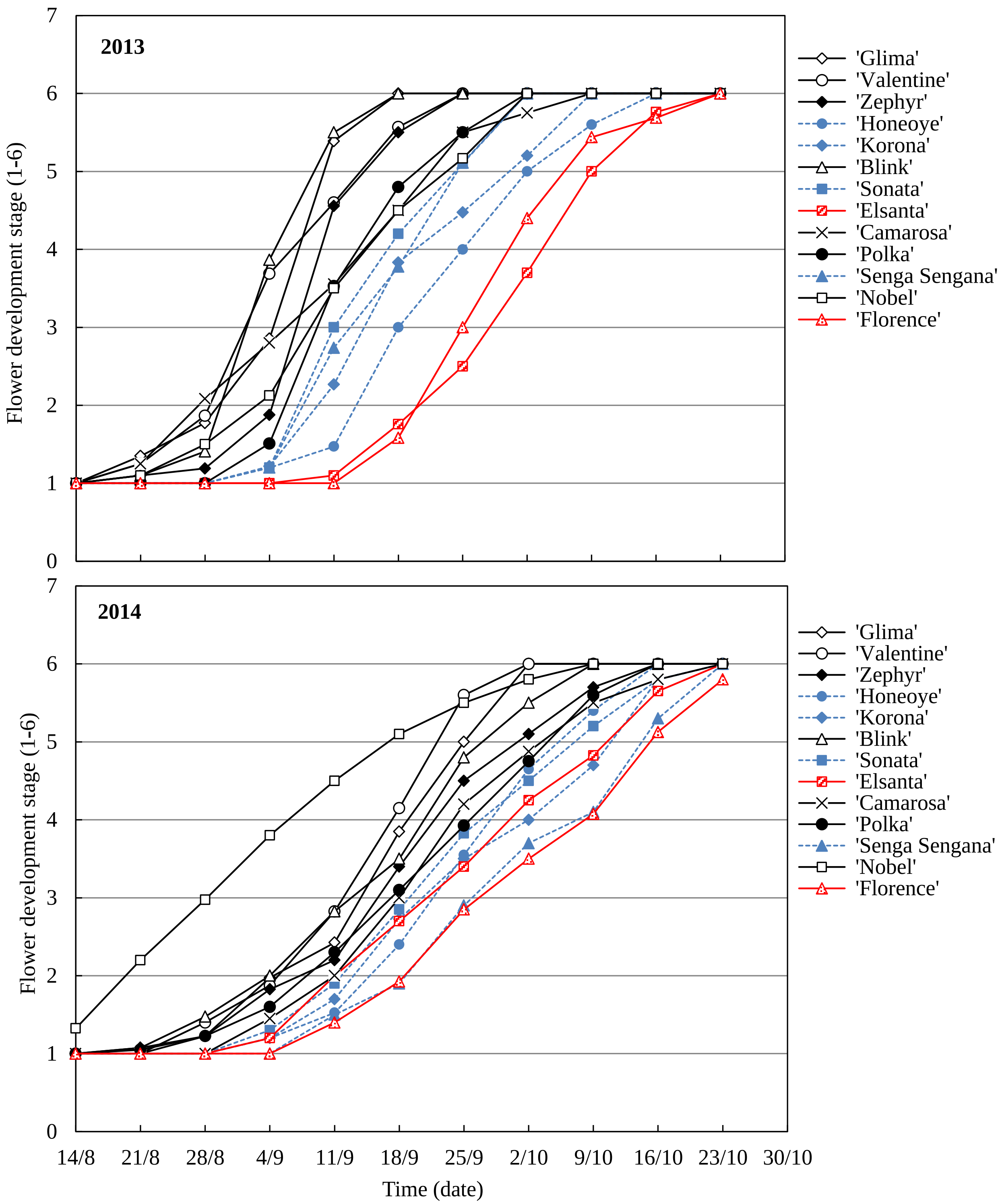
2013
2014
Flower development stage (1-6)
0
1
2
3
4
5
6
7
'Glima'
'Valentine'
'Zephyr'
'Honeoye'
'Korona'
'Blink'
'Sonata'
'Elsanta'
'Camarosa'
'Polka'
'Senga Sengana'
'Nobel'
'Florence'
14/8
21/8
28/8
4/9
11/9
18/9
25/9
2/10
9/10
16/10
23/10
30/10
Time (date)

Figure 2.

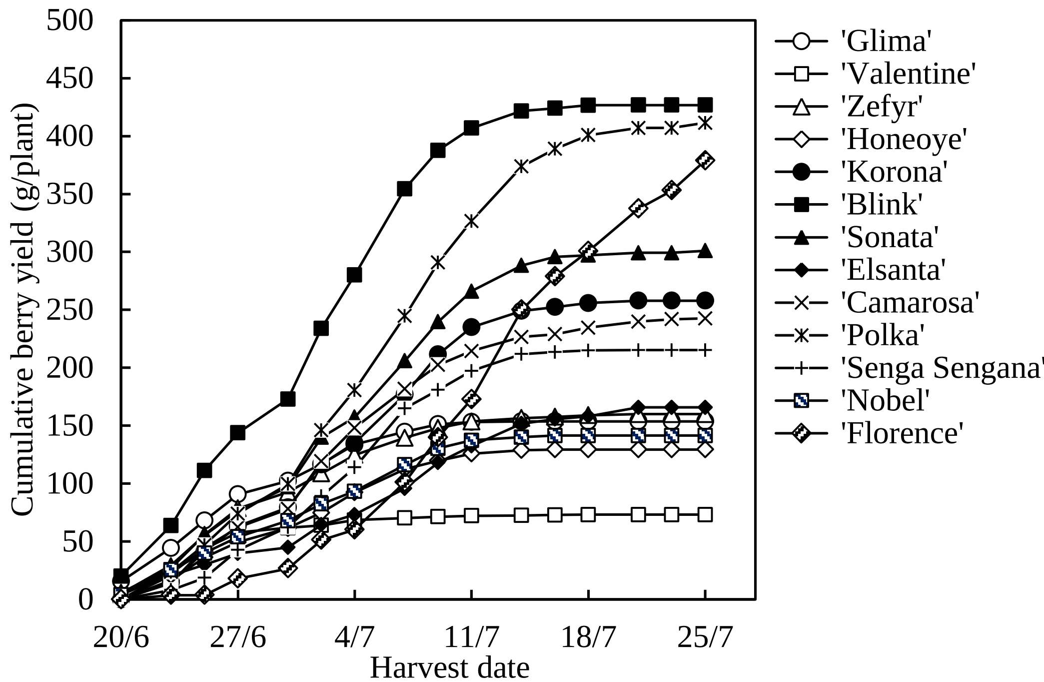
500
450
400
350
300
250
200
150
100
50
0
Cumulative berry yield (g/plant)
20/6
27/6
4/7
11/7
18/7
25/7
Harvest date
'Glima'
'Valentine'
'Zefyr'
'Honeoye'
'Korona'
'Blink'
'Sonata'
'Elsanta'
'Camarosa'
'Polka'
'Senga Sengana'
'Nobel'
'Florence'

Figure 3.