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Environmental manipulation for establishing high yield potential of strawberry forcing plants

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ABSTRACT

The production of ready-to-flower strawberry forcing plants with high yield potential has been studied by manipulation of temperature and fertilization during the natural transition to inductive SD conditions at a South Norwegian locality (60°40′ N; 10°52′ E, 250 m altitude). The cultivars 'Korona', Polka' and 'Sonata' were used. It was demonstrated that, in this environment, sub-optimal temperature is a limiting factor for adequate floral induction in these strawberry cultivars under natural out-door conditions, while the prevailing natural photoperiod is not a limiting factor. Elevated temperature (>15 °C) during the month of September increased flowering and fruit yield, and this effect was significantly enhanced when elevated temperature was combined with a pulse of extra fertilization. The highest flowering and yield potential was obtained when fertilization was applied for a three-week period starting shortly after the photoperiod had declined to the inductive length. It is concluded that, in the cool Nordic environment, strawberry forcing plants with high yield potential can only be produced on a regular basis by greenhouse cultivation at elevated temperature (>15 °C). Under these conditions flowering and yield potentials of the plants are further significantly enhanced by timely application of a pulse of autumn fertilization. While excessive flowering with reduced fruit size was often experienced with 'Korona', this did not occur in the large-fruited 'Sonata'.

1. Introduction

Commercial greenhouse production of strawberries in areas with cold winter climates has developed in response to year round consumer demands for fresh strawberries. Commonly, ready-to-flower forcing plants with fully differentiated floral primordia (often referred to as "60 days plants") are produced in late summer and autumn and, after a period of cold storage; the plants are cropped in a greenhouse during the following season (Jonkers, 1965; Dijkstra, 1989; Lieten, 1993). By varying the length of cold storage, either an early or an unusually late crop can be produced outside the main marketing season. This will facilitate the availability of high quality strawberries for the consumer in an extended fresh market season and, if successful, reward the producer with a premium fruit prize (Strik, 2012). However, the high capital costs involved in such a production, demand that plants with high yield potential can be produced on a regular basis.

This is a highly specialized production that requires thorough knowledge of the physiological mechanisms regulating strawberry plant growth and development. Central in this connection is the manipulation of environmental factors such as temperature and photoperiod which are known to control physiological processes such as floral initiation and differentiation as well as runner formation, dormancy induction and release in the strawberry (Guttridge, 1985; Heide et al., 2013). In the common seasonal flowering (June-bearing) strawberry cultivars, it is well documented that flowering is controlled by a pronounced interaction of photoperiod and temperature, with short days (SD) of 10–12 h length and temperatures of 15–18 °C being optimal for flower initiation (Darrow and Waldo, 1934; Ito and Saito, 1962; Heide, 1977; Verheul et al., 2007). 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.

Recently, it has also been reported that extra fertilization, particularly with nitrogen (N), applied shortly after commencement of the SD floral induction period, can significantly enhance the floral induction effect of SD (Lieten, 2002; Sønsteby et al., 2009). On the other hand, fertilizer application in the period immediately before SD had the opposite effect and delayed and reduced flowering.

Likewise, it is well known that vegetative vigour of strawberry plants decreases under SD conditions, rendering the plants in a state of relative dormancy (Jonkers, 1965; Guttridge, 1985; Heide

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et al., 2013). Under natural environment conditions in temperate regions of the Northern hemisphere, the deepest state of dormancy is usually attained in November (Jonkers, 1965; Guttridge, 1985). It has been demonstrated that flower formation and dormancy attainment are parallel responses induced by the same conditions, namely SD and relatively warm temperature conditions (Kronenberg et al., 1976; Sønsteby and Heide, 2006). On the other hand, release from the state of relative dormancy and reversal of the restrained growth habit requires several weeks of chilling at temperatures ranging from -2 °C to approximately 8 °C (Guttridge, 1985; Lieten, 1997). Long days (LD) can also fully or partially substitute for chilling, and prolonged exposure to LD will therefore, gradually re-establish normal growth in the absence of chilling (Lieten, 1997; Sønsteby and Heide, 2006). Although florally induced plants are able to flower without chilling, even under SD conditions (Heide, 1977), flowering will be delayed and peduncle growth restrained in the absence of chilling. For commercial greenhouse production, it is therefore customary to chill the plants before they are subjected to forcing conditions (Jonkers, 1965; Lieten, 1997).

In countries such as Belgium and The Netherlands, where glasshouse winter production of strawberry has relatively long traditions (Jonkers, 1965; Dijkstra, 1989; Lieten, 1993), research effort has led to development of standard management protocols. The predominant cultivar for this production is 'Elsanta' which is favoured for its healthy and robust performance. However, in the cooler climates of the Nordic countries, where other cultivars such as 'Korona' and 'Sonata' are grown because of consumer preferences, and where also the transition to inductive SD conditions is delayed compared with lower latitudes, the standard protocols have not given plants with satisfactory flowering and yield potential (Sønsteby and Heide, unpublished results).

This has led us to explore alternative cultivation strategies for production of strawberry forcing plants with high yield potential. In the present work we have attempted to improve flowering and yield potential of plants produced in a cool Nordic environment by manipulating temperature, photoperiod and plant nutrition during late summer and early autumn when floral induction takes place.

2. Materials and methods

2.1. Plant material and cultivation

Three experiments were conducted during the years 2009/2010 to 2011/2012 at the Bioforsk Experimental Centre Apelsvoll, in the central part of South Norway (60°40′ N; 10°52′ E; 250 m altitude). The first experiment (Experiment 1) was designed to quantify the effects of elevated temperature (>15 °C) during the month of September compared with continuous ambient (out-door) temperature, as well as the combined effect of elevated temperature and artificial SD treatment (12 h) during the same period. Since elevated temperature significantly increased flowering and fruit yield, while artificial SD had no such effect in Experiment 1, the second experiment (Experiment 2) focussed on the duration of elevated temperature under natural day-length conditions. Continuous ambient temperature was compared with elevated temperature (>15 °C) for 4, 6, or 8 weeks, all starting on September 1. In both of these experiments, all plants received a pulse of autumn fertilization, as described below, for a 3-week period, starting on September 8. Experiment 3, which was also carried out under natural day-length conditions, studied the effect of timing of such a fertilizer pulse in plants grown either continuously at ambient temperature or, for a period of 5 weeks (30/8–4/10), in a greenhouse with elevated temperature (>15 °C). The fertilization pulses were given for periods of 3 weeks, starting at three successive dates during August and September, i.e. 2 weeks before, concurrent with, or 2 weeks after the date when the natural day-length becomes inductive for flower initiation at this latitude (Opstad et al., 2011). Temperatures at plant level were recorded every 30 min and stored on a temperature USB data-logger (EL-USB-2, Lascar Electronics, UK). An overview of the temporal coordination of the fertilization and artificial SD manipulations in relation to the declining day-length and the ambient and elevated temperature conditions in the three experiments are shown in Fig. 1.

The cultivars 'Korona', 'Polka' and 'Sonata' were used in Experiments 1 and 3, only 'Korona' and 'Sonata' in Experiment 2. Runner plants were produced and rooted in a glasshouse maintained at 20 h photoperiod and a minimum temperature of 20 °C. Extension of the natural day-length was provided by 70 W incandescent lamps at a quantum flux density of approximately 10 μmol quanta m^{-2} s^{-1}, applied from 20.00 h to 24.00 h and 04.00 h to 06.00 h. Runners were planted directly in plastic modules of 0.25 l volume (Bato Strawberry Tray 9-holes, Bato Plastics B. V., The Netherlands) in mid-July (July 1 in Experiment II), 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 non-fertilized control plants did not receive any fertilization during the autumn treatments. After thorough rooting in a water saturated atmosphere, the plants were moved outdoors around August 1, and grown on under ambient out-door conditions for the rest of the season or, until exposed to artificial SD (12 h) and/or elevated temperature for a given period, as shown in Fig. 1. The fertilizer solution used for the fertilization pulses was a 2:3 mixture of Superba™ Rød (7-4-22% NPK + micronutrients) and Calcinit™ (15.5% N, 19% Ca) (Yara International, Oslo, Norway) with electric conductivity (EC) 3.0 mS cm^{-1}. Plants were fertilized manually 3 times per week for a period of 3 weeks as shown in Fig. 1.

After completion of all the photoperiod, temperature and fertilization treatments in early October, all plants were gathered out-doors, covered with one layer of white fibre cloth, and hardened under ambient out-door conditions until late November when they were moved into a cold store maintained at −2 °C. In each experiment, one batch of plants was taken out of the cold store in mid February after 10 weeks of chilling, potted into 12 cm plastic pots and forced in a glasshouse at 20 °C and 20 h photoperiod for determination of earliness and amount of flowering. During the forcing period, the plants were fertilized daily with the nutrient solution described above, diluted to EC 0.6 mS cm^{-1}. In addition to natural daylight, light at a fluence rate of 184 μmol quanta m^{-2} s^{-1} was provided by a mixture of SonT and incandescent lamps from 04.00 h to 24.00 h during the forcing period. The remaining plants were cold stored until June 1 when they were potted into 3.5 l plastic pots with 2 plants in each pot, and cropped on table-tops in an unheated Haygrove plastic tunnel. In each watering during this period, the plants were fertilized through an automatic fertigation system using the same fertilizer solution as described above, with EC 0.6 mS cm^{-1}. During berry ripening the EC was increased to 1.0 mS cm^{-1}. Temperature conditions in the tunnels during cropping in the three experiments were as shown in Fig. 2.

2.2. Experimental design, data observation and analyses

The experiments were factorial, with a split-plot design, with temperatures as main plots, and cultivars, and photoperiod or fertilization treatments as sub-plots. For the primary plant production manipulation treatments, 5 trays with 9 plants each of each cultivar were used for each treatment, of which 2 trays were used for the early forcing test in February, and the remaining 3 trays were used for the final cropping test. For the early forcing, the 18 plants from 2 trays of each cultivar were split into 3 replicates of 6 plants each,