Extending the Harvest Period of Saffron

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Abstract

Lifting the corms of saffron (*Crocus sativus* L.) after leaf withering (late June to early July) and storing them at 25 ºC during a variable period of time before forcing flowering at 17 ºC, allowed us to program flowering at will from mid September to mid December. An earlier flowering was obtained lifting the corms before leaf withering (by the end of May) and/or heat curing the corms at 30 ºC during 20 days before the incubation at 25 ºC. On the other hand, flowering could be delayed storing the corms at low temperature. The conditions of this cold storage were critical as regards to the stage of flower initiation of the corms, the temperature and duration of storage and the composition of the atmosphere. A departure from the optimal conditions resulted in flower abortion and/or a reduction in flower size. The combination of the techniques described allowed us to extend the harvest season of saffron in the greenhouse from early September to the end of January, with a saffron spice yield per corm higher than 17 mg. Since the mean duration of the period of flowering for a batch of corms was 13 days, we could grow 11 batches in that period. With the planting density we used (457 corms m^{-2}); 1 hectare of greenhouse yielded 855 Kg of saffron spice in a year. The period of flowering could be extended until the end of March but with a smaller spice saffron yield per corm (over 14 mg).

INTRODUCTION

Saffron spice has been used as a food additive from the Late Bronze Age (Zachary and Hopf, 1994), and nowadays has become the highest priced spice in the world (Winterhalter and Straubinger, 2000). Also, many of the components of saffron have potential medical applications as they have antitumour properties (Abdullaev and Frenkel, 1999; Fernández Pérez and Escribano Martínez, 2000). Despite these apparently bright prospects, saffron production has decreased rapidly in many traditionally producing countries as Spain, Italy and Greece, to become nearly testimonial (Negbi, 1999). An intensive (and expensive) hand labour of up to 15 working days per kilogram of dry saffron spice is required for flower picking and stigma separation (Anonymous, 1998). To the high cost of this labour it should be added the very uncomfortable stooping position of the flower pickers, and the very short picking period which comprises the early morning hours of the 20-30 days of duration of the flowering season. The mechanisation of flower picking in field grown saffron has proved difficult (Galigani and Garbati Pegna, 1999). The flowers are barely above ground level, and mechanisation would require a very careful levelling of the soil and of the movement of the harvesting machinery. The short duration of the flowering period in a particular geographical region makes necessary a heavy investment in harvesting machinery to be used only a few days a year.

A potential alternative is to grow potted corms under controlled environmental conditions. As we show below, the flowering of the corms may be controlled at will from early September until the end of March. Hence, several batches of corms could be grown in a year, reducing thus the investment and the running costs of the harvesting installations. Further, the movement of the potted plants may be mechanised in full or partly, and it is more precise than the movement of field machinery, thus reducing the picking problems caused by the small length of the peduncles.

In the present report we describe the way to control the time and duration of flower formation, and the incidence of several environmental parameters on corm forcing. Also, we describe the basic features for the growth and the manipulation of greenhouse forced corms.

MATERIALS AND METHODS

In the experiments we used saffron corms raised at Quero, Toledo, a traditional saffron production area of Spain. For the experiments we selected corms of >30 mm in diameter that had no flowered the previous year. These corms had therefore a single main dominant bud at the apex (Molina et al., 2004a). When kept in the orchard formed in average 2.5 to 3 flowers per corm depending on the batch. The corms were lifted after the completion of growth either before leaf withering (at the end of May; early lifted corms), or after leaf senescence (by the end of June or in early July; late lifted corms). The handling of the corms after lifting has been described in detail previously (Molina et al., 2004a). Briefly, after sorting and disinfestations the corms were placed on a mat of rock wool in plastic trays at a density of 457 corms m^{-2} and kept in the dark at 25 ºC for flower initiation. After flower formation, the corms were covered with a layer of expanded clay (arlite), watered and kept in the dark at 17ºC for shoot growth and flower emergence. During flowering the corms were kept in a greenhouse at 17 ºC with a photoperiod of 8/16 hours (light/darkness) and a photosynthetic photon flux density of 20 µmol m^{-2} s^{-1} provided by Pope FTD 58W/82 fluorescent lamps. The greenhouse was built inside a thermostated room with shelves separated 75 cm in height to place the trays with the corms. These shelves were provided with rollers for the automated movement of the trays to the flower harvesting device.

The cold storage was performed in atmosphere controlled rooms with the corms placed on the plastic trays used for flower induction.

RESULTS AND DISCUSSION

Temperature Effects on Flower Formation

No flower primordia were present in the corms by the end of the winter vegetative growth period. Flower formation required an incubation of the corms at a high temperature regime for flower initiation, followed by a period at a moderately low temperature for flower emergence. This may be defined as a hot-intermediate temperature regime according to Res (1992). Under field conditions, flower initiation occurred during summer coinciding with the resumption of meristematic activity in the apical bud. The wide differences in the timing of flower initiation in different countries reported in the literature, were previously considered caused by differences in corm size (Negbi, 1999). However, Molina et al. (2004a) reported up to 2 month differences both in the timing of flower initiation and of flowering for corms of the same batch planted in different locations in Spain. These authors related the timing of these events to the prevailing air and soil temperatures.

When the corms were incubated under controlled conditions at a constant temperature, the optimal temperature for flower initiation was in the range of 23-27 ºC (Molina et al., 2004b). Flower initiation occurred as the growth of the cataphylls resumed. The increase in length of the cataphylls was already significant by day 40 after the commencement of the high temperature incubation (Figure 1). The bracts were initiated by day 50 and the stamen primordia were visible by day 60. Then, in rapid succession, followed the initiation of the tepals and the gynoecium. By day 85 all the flower parts were already initiated (Figure 1). The same time-course both for cataphyll growth and for flower initiation was found for corms lifted after leaf withering (late lifted corms) and for corms lifted 2 months earlier (by mid May; early lifted corms). The potential of flower formation by the corms was determined by the time the bracts differentiated. Thus, corms incubated at high temperature for 45 to 60 days and then transferred at a lower temperature (see below) formed a maximum number of flowers (Molina et al., 2004b). At

this time, the cataphylls (=shoot) were between 2 and 3 mm long (Figure 1).

A further extension of this incubation at high temperature had no additional favourable effect on flower formation. The number of flowers formed was the same in corms incubated during 60 days than in corms incubated for as long as 150 days (Figure 2). During this extended high temperature incubation there was a marked increase in the growth rate of the cataphylls and a significant loss of weight by the corms (Figure 2). On the contrary, too a long duration of incubation (lasting more than 150 days) at this high temperature resulted in flower abortion (Figure 2). Cataphyll growth was not impaired while weight loss by the corms increased markedly. We could not find a causal link between these factors and flower abortion. Covering the corms with a layer of expanded clay to reduce transpiration water losses, increased cataphyll growth and reduced the loss of weight, but had no effect on flower abortion. Further, incubating the corms at 30 ºC reduced markedly both the growth of the cataphylls and weight loss, but enhanced flower abortion. Although a causal link could not be established, the length of the cataphyll was a good parameter to evaluate the risk of flower abortion and hence to monitor the maximum duration of incubation.

Flower emergence required a markedly lower temperature than that reported for flower initiation. It was optimal at around 17 ºC.

The Determination of the Time of Flowering

As stated above, the extension of the incubation at 25 ºC in the range of 60 to 150 days had no effect either on flower formation or in flower size. However, it markedly affected the time of flower emergence. The longer the duration of this incubation, the shorter the time needed afterwards at 17 ºC for flower emergence, and the longer the time elapsed from corm lifting to flowering (Figure 3). Corms incubated at 25 ºC during 59 days started to flower 118 days after corm lifting (i.e. on October 11 for corms lifted on 15 June). When the incubation was extended to 150 days, flowering started 172 days after corm lifting (on December 4), to be completed by December 10. Therefore, through the duration of the incubation at 25 ºC we could obtain a difference of 54 days in the beginning of flowering.

The influence of the duration of incubation on the time of flowering was remarkably reproducible. In the four experiments performed during two consecutive years to test the effect of the duration of incubation on the time of flowering using different batches of corms, the deviation of the real date of flowering from the date predicted using the regression curve for all the observations (Figure 3) was smaller than 5 days. This is an important aspect as regard the programming of corm planting and greenhouse occupation (see below). Air humidity (in the range 65 to 85% relative humidity) and CO_2 concentration (in the range 400 to 3000 $\mu L\ L^{-1}$) had no effect on flower formation.

The Influence of the Time of Bulb Lifting

No morphological change was detectable in the shoot apex of the corms during the 2 months previous to leaf withering (Molina et al., 2004b). Further, the bulbs lifted at this time had a similar response to high temperature incubation than bulbs lifted after leaf withering (Figures 1 and 2). In our experiments, corms lifted on May 4 and incubated during 55 days at 25 ºC flowered by September 10 with a yield of saffron similar to corms lifted 2 months later, extending thus in one month the effective period of flowering.

We did not determine the behaviour of corms lifted at an even earlier date. This earlier lifting caused a significant reduction in corm weight, and this parameter was directly related to flowering (De Mastro and Ruta, 1993).

A further advancement of the time of flowering could be obtained heat curing the corms during 20 days at 30 ºC. This heat curing accelerated flowering by 4 to 7 days as compared to bulbs incubated all the time at 25 ºC (Molina et al., 2004b). A longer duration of this heat curing had no additional benefit. When too long (91 days) it reduced flower formation and delayed flower emergence.

The Effect of Low Temperature

At variance with most geophytes, which show low temperature requirements for breaking bud dormancy and/or complete flower formation (Dole, 2003), no benefit of chilling on saffron flowering has been demonstrated in saffron (Molina et al., 2004c). Cold markedly reduced growth and delayed flower formation, but a long cold storage or departure from the optimal storage conditions resulted in a reduction in saffron spice yield. Critical parameters were the stage of flower formation of the meristems at the beginning of storage, temperature of storage and oxygen concentration. Corms stored before flower primordia formation required incubation at 25 ºC for the initiation of flower primordia before flower forcing at 17 ºC.

The complex influence of these parameters on flowering and saffron yield has been determined by Molina et al. (1994b). Corms lifted on June 22 after leaf withering at the time they had a flower score of 1.5 (leaf primordia were initiated in 50% of the meristems) and stored at 2 ºC during 70 days (until September 15), could be forced to flower from mid December until the end of January. Saffron yield per corm was slightly lower (by 10%) than in corms kept in the orchard or induced to flower directly without a cold storage (Molina et al., 2004c). Extending the cold storage until day 160 after corm lifting allowed to extend the flowering period until the end April. This delayed flowering resulted in a decrease of saffron spice yield per corm. This decrease was directly related to the duration of the cold storage (Table 1).

CONCLUSIONS

Through the modification of the duration of incubation at 25 ºC we were able to obtain batches of corms whose commencement of flowering differed in 54 days. Since early lifted corms started to flower 40 days earlier, we obtained an effective duration of flowering of 107 days (to the sum of the two figures we should add the 13 days of duration of flowering of the last batch of corms). Since the mean duration of flowering of one batch of corms was 13 days, during these 107 days we could force in the greenhouse the flowering of 8 batches of corms. At the planting density we used (457 corms m^{-2}) and the saffron spice yield we obtained (21.1 mg $corm^{-1}$), this resulted in a saffron yield of 672 Kg in a hectare of greenhouse. To feed corms to one hectare of greenhouse, we needed the corms produced in 20 to 30 hectares in the open. Also, storage facilities were needed to incubate the corms at 25 and 17 ºC for the programming of the time of flowering.

The period of flowering in the greenhouse could be further extended through the use of the more expensive cold storage. Cold storing the corms during 70 days had little detrimental effect on saffron spice yield per corm and allowed us to extend greenhouse occupation until the end of January. Thus, four additional batches of corms could be harvested bringing saffron yield to 855 Kg a hectare. A further extension of the flowering period required a longer duration of the costly cold storage and resulted in a smaller saffron spice yield per corm (Table 1). Its economic feasibility has to be evaluated.

In summary, the environmental control of flowering allowed us to produce saffron spice like an industrial crop. The field was used for the production of corms of the appropriate size. These corms were lifted using a bulb-picking machine, disinfected and programmed in the greenhouse facilities to flower in the appropriate time. A summary of the conditions of this programming along with the period of flowering and the yield characteristics is presented in Table 1. After flower formation and mechanised stigma picking, the corms could be returned to the orchard for the formation of new corms. If not needed, they may be used as foodstuff for farm animals. This production system obviates many of the problems of saffron production in many countries. From one side, it requires much less hand labour than the traditional system of production in the orchard. Further, the extension of flowering during several weeks obviates the intensive labour needed nowadays for flower picking and stigma separation. The mechanization of flower picking in container-grown plants does not present the insurmountable difficulties encountered with the mechanization of flower harvesting in the orchard (Galiano and Garbati Pegna,

1999).

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Tables

Table 1. Summary of the protocol for the greenhouse production of saffron. For each batch of corms the parameters of storage, flower forcing, the time of flowering and saffron spice yield are given. Source of data: Molina et al. (2004b, c).

Desired period of flowering[a]	1 Sep 10 Oct	11 Oct 10 Dec	13 Dec 25 Jan	19 Jan 26 Feb	10 Feb 22 Mar	24 Mar 8 May
Handling parameters						
Corm lifting[b]	Early	Late	Late	Late	Late	Late
Heat curing	Yes	Optional	No	No	No	No
Cold storage (days)	None	None	70	100	130	160
25ºC incubation (days)	41-84	59-150	45-109	45-109	45-109	45-109
Flowering parameters						
Flowers per corm	2.4	2.7	2.3	1.6	1.8	1.4
Saffron (mg flower^{-1})	8.1	8.5	8.6	8.8	8.3	8.1
Saffron (mg corm^{-1})	19.6	22.3	19.6	14.1	14.7	11.2

a) The range of flowering within each batch of corms is determined by the duration of the incubation at 25 ºC.

b) Early by early May; Late by the end of June. Data from Quero, Toledo, Spain.

Figures

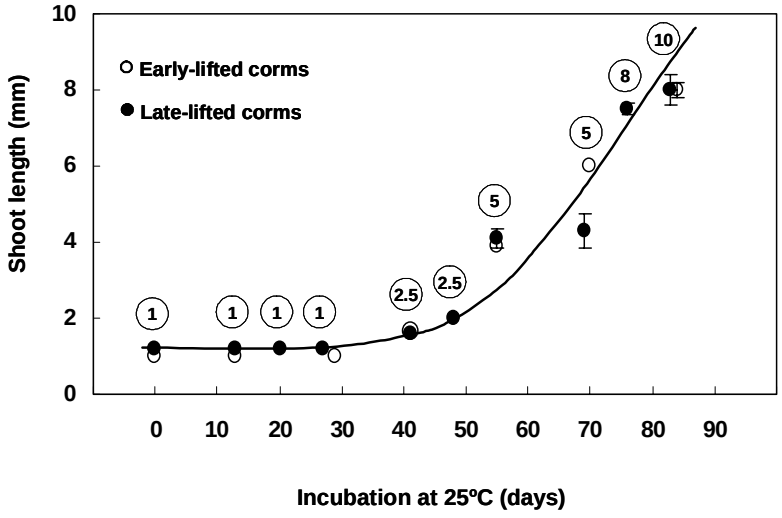

Fig. 1. The time course of cataphyll (=shoot) growth and stage of flower initiation (numerical score encircled) during incubation of the corms at 25 ºC. Data for early lifted (early May; ○) and late lifted (early July; ●) corms. Numerical score for flower initiation as defined by Molina et al. (2004a). Score 4, bract formation; score 6, stamen formation; score 8, tepal formation; score 10, gynoecium formation.

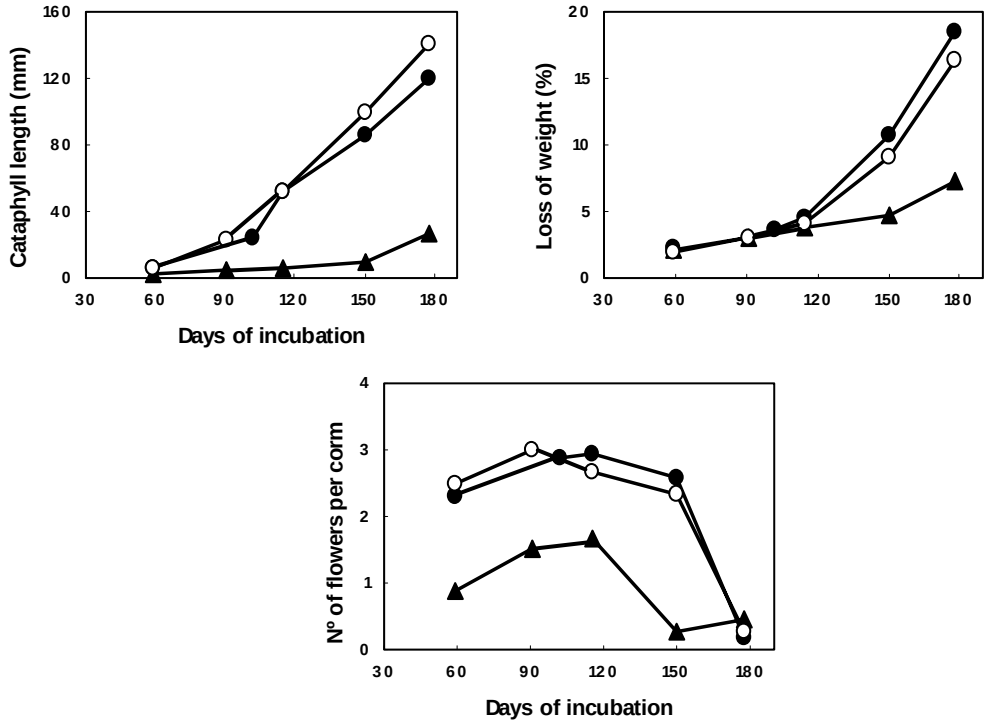

Fig. 2. The effect of duration of high temperature incubation effects on flower formation, cataphyll length and loss of weight by the corms. Corms incubated either at 25 (●) or 30 ºC (▲). Some corms incubated at 25 ºC were covered with a layer of expanded clay to reduce transpiration losses (○). Flower count done at flower emergence after incubating the corms at 17 ºC.

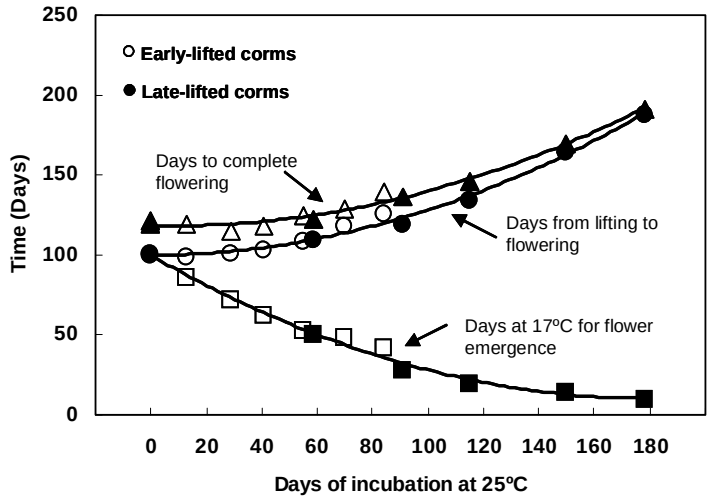

Fig. 3. The effect of the duration of incubation at 25 ºC on the time needed at 17 ºC for the beginning of flower emergence and the days from corm lifting to flowering. The difference between the days to the beginning of flower emergence (indicated by the line marked days from lifting to flowering) and days to complete flowering is the duration of flowering.