Chapter 7

Saffron "seed", the corm

Alireza Koocheki and Seyyed-Mohammad Seyyedi

Department of Agrotechnology, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran

Chapter Outline

7.1 Introduction

Saffron (*Crocus sativus* L.) is globally known for its flowers value in food and pharmaceutical industries (Giaccio, 2004; Xi et al., 2007). Despite the numerous studies on saffron flowers, insufficient attention has been paid to saffron corms as the main important factor in saffron flowering. Although saffron's phenological stages are essentially defined based on corm formation and growth (Gresta et al., 2008), agronomic management is performed mainly based on flower emergence rather than corm growth (Koocheki et al., 2016a; Rubio-Moraga et al., 2013).

In 2016, Iran's saffron cultivation area and production were 105,200 ha and 336 tons, respectively, with an average farm age of 6−10 years (Agricultural Statistics, 2017). Hence, 12.5% of the total farm area (13,150 ha) is estimated to be about 8 years old. On the other hand, given the average yield of 31.85 ton ha^{-1} saffron corm from 8-year-old farms (Mollafilabi et al., 2015), the total annual harvest of saffron corm in Iran is recorded as 418,830 tons.

7.2 Corm botanical criteria

7.2.1 Mother and daughter corms

Saffron is a sterile triploid geophyte plant, which is propagated by corms (Fernandez, 2004; Gresta et al., 2008). Botanically, corms are short and thick underground stems covered with fibrous reticulated leaf tunics to protect a creamy colored smooth epidermis (Molina et al., 2004b). The shape of saffron corm varies from circular to elliptical, and its base is usually flat or slightly curved (Kumar et al., 2009; Renau-Morata et al., 2013).

The saffron plant is propagated by mother corms due to its sterility caused by being triploid (Nehvi et al., 2010). Mother corms, which are underground organs, have meristematic tissues that generate new corms as replacement or daughter corms (Fig. 7.1).

Mother corms deteriorate gradually with increasing daughter corm growth. In other words, each mother corm produces new daughter corms before withering (Renau-Morata et al., 2012). Each daughter corm is also considered as a potential mother corm for the next growing season (Bhagyalakshmi, 1999). At the end of growing season, remaining mother corms (Fig. 7.2) appear as brown, oval, and flat disks attached to the daughter corms (Kumar et al., 2009).

Saffron: Science, Technology and Health. DOI: https://doi.org/10.1016/B978-0-12-818638-1.00007-1

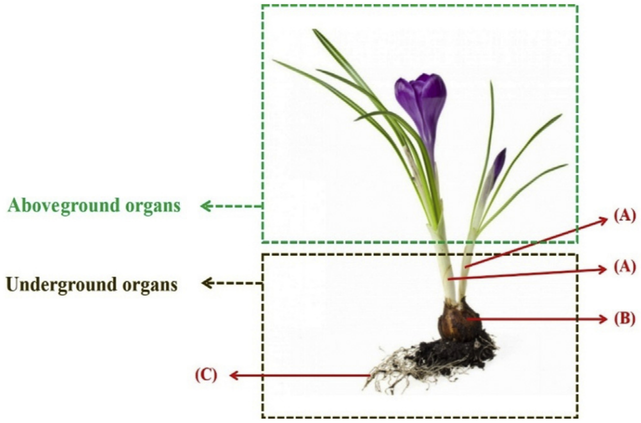

FIGURE 7.1 Saffron above- and underground organs. (A) Stem sheath, (B) mother corm, and (C) absorbing (fibrous) roots. The formation and growth of saffron daughter corms affect flower yield during the next growing season. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

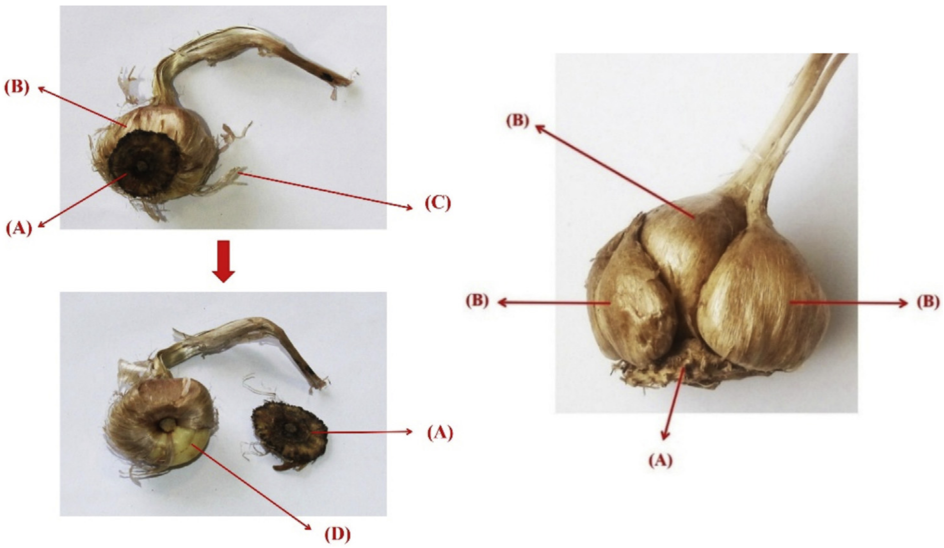

FIGURE 7.2 Daughter corm organography. (A) Remaining mother corm, (B) daughter corm, (C) fibrous reticulated leaf tunics, and (D) uncovered smooth epidermis corm. During each growing season, saffron propagates vegetatively by means of a tuberous-bulb formation and growth called the mother corm. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during the growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

Accordingly, saffron stigma yield highly depends on daughter corm growth in the previous growing season, because the reproductive mechanism at the onset of the growing season is affected by the concentration of nutrient reserves in the corms (Gresta et al., 2008; Koocheki and Seyyedi, 2019; Renau-Morata et al., 2012).

7.2.2 Main and lateral buds

From a botanical point of view, growth induction and daughter corm formation is controlled by cell division in apical, subapical, and lateral (axillary) buds (Kumar et al., 2009). The apical and subapical buds are known as vegetative-reproductive sprouts, while the lateral buds are differentiated for the production of leaves (Bhagyalakshmi, 1999; Kumar et al., 2009). By removing leaf tunics pale and circular lines become visible on the epidermis surface. In addition, the epidermis surface is creamy and yellowish in color and has dots on it. The brown apical and lateral buds are visible on the epidermis surface (Fig. 7.3).

The apical bud is located at the tip of the corm, but lateral buds are found only on the sides (Abrishamchi, 2003; Kumar et al., 2009). Depending on mother corm size, the number of subapical and lateral buds range from 1 to 2 and from 2 to 10 buds, respectively (Koocheki and Seyyedi, 2015a; Molina et al., 2005a). Normally, buds become smaller

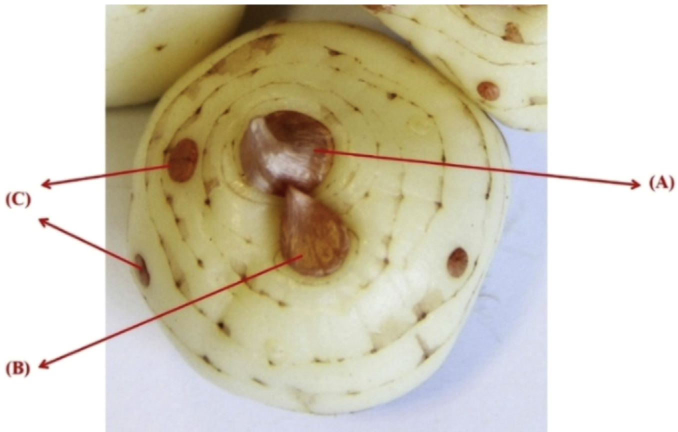

FIGURE 7.3 Saffron corm morphology after removing leaf tunics. (A) Apical, (B) subapical, and (C) lateral (axillary) buds. From a botanical point of view, saffron reproduction is made through the growth of meristem tissues and establishment of new daughter corms produced by the mother corms. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

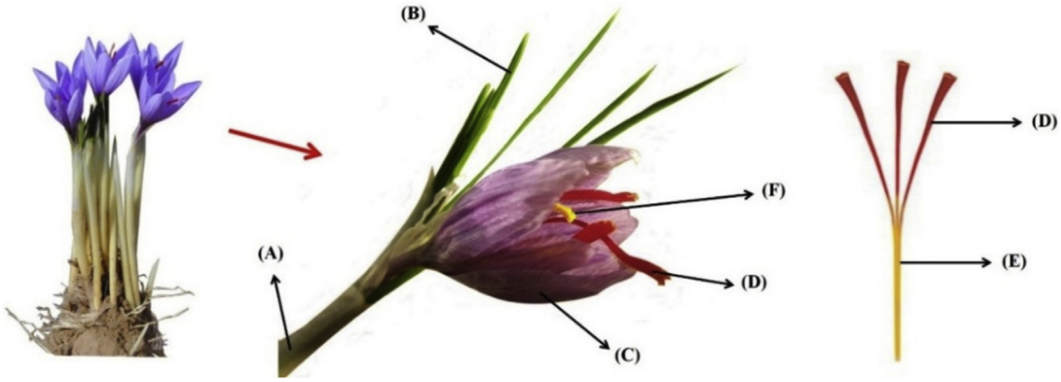

FIGURE 7.4 Saffron flowering due to stimulating reproductive buds on mother corms. (A) Stem sheath, (B) initial leaves, (C) petals, (D) stigma, (E) style, and (F) stamen. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

from the tip to the base of each corm (Tavakkoli et al., 2014). On the other hand, apical buds are more capable of forming daughter corms than lateral ones (Fig. 7.3).

Saffron corm dormancy starts after drying aboveground parts, normally in May (Babaei et al., 2014; Koocheki et al., 2016b). The dormancy has two phases: true and apparent dormancy. Until mid-July, meristematic cells of the tip of the buds have detained activity, which is called true dormancy (Sadeghi et al., 2003). Apparent dormancy is also divided into two stages; during the first stages (until early August) vegetative organs start to develop (Abrishamchi, 2003), whereas in the second stage (until late August) reproductive organs differentiate (Koul and Farooq, 1982; Sadeghi et al., 2003). The dormancy is broken and flowering-related physiological processes start to occur at the end of August (Abrishamchi, 2003; Koocheki and Seyyedi, 2016a). The first flowers start to appear (Fig. 7.4) through increasing reproductive organ activity with decreasing temperature in autumn (Kumar et al., 2009; Rabani-Foroutagheh et al., 2013).

Flowers appear before or after or at the same time of leaves appearance depending on weather conditions (Koocheki and Seyyedi, 2015a; Molina et al., 2004a). As can be seen from Fig. 7.5 a relative increase in air temperature, postpone flowering until the leaves have started to appear (Arsalani et al., 2015; Kumar et al., 2009). At this stage, daughter corm growth reduces, as more energy is needed for flowering and early growth (Maleki et al., 2011; Renau-Morata et al., 2012).

After flowering, vegetative growth starts to increase and the first daughter corms appear on mother corms (Gholami et al., 2017; Koocheki et al., 2016a). The daughter corms may continue to form throughout the vegetative growth period (Fig. 7.6). However, the daughter corm growth rate reaches to its maximum in December (Koocheki and Seyyedi, 2015a; Renau-Morata et al., 2012).

As mentioned earlier, apical buds are more capable of producing flowers and daughter corms in comparison with lateral buds (Amirshekari et al., 2007; Tavakkoli et al., 2014). However, buds stimulation increases competition between these buds (Sabet-Teimouri et al., 2010; Tavakkoli et al., 2014). Extensive use of water and fertilizers,

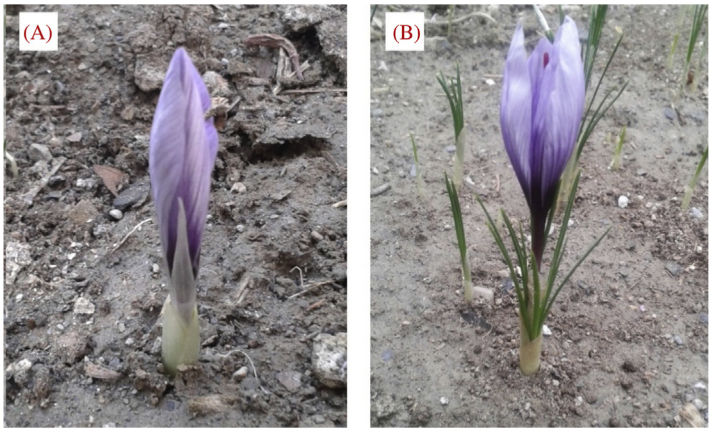

FIGURE 7.5 Saffron flowering process in autumn. (A) Saffron flower appearance before its leaves emerge and (B) saffron flower appearance after its leaves emerge.

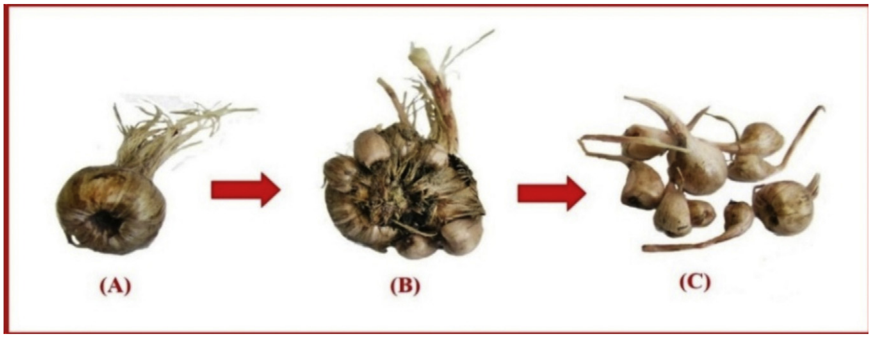

FIGURE 7.6 Daughter corm formation from mother corm. (A) A mother corm at planting time (11.93 g), (B) the mother corm at the end of the first growing season, and (C) daughter corms (average weight per corms: 1.71 g). *From Koocheki, A., Seyyedi, S.M., 2016. Effects of corm size, organic fertilizers, Fe-EDTA and Zn-EDTA foliar application on nitrogen and phosphorus uptake of saffron (*Crocus sativus *L.) in a calcareous soil under greenhouse conditions. Not. Sci. Biol. 8, 461–467.*

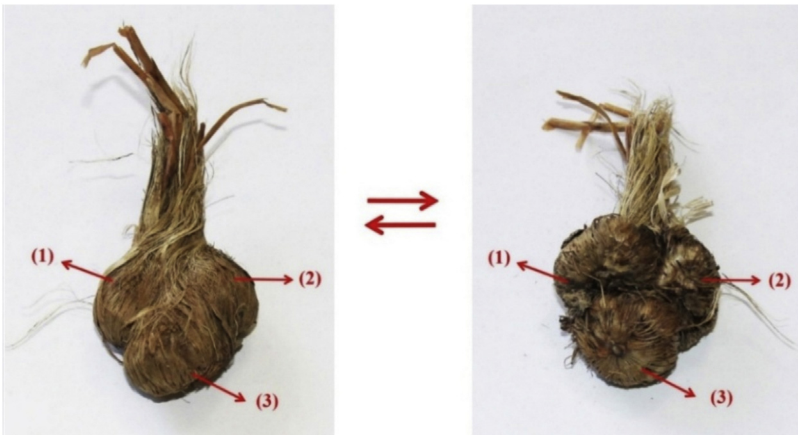

FIGURE 7.7 Formation of three large daughter corms (average weight: 10.31 g) from mother corm. 1 to 3: Dense and compact daughter corms at the end of the growing season. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

especially nitrogen as well as increased temperature, increase the competition between saffron buds (Chaji et al., 2013; Koocheki and Seyyedi, 2015b). To prevent competition, removing extra buds has been suggested (Kumar et al., 2009; Tavakkoli et al., 2014). Although removing weak buds may reduce daughter corm numbers, it may result in increased daughter corm weight, which plays a key role in increasing saffron yield (Fig. 7.7). In general, in corms weighing 6–8 g, the most desirable bud number is three: two lateral buds and one apical bud (Tavakkoli et al., 2014).

7.2.3 Root system

There are two structurally and functionally different types of roots in saffron: absorbing (fibrous) and contractile roots (Fig. 7.8). The fibrous roots (about 1–3 mm diameter) that form from the base of each corm absorb water and nutrients

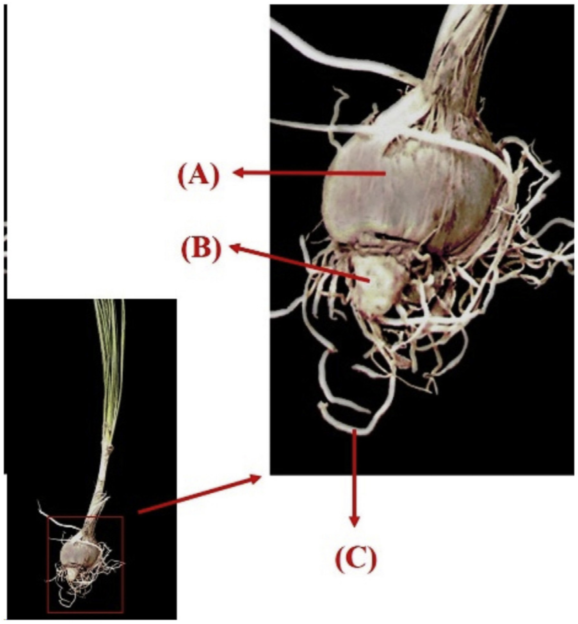

FIGURE 7.8 Formation and growth of root system in saffron mother corm. (A) Mother corm, (B) initial growth of contractile root at the base of the mother corm (pulling and pushing activity of contractile roots enables mother and daughter corms to move into the ground), and (C) absorbing root of mother corm (about 1–3 mm diameter). *From Koocheki, A., Ebrahimian, E., Seyyedi, S.M., 2016. How irrigation rounds and mother corm size control saffron yield, quality, daughter corms behavior and phosphorus uptake. Sci. Hortic. 213, 132–143.*

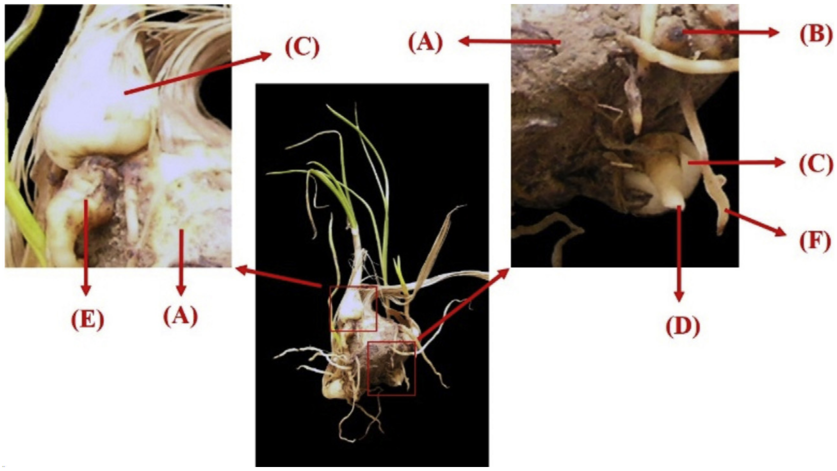

FIGURE 7.9 Formation and growth of daughter corms above, below, or at the side of each mother corm. (A) Mother corm, (B) mother corm's bud (by growing these buds, new daughter corms are formed), (C) formation of new daughter corms below or at the side of the mother corm, (D) formation of contractile root at the base of the new daughter corm, (E) more growth of contractile root, and (F) mother corm's absorbing roots. *From Koocheki, A., Ebrahimian, E., Seyyedi, S.M. 2016a. How irrigation rounds and mother corm size control saffron yield, quality, daughter corms behavior and phosphorus uptake. Sci. Hortic. 213, 132–143.*

(Koocheki et al., 2016a; Kumar et al., 2009). Depending on soil microbial, physical and chemical properties, mother corm size and soil moisture content, the depth of penetration of these roots in the soil can be up to 30 cm (Koocheki and Seyyedi, 2015a). The contractile roots (about 3–10 mm diameter), which are usually tuber, fleshy, and white in color pull the plants deeper into the soil with a strong pulling force (Kumar et al., 2009; Rajaei et al., 2009; Zeybek et al., 2012).

Being a perennial species (Gresta et al., 2016), the saffron parts that are above and underground grow more from year-to-year (Koocheki et al., 2016b; Yarami and Sepaskhah, 2015). Absorbing and contractile root density (Fig. 7.9) increases from year-to-year with increasing daughter corm formation and density in each year (Nassiri-Mahallati et al., 2007; Sepaskhah and Kamgar-Haghighi, 2009). Yarami et al. (2011) noted that evapotranspiration in saffron increases from year-to-year due to additional corm growth and vegetation. Hence, increases in growth, especially in underground parts, lead to absorbing and contractile root system development (Fig. 7.10) and an increase in the plant's ability to uptake nutrients in each subsequent year (Seyyedi et al., 2018; Yau et al., 2006).

In general, developed aboveground organs stimulate root growth and in turn improve plant capability to uptake water and nutrients (Alizadeh et al., 2009; Asadi et al., 2014; Koocheki et al., 2014). On the other hand, an increase in

FIGURE 7.10 Saffron compacted root system in the third year. From the third year onward, due to daughter corm increased growth mother and daughter corms appear as a dense and compact mass, making it difficult to distinguish them from each other. Furthermore, root system expansion increases in daughter and mother corms compared with previous years. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

root system expansion improves plant growth and daughter corm formation (Kafi et al., 2002; Renau-Morata et al., 2012). Therefore, the growth of the above- and underground parts of saffron is in line with each other and leads to better absorption of most nutrients from the soil (Gholami et al., 2017; Gresta et al., 2009; Koocheki and Seyyedi, 2016a).

7.2.4 Developmental stages and phonological description

Saffron is known as a perennial crop in terms of agronomy but an annual plant in botany (Koocheki and Seyyedi, 2015b). In fact, saffron fields can survive for 6–8 years, depending on agronomic management, soil microbial, physical and chemical properties, or climate parameters (Halvorson, 2008; Helalbeyki et al., 2015; Khademi et al., 2014). Developmental stages and phonological descriptions are based on corm formation and growth (Koocheki and Seyyedi, 2015a).

After flowering in November, daughter corms start to form (Koocheki and Seyyedi, 2016b). Later in March, when vegetative growth reaches its maximum, daughter corm formation will be complete (Koocheki and Seyyedi, 2015b; Renau-Morata et al., 2012). All aboveground parts will dry and daughter corms will remain dormant from May to September (Fig. 7.11). During the dormancy period, especially true dormancy, the activity of all antioxidant enzymes in the apical, subapical, and lateral buds of saffron corms, including peroxidase, polyphenol oxidase, superoxide dismutase, and catalase, has been observed to be at the minimum level (Nasirian et al., 2014; Sabet-Teimouri et al., 2010). Hence, saffron fields are free of vegetation during the summer season (Koocheki et al., 2014; Renau-Morata et al., 2012).

In general, saffron vegetative growth and stigma yield are typically low in the first year (Feizi et al., 2015; Koocheki and Seyyedi, 2015b). From the second year, increase in saffron yield is achieved, which is due to increasing numbers of daughter corms (Koocheki and Seyyedi, 2015b; Koocheki et al., 2014; Rezvani-Moghaddam et al., 2013b).

7.2.5 Corm nutrient content

The saffron corm, the organ intended for planting (Koocheki et al., 2011), contains the storage of nutrient reserves (Kumar et a, 2009; Yau et al., 2006). The nutrient reserves in the mother corms are vital for plant establishment, flowering, and early growth (Koocheki et al., 2014; Mirsafi et al., 2016; Sadeghi et al., 2014). It has been proven that daughter corm growth depends on mother corms until they become independent (Hassanzadeh-Aval et al., 2014; Koocheki and Seyyedi, 2015b). Dynamic nutrients including N and P may be remobilized and stored in the corms, simultaneously with leaves senescence at the end of each year, so they can be reused at the beginning of the next growing season (Gholami et al., 2017; Koocheki et al., 2014).

Saffron corm has a set of micro- and macronutrients. N, P, and K contents in saffron corm are recorded as 1.41%, 0.28%, and 0.92%, respectively, on a dry weight basis (Koocheki and Seyyedi; 2015a). The percentage of nutrients in saffron corms is directly related to corm weight (Gresta et al., 2008; Koocheki et al., 2014). An increase in the size of saffron corms results in an increase of nutrients and hence an increase in N and P uptake (Koocheki and Seyyedi, 2019). Nitrogen and phosphorus concentration in large-sized daughter corms increased up to 24% and 36%, respectively, compared with small-sized daughter corms (Koocheki and Seyyedi, 2015b) (Table 7.1).

FIGURE 7.11 Vegetative stages and phenological description of saffron based on daughter corm growth. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

TABLE 7.1 Effects of mother corm size and year on number of daughter corms and N and P concentration in saffron organs.

Experimental treatments	N concentration ($g\ kg^{-1}$)				P concentration ($g\ kg^{-1}$)			
	Daughter corms			Aerial part	Daughter corms			Aerial part
	0.1–4 g	4.1–8 g	Over 8 g		0.1–4 g	4.1–8 g	Over 8 g	
Mother corm size (g)								
4 and lower	8.59 a	9.07 d	12.04 d	11.59 a	1.64 a	1.85 b	2.41 b	2.01 a
4.1–8	8.60 a	9.69 c	13.24 c	11.47 a	1.68 a	1.93 b	2.51 b	1.96 a
8.1–12	8.49 a	10.32 b	13.99 b	11.61 a	1.67 a	1.98 ab	2.67 ab	2.03 a
Over 12	8.62 a	10.72 a	14.88 a	11.57 a	1.69 a	2.18 a	2.82 a	1.96 a
Year								
First year	8.54 a	9.74 a	12.74 b	11.55 a	1.70 a	1.90 b	2.42 b	1.97 a
Second year	8.62 a	10.16 b	14.34 a	11.57 a	1.64 a	2.07 a	2.78 a	2.01 a

Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT).
Source: From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.

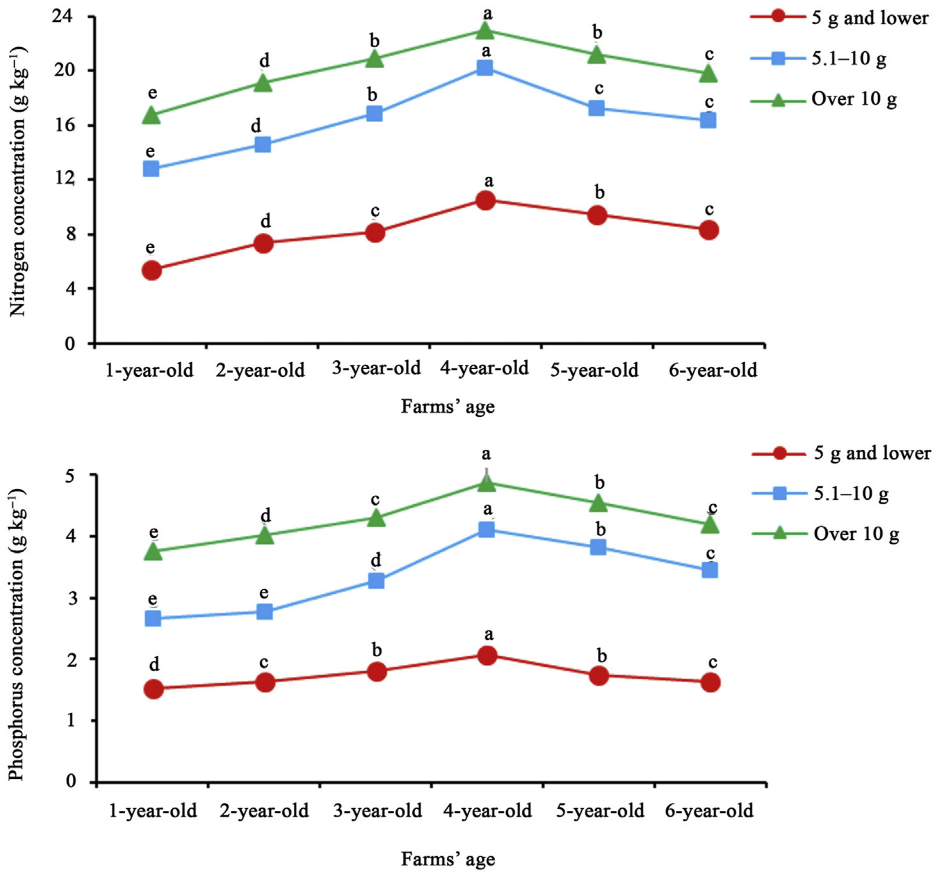

FIGURE 7.12 Effects of farm age on nitrogen (A) and phosphorus (B) uptake in saffron daughter corms. Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT). *From Koocheki, A., Seyyedi, S.M., 2019. Nutrition management and farm's age affect saffron daughter corms behavior, nutrients uptake and economic water and fertilizer use efficiency: a large scale on-farm experiment in Torbat Heydarieh, Iran. Commun. Soil Sci. Plant Anal. In Press.*

Farm age is another factor that can affect the concentration of nutrient reserves in corms (Khademi et al., 2014; Rahimi-Daghi et al., 2015). Koocheki and Seyyedi (2015b) reported that N and P concentration in medium- and large-sized daughter corms increased in the second year compared with the first year. In another study (Koocheki and Seyyedi, 2019), N and P percentage in small-, medium-, and large-sized daughter corms increased with increasing farm age from 1 to 4 years old. However, these parameters decreased with increasing farm age from 4 to 6 years (Fig. 7.12).

As mentioned before, with the activation of the corm buds, daughter corms can gradually grow (Molina et al., 2004a; Renau-Morata et al., 2012). The growth and differentiation processes in the apical, subapical, and lateral bud meristems usually occurs after flowering, and as a result of cell division, the first daughter corms are formed on the mother corm (Yarami and Sepaskhah, 2015; Yasmin and Nehvi, 2014). This causes a relative increase in the growth of saffron above- and underground organs each year. However, if this phenomenon causes an excessive increase in saffron corms during the perennial lifecycle, it can promote competition over water and nutrients between daughter corms (Gholami et al., 2017; Koocheki and Seyyedi, 2016b; Koocheki et al., 2016a).

The imposition of drought stress is another factor that affects the nutrient concentration of saffron corms (Koocheki and Seyyedi, 2016b; Sepaskhah and Kamgar-Haghighi, 2009; Sepaskhah and Yarami, 2009). In general, the nutrient concentration gradually increases due to an increase in the intensity of drought stress (Koocheki and Seyyedi, 2016b). Phosphorus concentration in the saffron parts increases with decreasing irrigation rounds (Koocheki et al.; 2016a) and also reduction in saffron water requirement from 100% to 50% increased phosphorus concentration in daughter corms (Koocheki et al., 2014) (Fig. 7.13).

Generally, nutrient and metabolite accumulation along with a reduction in cell volume expansion increase plant resistance against water-deficit stress (Chaves et al., 2002; Ebrahimian and Bybordi, 2011; Wu et al., 2016; Zhang et al., 2017). Drought stress increases protein content in corms, leaves, and roots of saffron (Maleki et al., 2011). Mobile elements, especially phosphorus, can transfer from shoots to underground organs at the end of the growing season before entering into dormancy (Koocheki et al., 2014). Hence, it seems that an increase in nutrient concentration due to limited irrigation is an adaptability mechanism to deal with drought seasons during the perennial lifecycle of saffron.

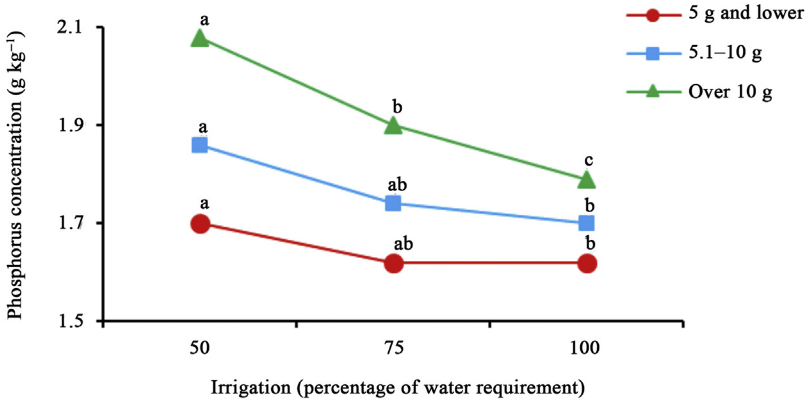

FIGURE 7.13 Effects of irrigation regimes on phosphorus concentration in saffron daughter corms. Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT). *From Koocheki, A., Seyyedi, S.M., Jamshid Eyni, M., 2014. Irrigation levels and dense planting affect flower yield and phosphorus concentration of saffron corms under semi-arid region of Mashhad, Northeast Iran. Sci. Hortic. 180, 147–155.*

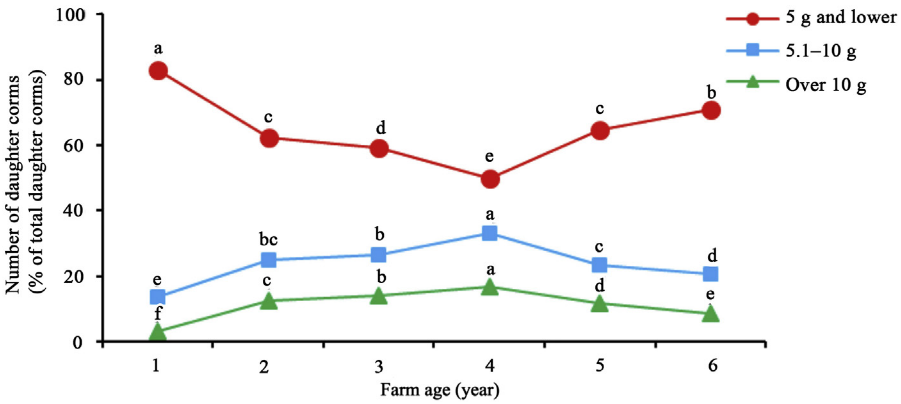

FIGURE 7.14 Effects of farm age on number of daughter corms (% of total daughter corms). Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT). *From Koocheki, A., Seyyedi, S.M., 2019. Nutrition management and farm's age affect saffron daughter corms behavior, nutrients uptake and economic water and fertilizer use efficiency: a large scale on-farm experiment in Torbat Heydarieh, Iran. Commun. Soil Sci. Plant Anal. In Press.*

7.2.6 Field age effect on corm production

During each growing season, saffron passes its phonological stages by producing daughter corms from each mother corm (Behnia et al., 1999). New corms are generally formed on older corms after flowering (Renau-Morata et al., 2012), so that plant density increases in each growing season (Khademi et al., 2014; Mollafilabi et al., 2015). Accordingly, saffron stigma yield in the first year is usually low and in the fourth to fifth years, the highest stigma yield is recorded. Nonetheless, due to the high number of corms formed in the soil, increased soil stiffness and compaction, and reduced soil fertility, a gradual reduction of flower yield can be observed (Khademi et al., 2014; Koocheki and Seyyedi, 2019; Rahimi-Daghi et al., 2015).

Koocheki and Seyyedi (2019) noted that the number of medium- and large-sized daughter corms and weight per m^2 increased with increasing farm age from 1 to 4 years. However, these parameters decreased with increasing farm age from 4 to 6 years. The lowest percentage of small-sized daughter corms was also obtained from 4-year-old farms (Fig. 7.14).

In a similar study (Mollafilabi et al., 2015), the average number of saffron corms from 1- to 8-year-old farms was recorded as 55, 65, 71, 128, 151, 152, 184, and 248 per m^2, respectively, while the highest large-sized corm percentage (over 8 g) was observed from 3-year-old farms (Table 7.2).

Increase in saffron flower yield is mainly due to leaf development and the expansion of the root system during the first to fourth growing season (Fig. 7.15). Absorbing and contractile root density increase from year-to-year with increasing daughter corm formation and density in each year (Mollafilabi et al., 2015; Nehvi et al., 2010). Increase in growth, especially underground parts, leads to absorbing and contractile root system development and increase in plants' ability to uptake nutrients such as phosphorus, which in turn increases phosphorus acquisition efficiency in each consecutive year (Koocheki et al., 2016a).

7.3 Agronomical practices

7.3.1 Corm lifting time and storage

As mentioned before, daughter corms become independent of the mother corms after aboveground leaves dry out in May (Koocheki and Seyyedi, 2015a; Nehvi et al., 2010). Each daughter corm continues to grow as a mother corm

TABLE 7.2 Saffron corm number by farm age.

Farm age (year)	Corm number (%)				Total corm number (m^2)
	8 g and lower	8.1–16 g	16.1–24 g	Over 24 g	
1	63.15	29.63	5.43	1.78	55
2	49.41	25.10	14.68	10.8	65
3	40.91	28.55	18.60	11.9	71
4	63.01	27.12	8.10	1.76	128
5	65.91	25.65	6.35	2.07	152
6	47.89	32.97	14.34	4.78	151
7	77.73	19.26	2.76	0.24	184
8	80.11	19.24	0.63	0.00	248

Source: From Mollafilabi, A., Koocheki, A., Rezvani-Moghaddam, P., Nassiri Mahalati, M., 2015. Investigation on the effect of location and field age on yield and frequency of different corm weights of saffron (*Crocus sativus* L.). Iran. J. Field Crop. Res. 12, 605–612 (in Persian).

FIGURE 7.15 Comparing saffron stand between 1- and 4-year-old farms. In general, saffron vegetative growth is typically low in the first year. From the second year on, an increase in saffron yield is seen, which is primarily due to the increase in the number of daughter corms, additional leaf growth, and expansion of the root system. In the fourth year, saffron produces more roots able to increase the absorption of nutrients, compared to the first year.

during the next growing season (Behnia et al., 1999; Koocheki et al., 2017). Accordingly, mother corms are considered as reproductive organs, that is, seeds (Koocheki et al., 2014).

Saffron dormancy starts with a drying phase (Behnia et al., 1999; Kumar et al., 2009). Saffron corms cannot be stored in cold rooms for a long time and prefer to complete their phenological cycles under the soil surface (Koocheki et al., 2016a; Molina et al., 2004b). Hence, poor storage practices may cause serious damage to the corms through increasing respiration and oxidation as well as cause more sensitivity to the activity of pests and diseases (Fig. 7.16), especially fungal pathogens such as *Aspergillus niger*, *Penicillium digitatum*, and *Rhizopus stolonifera* (Saeedizadeh, 2014; Sud et al., 1999). However, irrespective of corm lifting time, the optimal duration of corm incubation before planting was determined to be 30°C for 20 days (Molina et al., 2004b).

Reducing storage period from harvesting to planting, controlling storage conditions in terms of temperature, moisture, light, gases, and pests and diseases are considered as the most important measures for saffron corm storage (Molina et al., 2005a; Nassiri-Mahallati et al., 2007). Early true dormancy is the most suitable time for taking daughter corms out of the soil (Koocheki and Seyyedi, 2015a; Koocheki et al., 2016a). Reducing the storage period extends dormancy and allows corms to be able to better establish themselves in new planting beds (Behnia et al., 1999; Molina et al., 2004a). Therefore, a reduction in storage period would increase flowering in the next blooming season (Nassiri-Mahallati et al., 2007; Sadeghi et al., 2003).

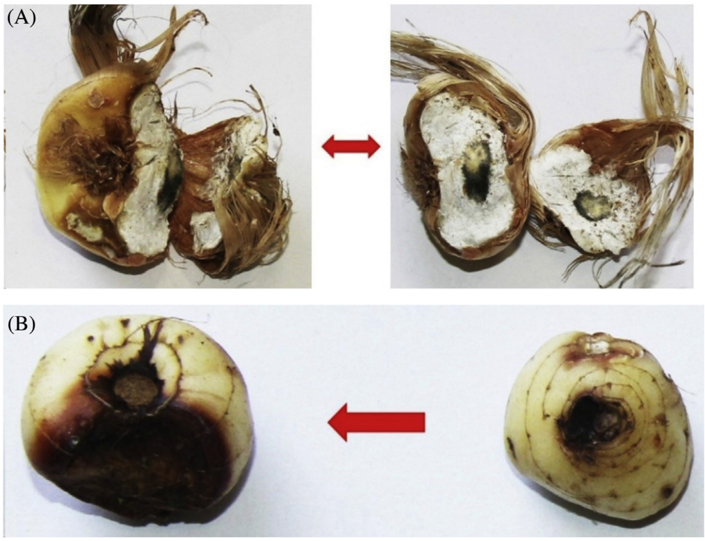

FIGURE 7.16 Saffron corm decay due to poor storage practices. (A) Saffron corm rot (*Penicillium digitatum*) and (B) corm neck rot (*Rhizoctonia crocorum*). *From Koocheki, A., Seyyedi, S. M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

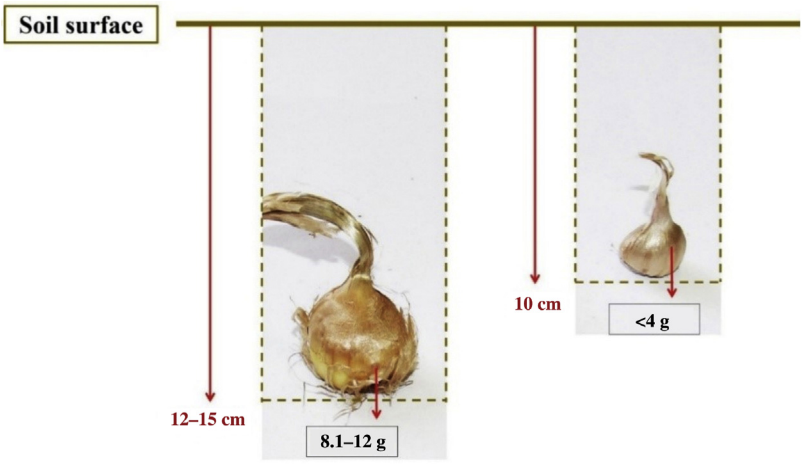

FIGURE 7.17 The best planting depth for saffron corms. In general, by increasing the mother corm size, planting depth can be slightly increased. *From Koocheki, A., Seyyedi, S.M., 2015. Phonological stages and formation of replacement corms of saffron (*Crocus sativus *L.) during growing period (review article). J. Saffron Res. 3, 134–154 (in Persian).*

7.3.2 Planting time

Due to reduced storage period, saffron corm planting in the beginning or middle of the true dormancy period is known to induce flower formation (Rostami and Mohammadi, 2013; Sadeghi et al., 2003). During this period, saffron corm growth is suppressed by inhibitor hormones (Koul and Farooq, 1982; Sadeghi et al., 2014), which make farmers able to lift corms out of the soil for future replanting (Ghobadi et al., 2015; Molina et al., 2004b). After this period, the corms start to grow and tissue differentiation occurs. Hence, they are more sensitive to translocation (Koocheki and Seyyedi, 2015a; Sadeghi et al., 2003). Saffron corm planting after terminating dormancy until the end of the summer results in reduced flower yield since flower induction is affected and establishment time reduced (Ghobadi et al., 2015; Koocheki and Seyyedi, 2015b; Rostami and Mohammadi, 2013). Therefore, the best time for daughter corm planting is sometime between daughter corm harvesting and the middle of the true dormancy period (early July).

7.3.3 Planting depth

Corm planting depth plays a key role in flowering and daughter corm growth. Planting depth depends on mother corm weight; a depth of 12–15 cm is recommended for 8.1–12 g corms (Koocheki et al., 2011). By increasing or decreasing the mother corm size, planting depth can be slightly changed (Fig. 7.17).

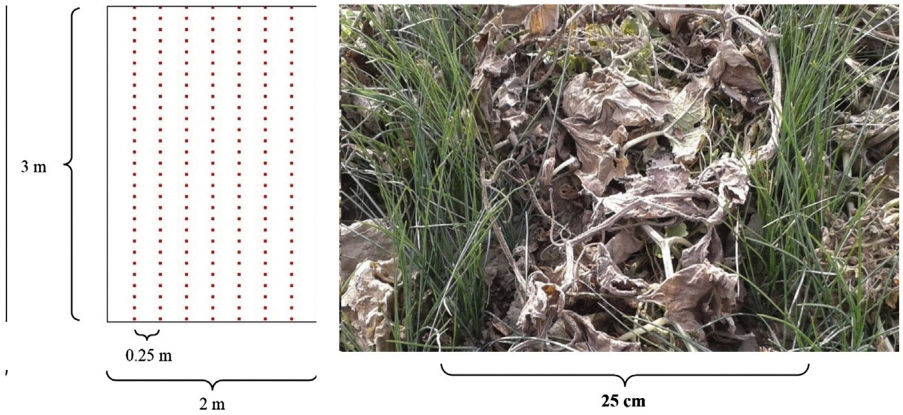

FIGURE 7.18 Saffron corms planting using basin method at 100 corms m^{-2} and 25 cm distance between planting rows. *From Koocheki, A., Rezvani-Moghaddam, P., Seyyedi, S.M., 2019. Saffron-pumpkin/watermelon: a clean and sustainable strategy for increasing economic land equivalent ratio under limited irrigation. J. Clean. Prod. 208, 1327–1338.*

Deeper planting causes a significant reduction in flowering, especially for buds located on the base of the corms (De Juan et al., 2009; Gerdakaneh et al., 2017). Most of the daughter corms are generated from the subapical or lateral buds of the mother corms, so it is not surprising that an increase in planting depth is a reason for a reduced number of daughter corms (Aghazadeh and Hemmatzadeh, 2012; Koocheki and Seyyedi, 2015a). On the other hand, surface planting can cause serious injury to corms due to heat stress in summer or cold stress in winter (De Juan et al., 2009; Gerdakaneh et al., 2017).

7.3.4 Row spacing, corm density

In addition to planting depth, the planting pattern and mother corm density are considered as crucial factors determining daughter corm generation and flower yield (De Juan et al., 2009; Koocheki et al., 2011; Nazarian et al., 2016). In the row planting method, 75–100 corms m^{-2} with 25 cm distance is recommended (Fig. 7.18). Depending on mother corm size, 8–13 tons ha^{-1} of corm is needed to reach to this planting density (Koocheki et al., 2011).

Even when using the recommended planting pattern and density, saffron yield in the first year of cultivation is usually low, but from the second year, it increases due to daughter corm formation (Khademi et al., 2014; Koocheki et al., 2016a; Mollafilabi et al., 2015). Therefore, saffron cultivation at low densities (conventional practice) is not economically feasible in the early years (Koocheki et al., 2011; Rezvani-Moghaddam et al., 2013b). Hence, higher planting densities, called dense corm planting, are considered as an alternative approach and planting pattern to offset yield loss during early years (Koocheki et al., 2014).

Higher planting densities help saffron to use growth resources such as nutrients efficiently. Dense planting up to 400 corms m^{-2} (Fig. 7.19) was investigated by Koocheki et al. (2012). In another study, Koocheki et al. (2011) investigated different planting densities and found that an increase in planting density (from 4 to 12 tons corms per hectare) leads to an increase in flower number and stigma yield.

7.3.5 Corm size/weight

Saffron corm is known as a source of food reserves (Koocheki and Seyyedi, 2015a; Maggio et al., 2006). With drying aboveground parts, the beginning of the dormancy period, the nutrients are remobilized to the underground organs (Akrami et al., 2014; Koocheki et al., 2014). Hence, nutrient reserves in mother corms determine saffron growth, especially during early growth stages (Hassanzadeh-Aval et al., 2014; Sahabi et al., 2017).

In general, heavier mother corms supply more energy to daughter corms (Douglas et al., 2014; Koocheki et al., 2014). Thus, mother corms with appropriate weight can improve plant regrowth and yield (Alizadeh-Salteh, 2016; De Juan et al., 2009; Renau-Morata et al., 2012). It has been proven that daughter corm growth depends on the mother corm until they become independent; consequently, mother corm size has a significant impact on daughter corm formation (Koocheki et al., 2014; Renau-Morata et al., 2012). Accordingly, the greater amount of food reserves in mother corms can increase flower yield by increasing plant growth and fibrous and contractile root expansion (Amirian and Kargar, 2016; Koocheki et al., 2016a; Tavakkoli-Kakhki et al., 2016).

Large-sized mother corms produce plants with more leaf area than those grown from small corms as a result of more carbohydrate reserves (Alizadeh-Salteh, 2016; Hassanzadeh-Aval et al., 2014). These plants are able to uptake

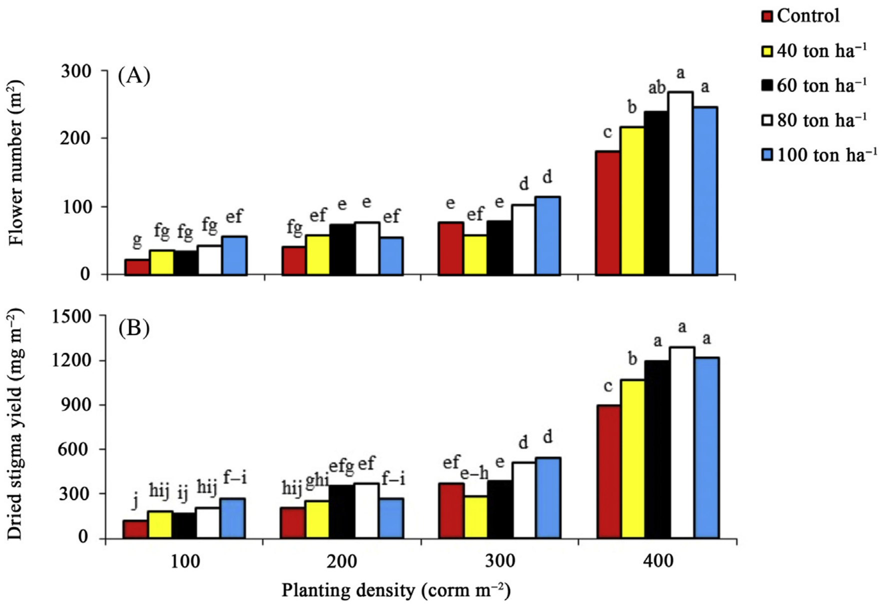

FIGURE 7.19 Interaction effects of corm density and manure application on flower number (A) and dried stigma yield (B) in saffron. Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT). *From Koocheki, A., Rezvani-Moghaddam, P., Mollafilabi, A., Seyyedi, S. M., 2012. Effects of high corm planting density and applying manure on flower and corm yields of saffron (*Crocus sativus *L.). Fourth International Saffron Symposium: Advanced in Saffron Biology Technology and Trade. 22–25 October 2012, Kashmir.*

TABLE 7.3 Effects of mother corm size on number of saffron daughter corms.

Experimental treatments	Number of daughter corms (m^2)			
	0.1–4 g	**4.1–8 g**	**Over 8 g**	**Total**
Mother corm size (g)				
4 and lower	99.94 (81.0) d	17.89 (15.1) d	4.89 (7.3) d	122.72 d
4.1–8	111.28 (71.1) c	34.89 (22.7) c	10.17 (6.9) c	156.33 c
8.1–12	120.72 (66.2) b	50.00 (26.9) b	13.00 (6.2) b	183.72 b
Over 12	145.83 (63.7) a	66.89 (29.0) a	17.72 (3.9) a	230.44 a

Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT).
The number in parenthesis indicated the percentage of daughter corms from total daughter corms.
Source: From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.

minerals from the soil and produce more daughter corms at the end of the growing season (Douglas et al., 2014; Koocheki and Seyyedi, 2016a). In fact, smaller corms produce plants with low growth rate and smaller leaf area compared with larger corms (Gresta et al., 2008; Khavari et al., 2016; Nassiri-Mahallati et al., 2007). Increase in leaf area, root dry weight, and active bud number in saffron corm due to increased mother corm size from 4 to 12 g has been confirmed by Koocheki et al. (2007). Similarly, the medium- (4.1–8 g) and large-sized (over 8 g) daughter corms number increased with increasing mother corm size (Table 7.3).

Koocheki et al. (2016a) noted that the maximum flower number and stigma yield were obtained when large-sized (> 10 g) mother corms were planted (Fig. 7.20A,B). The direct relationship between mother corm size and saffron flower yield has been reported by numerous researchers (De Mastro and Ruta, 1993; Gresta et al., 2008; Hassanzadeh-Aval et al., 2014; Kumar et al., 2009). In one study (Table 7.4), N acquisition efficiency, N use efficiency, N harvest index, P acquisition efficiency, P use efficiency, and P harvest index significantly improved by increasing mother corm size (Koocheki and Seyyedi, 2015b).

Generally, large-sized daughter corms are more important than small ones because small-sized daughter corms (4 g and lower) lead to less or no flower production (Gresta et al., 2008; Koocheki et al., 2014; Kumar et al., 2009). Considering the positive role of N and P in improving flower and corm yields (Chaji et al., 2013; Omidi et al., 2009),

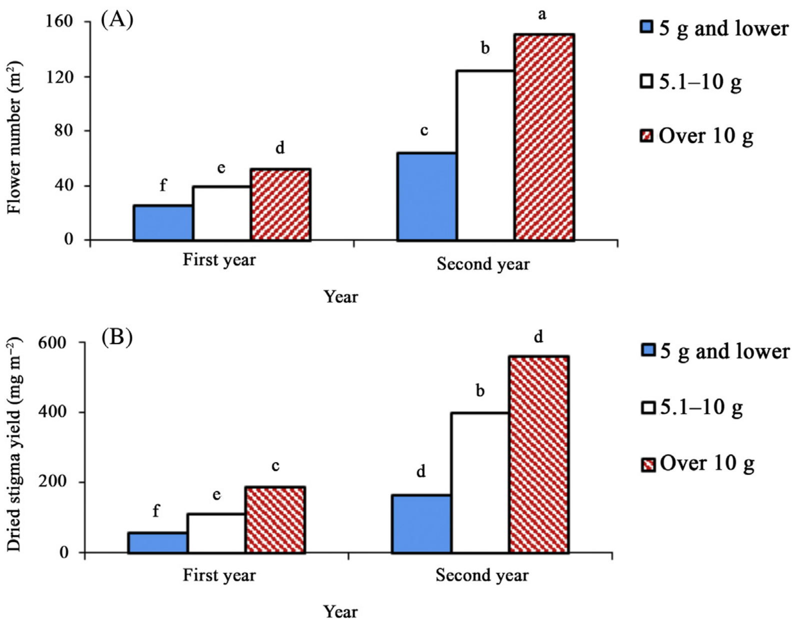

FIGURE 7.20 Interaction effects of year and mother corm size on flower number (A) and dried stigma yield (B) in saffron. Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT). *From Koocheki, A., Ebrahimian, E., Seyyedi, S.M., 2016. How irrigation rounds and mother corm size control saffron yield, quality, daughter corms behavior and phosphorus uptake. Sci. Hortic. 213, 132–143.*

TABLE 7.4 Interaction effects of year and mother corm size on nitrogen and phosphorus uptake in saffron.

Year	Mother corm size (g)	N acquisition efficiency (%)	N use efficiency ($g\ g^{-1}$)	N harvest index (%)	P acquisition efficiency (%)	P use efficiency ($g\ g^{-1}$)	P harvest index (%)
First year	4 and lower	16.87 g	6.29 f	38.35 e	8.76 f	3.49 f	40.96 de
	4.1–8	20.92 f	10.51 e	50.42 cd	11.13 e	6.03 e	55.03 bc
	8.1–12	24.88 e	13.59 d	54.16 bc	13.60 d	7.75 d	56.60 bc
	Over 12	30.26 d	18.30 c	60.93 a	16.94 c	10.88 c	64.82 a
Second year	4 and lower	28.19 d	9.19 e	32.72 f	14.29 d	5.17 e	36.16 e
	4.1–8	34.37 c	14.43 d	40.89 e	18.36 c	8.10 d	43.34 d
	8.1–12	42.93 b	21.70 b	49.62 d	23.66 b	12.60 b	52.23 c
	Over 12	50.85 a	28.90 a	55.92 b	28.98 a	17.55 a	59.37 ab

Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT).
The number in parentheses indicates the percentage of phosphorus content from the total plant.
From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.

an increase in the concentration of these elements, especially in large-sized daughter corms (over 8 g), could be an effective way to increase saffron yield. A positive correlation between N and P concentration in daughter corms (Fig. 7.21A) and between P and N harvest index (Fig. 7.21B) represents the importance of balanced nutrition in daughter corm growth and saffron production.

7.3.6 Corm size classification

Despite the importance of corm size in the flowering process of saffron, there is no uniform and precise index for corm classification. Moreover, the criteria presented in the available literature are somewhat different. For example,

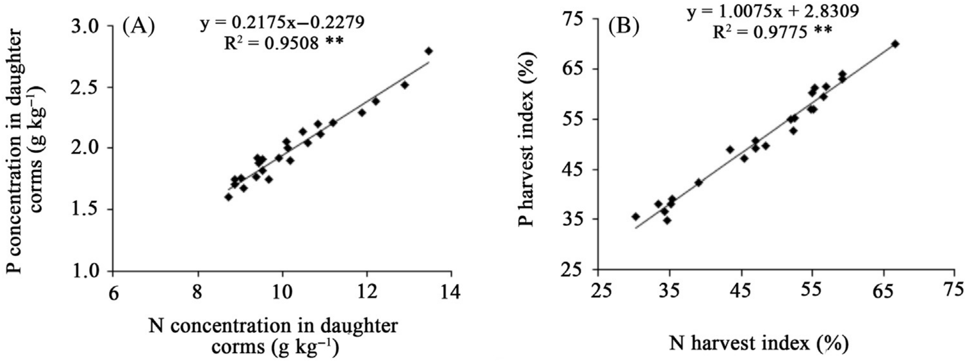

FIGURE 7.21 Relationship between (A) nitrogen (N) concentration and phosphorus (P) concentration in daughter corms and (B) N harvest index and phosphorus (P) harvest index in saffron. **Statistical differences at $P \leq 0.01$. *From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus *L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.*

FIGURE 7.22 Saffron corm sorting based on the weight value criterion. *From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus *L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.*

Ghobadi et al. (2015) considered 5–9 g mother corms as small-sized and 10–14 g mother corms as large-sized. Mollafilabi et al. (2015) divided saffron corms into four groups: small (8 g and lower), medium (1.8–16 g), large (16.1–24 g), and very large (over 24 g). In another study, Nassiri-Mahallati et al. (2007) identified 3 and 7 g mother corms as small-sized and large-sized, respectively.

In order to provide clear and precise criteria for classification of produced saffron corms, corm sorting has been proposed based on weight rather than diameter (De Mastro and Ruta, 1993), as it is more accurate and practical (Koocheki et al., 2016a). The weighing value is considered based on corm moisture content (16% plus corm tunics). As can be seen from Fig. 7.22 this sorting is as follows (Koocheki and Seyyedi, 2015b): (1) small-sized (4 g and lower), (2) medium-sized (4.1–8 g), (3) relatively large-sized (1.8–12 g), and (4) large-sized (over 12 g).

It is possible to produce corms over 12 g under field conditions (Mollafilabi et al., 2015; Seyyedi et al., 2018). Nonetheless, given that saffron is basically cultivated in arid and semiarid regions (Sepaskhah and Kamgar-Haghighi, 2009), over 12 g mother corms contain a very small proportion of the total produced corms (Koocheki and Seyyedi, 2016b; Rezvani-Moghaddam et al., 2013b). Hence, corms weight more than 12 g are considered as large-sized (Koocheki and Seyyedi, 2015b).

Generally, there is a direct relationship between corm diameter and corm weight, so that corms weighing about 10 g are 30 mm in diameter (Mollafilabi et al., 2015). Nonetheless, as stated, the criteria for the classification of mother corms based on diameter value is less important as it is not very practical.

7.3.7 Planting beds

7.3.7.1 Application of organic and chemical fertilizers

In general, heavy soils with high clay and low sand content can reduce the growth of daughter corms. However the loose, low density, and well drained soils with high organic content are considered suitable for saffron production (Kumar et al., 2009; Lage and Cantrell, 2009). Aghhavani-Shajari et al. (2015) reported that light soil texture has more advantages than heavy soil texture in saffron cultivation. Therefore, soil amendments can improve saffron flower and corm yields (Akrami et al., 2014; Madahi et al., 2017; Mollafilabi and Khorramdel, 2016; Rezvani-Moghaddam et al., 2013a; Teimori et al., 2013).

TABLE 7.5 Effects of type of fertilizer on number of daughter corms and N and P concentration of daughter corms.

Type of fertilizer	Number of daughter corms (m^2)			N concentration in daughter corms ($g\ kg^{-1}$)			P concentration in daughter corms ($g\ kg^{-1}$)		
	0.1–4 g	**4.1–8 g**	**Over 8 g**	**0.1–4 g**	**4.1–8 g**	**Over 8 g**	**0.1–4 g**	**4.1–8 g**	**Over 8 g**
Manure	107.00 c	54.25 a	17.58 a	8.65 a	10.63 a	15.42 a	1.67 a	2.27 a	2.92 a
Chemical	118.75 b	44.25 b	10.58 b	8.51 a	10.01 b	13.49 b	1.72 a	1.96 b	2.58 b
Control	132.58 a	28.75 c	6.17 c	8.58 a	9.21 c	11.70 c	1.63 a	1.72 c	2.30 c

Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT).
Source: From Koocheki, A., Seyyedi, S.M., 2015. Relationship between nitrogen and phosphorus use efficiency in saffron (*Crocus sativus* L.) as affected by mother corm size and fertilization. Ind. Crop. Prod. 71, 128–137.

The lifecycle of saffron, as a perennial plant under field conditions, can change the physical and chemical properties of soil in the long term (Helalbeyki et al., 2015; Khademi et al., 2014; Maleki et al., 2017). Unlike chemical fertilizers, which have an adverse effect on soil biology and structure (Savci, 2012), organic fertilizers improve the physical, chemical, and biological properties of the soil (Celik et al., 2004; Gracey, 1984; Qiu et al., 2016).

The positive role of manure in increasing flower and stigma yield was reported by Amiri (2008) who stated that manure application improves the physical and chemical properties of soil and increases the cation exchange capacity and N, K, and Ca uptake by saffron plants. According to Koocheki and Seyyedi (2015b), large-sized daughter corms number and N and P concentration of daughter corms in composted cattle manure were significantly higher than chemical fertilizer (Table 7.5). Behdani et al. (2017) noted that an organic production system had a significant positive effect on the growth of saffron daughter corms and number of flowering buds when compared to conventional production systems. Similar results have been reported by other researchers (Alipoor-Miandehi et al., 2014; Rezvani-Moghaddam et al., 2013a; Yarami and Sepaskhah, 2015).

Application of organic fertilizers in saffron production is essentially dependent on the amount of organic matter in the soil (Behdani et al., 2006; Mollafilabi and Khorramdel, 2016; Rezvani-Moghaddam et al., 2013a). In general, the use of organic fertilizers in saffron farms is important for these reasons:

1. As noted, the distribution of saffron farms is mainly in arid and semiarid regions. However, soil organic matter deficiency is one of the most important factors limiting cultivation in these areas (Behdani et al., 2006; Seyyedi et al., 2015). Annual rainfall shortage, poor vegetation, and frequent harvesting are among the most important reasons for reducing soil organic matter content (Koocheki and Seyyedi, 2015b; Rezvani-Moghaddam et al., 2015).
2. The perennial lifecycle of saffron under the field conditions is another factor that leads to a decrease in the amount of soil organic matter, especially in the third year onward (Koocheki et al., 2017, 2018; Rabani-Foroutagheh et al., 2013). In fact, multiyear production in saffron farms is the result of plant cultivation in the first year. Therefore, application of organic fertilizer after plant establishment is practically difficult (Ahmadi et al., 2017).
3. Changes in soil compaction in response to agricultural operations, especially after the third growing season, is a common phenomenon in saffron farms (Koocheki et al., 2017; Rahimi-Daghi et al., 2015). In general, for each unit of reduction in soil organic matter content, the negative effects of soil compaction on the growth of the corms are equally increased (Koocheki and Seyyedi, 2015b; Madahi et al., 2017; Mollafilabi and Khorramdel, 2016).

7.3.7.2 Crop residue

Based on phonological stages, there is no vegetation in saffron fields during the summer season (Mollafilabi et al., 2015). On the other hand, the optimum temperature for flower induction in saffron is between 23°C and 27°C (Molina et al., 2005b). Hence, nutrients loss due to soil erosion, increased soil temperature, and reduced flower initiation are the most obvious impacts and problems of saffron cultivation occurring during the saffron dormancy period (Koocheki et al., 2019; Rezvani-Moghaddam et al., 2013b).

FIGURE 7.23 Saffron flowering (in October) after applying the wheat straw mulch (in June). Generally, retaining wheat residue improves the physical characteristics of soil and facilitates flower emergence. Source*: From Rezvani-Moghaddam, P., Koocheki, A., Mollafilabi, A., Seyyedi, M., 2013. The effects of different levels of applied wheat straw in different dates on saffron* (Crocus sativus *L.) daughter corms and flower initiation criteria in the second year. Saffron Agron. Technol. 1, 55−70 (in Persian).*

In order to increase the production and stability of saffron cropping systems, green cover or companion crop residue can be used to effectively reduce the adverse effects of high temperatures on dormant daughter corms (Koocheki et al., 2019; Shabahang et al., 2013). Furthermore, retaining crop residue improves soil physical characteristics and facilitates flower emergence (Aghhavani-Shajari et al., 2017; Rezvani-Moghaddam et al., 2013b; Shabahang et al., 2013). During the process of residue decomposition, considerable amounts of mineral nutrients are released into the soil (Blanco-Canqui and Lal, 2009; Butterly et al., 2011; De Gryze et al., 2005), which can be recycled by the saffron roots (Koocheki et al., 2017).

The use of wheat residue is one of the most effective and recommended methods in saffron cultivation. It can be spread on the soil surface at the beginning of the saffron dormancy period (Fig. 7.23). Retaining wheat residue during the saffron dormancy period can accelerate the flowering process and increase the number of large-sized daughter corms (Table 7.6) (Rezvani-Moghaddam et al., 2013b).

The amount of N and P in the wheat residue are 0.47% and 0.27%, respectively (Ebrahimian et al., 2016), which can be recycled during the perennial lifecycle of saffron (Koocheki and Seyyedi, 2019; Madahi et al., 2017). Moreover, reducing soil erosion, increasing organic matter content, and improving soil permeability are among the other benefits of wheat mulch application (Bastian et al., 2009; Bruce et al., 2005; Du Preez et al., 2001).

7.3.7.3 Intercropping

In addition to plant mulches, proper implementation of intercropping, especially with medicinal and aromatic plants, helps to cover soil and avoid loss of water and nutrients (Rezvani-Moghaddam et al., 2014; Singh et al., 2010; Sujatha et al., 2011). In order to successfully develop the intercropping systems in saffron cultivation, the candidate species should essentially have the same ecophysiological requirements as saffron (Asadi et al., 2016; Khorramdel et al., 2016). For instance, cumin (*Cuminum cyminum* L.) is an annual and herbaceous plant from the Apiaceae family (Bettaieb Rebey et al., 2012) that is cultivated in arid and semiarid regions of Iran as a medicinal plant (Alinian and Razmjoo, 2014). Cumin plants grow to 22−30 cm tall and are drought-tolerant (Alinian and Razmjoo, 2014; Alinian et al., 2016) so can be intercropped with saffron.

Furthermore, saffron intercropping with other crops, including Cucurbitaceae and Poaceae families, may economically and environmentally be feasible and can be considered to neutralize some environmental adverse impacts (Koocheki et al., 2016b, 2009; Naderidarbaghshahi et al., 2013). Watermelon and pumpkin are the two most commonly cultivated crops in semiarid regions (Choopan et al., 2014; Erdem and Yuksel, 2003). They are suitable to be intercropped with saffron as their lifecycle does not overlap (Koocheki et al., 2019). Furthermore, watermelon and pumpkin make excellent groundcover (Fandika et al., 2011; Olasantan, 2007) and act as a live mulch to hold moisture in the soil and keep the soil cool during warm seasons (Koocheki et al., 2019; Soltani et al., 1995). Consequently, saffron-watermelon or saffron-pumpkin intercropping (Fig. 7.24) can provide considerable profitability in both spatial and temporal dimensions (Koocheki et al., 2019).

TABLE 7.6 Interaction effects of applying dates and wheat mulch levels on some characteristics of saffron daughter corms.

Application dates	Wheat mulch levels (t ha^{-1})	Number of daughter corm (m^{-2})			
		0.1–4 g	**4.1–8 g**	**8.1–12 g**	**More than 12 g**
June	0	77.3 cd	17.0 f-h	7.3 f	6.7 def
	2	55.0 def	16.6 fgh	8.7 ef	7.7 cde
	4	94.3 bc	34.0 b	8.3 f	5.3 efg
	6	106.7 b	30.3 bcd	16.7 c	10.3 abc
	8	91.7 bc	31.3 bc	18.0 bc	12.0 a
August	0	59.0 def	10.6 h	9.3 def	7.7 cde
	2	36.7 f	11.3 h	12.0 de	5.0 efg
	4	75.0 cde	24.7 c-f	9.3 def	4.7 fg
	6	97.6 bc	23.3 c-f	20.3 b	11.3 ab
	8	74.6 cde	27.0 bcd	16.7 c	9.0 bcd
October	0	54.6 def	17.7 f-h	9.3 f	9.0 bcd
	2	148.3 a	14.3 gh	10.7 def	3.0 g
	4	55.0 def	25.3 b-f	7.3 f	4.7 fg
	6	98.0 bc	22.0 d-g	12.3 d	11.0 ab
	8	109.7 b	45.0 a	28.0 a	11.0 ab

Values followed by the same letter are not significantly different at $P \leq .05$ (DMRT).
Source: From Rezvani-Moghaddam, P., Koocheki, A., Mollafilabi, A., Seyyedi, M., 2013b. The effects of different levels of applied wheat straw in different dates on saffron (*Crocus sativus* L.) daughter corms and flower initiation criteria in the second year. Saffron Agron. Technol. 1, 55–70 (in Persian).

(A) (B)

FIGURE 7.24 Saffron flowering onto pumpkin (A) and watermelon (B) aboveground parts in autumn after passing dormancy period. *From Koocheki, A., Rezvani-Moghaddam, P., Seyyedi, S. M., 2019. Saffron-pumpkin/watermelon: a clean and sustainable strategy for increasing economic land equivalent ratio under limited irrigation. J. Clean. Prod. 208, 1327–1338.*

The implementation of intercropping systems based on saffron-ajwain (Koocheki et al., 2009), saffron-chamomile (Naderidarbaghshahi et al., 2013), and saffron-black seed (Koocheki et al., 2009) has also shown positive results. Moreover, the successful cultivation of saffron between apple trees based on the agroforestry system has also been considered (Moosavi et al., 2014).

7.3.7.4 *Planting under controlled environment*

Where saffron cultivation is faced with barriers and restrictions under field conditions, production under controlled conditions is considered as an alternative approach (Koocheki and Seyyedi, 2016a; Sabet-Teimouri et al., 2010).

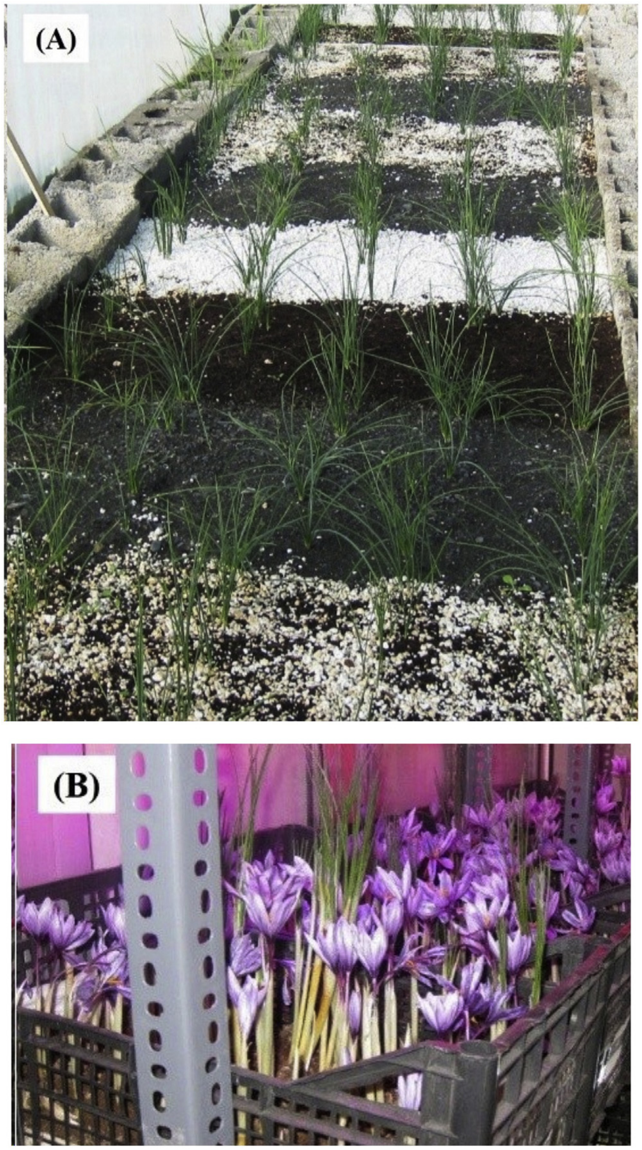

FIGURE 7.25 Saffron corm planting under a controlled environment. (A) Saffron corm planting into the perlite, vermiculite, and coco peat substrates and (B) saffron production based on soilless plant culture using hydroponics system. *From Mollafilabi, A., Koocheki, A., Rezvani-Moghaddam, P., Nassiri-Mahallati, M., 2014. Effect of plant density and corm weight on yield and yield components of saffron (*Crocus sativus *L.) under soil, hydroponic and plastic tunnel cultivation. Saffron Agron. Technol. 1, 14–28 (in Persian).*

The production of saffron in controlled environments, especially in modern greenhouses, is possible by preparing optimum culture media using commercial substrates (Mollafilabi et al., 2014, 2013). These substrates include solid compounds that are free of pathogens and can supply micro- and macronutrients during the growing season (Packer and Clay, 2000; Yasmin and Nehvi, 2014). On the other hand, the commercial substrates have the physically stable structure (Fuller et al., 2009; Yang et al., 2017) and, from a chemical point of view, are composed of relatively neutral compounds (Malandrino et al., 2006; Souret and Weathers, 2000). Among the organic and inorganic substrates used for saffron production are peat moss, perlite, vermiculite, and coco peat (Fig. 7.25A).

In addition to commercial substrates, the production of saffron based on soilless plant culture using hydroponic or aeroponic systems (Fig. 7.25B), as alternative approaches, can be implemented (Mollafilabi et al., 2014, 2013). In general, the accurate adjustment of temperature, humidity, and light (Souret and Weathers, 2000; Yasmin and Nehvi, 2014), saffron corm planting in high densities (Maggio et al., 2006), the production of flowers in shorter periods of time compared with production under field conditions (Mollafilabi et al., 2013; Sorooshzadeh and Tabibzadeh, 2015), the feasibility of controlling pests and pathogens in a simpler and faster pattern (Maggio et al., 2006;

Renau-Morata et al., 2013), as well as the availability of conditions for accurate management of water and nutrients (Sorooshzadeh and Tabibzadeh, 2015; Yasmin et al., 2013) are considered as positive aspects of soilless saffron culture. Souret and Weathers (2000) noted that saffron corms grown aeroponically and hydroponically produced more flowers and leaves compared with corms from soil-grown control plants.

7.3.8 Application of hormones

Plant hormones (including auxin, gibberellin, cytokinin, and ethylene) are produced in very small amounts in certain parts of plants and transferred to other parts (Campos-Rivero et al., 2017; Zhang et al., 2009). The role of plant hormones in the saffron plant involves biochemical, physiological, and morphological responses during the perennial lifecycle (Amirshekari et al., 2007; Aytekin and Acikgoz, 2008). The development of the root system, the induction of flowering, and the stimulation of growth in the above- and underground parts have been identified as some of the positive effects of the external application of hormones in saffron production (Amirian and Kargar, 2016; Azizbekova et al., 1978; Koul and Farooq, 1982). For instance, gibberellic acid can reduce the potential of water in the cell and cause more water to enter the cell and increase its volume by condensing the cell sap through starch-to-sugar hydrolysis (Konishi et al., 2005; Ohkawa et al., 1989; Xu et al., 2016). Therefore, due to these effects, it is possible to increase root dry weight (Amirshekari et al., 2007; Komatsu and Konishi, 2005). Application of gibberellin on dormant corms has resulted in a decrease in sprouting buds and hence fewer daughter corms. In this case, apical buds produced larger daughter corms (Amirshekari et al., 2007; Greenberg-Kaslasi, 1991). Moreover, the positive role of gibberellin on flowering induction has also been reported (Amirian and Kargar, 2016).

7.4 Corm and climate change

Establishment and differentiation of reproductive organs to the buds (late August to early September), organogenesis (late September), and reproductive organ growth into the buds (late September to early October) are some of the saffron development stages prior to flowering (Kafi et al., 2002). The optimum temperature for flower induction in saffron is 23°C−27°C (Molina et al., 2005b). The appropriate temperature for flowering has also been reported in the range of 15°C−17°C (Molina et al., 2005b). Hence, flower induction (early summer) until flowering is directly affected by temperature (Arsalani et al., 2015; Koocheki et al., 2010; Molina et al., 2005a) so that high temperatures during summer negatively affect flowering in saffron (Ensaf et al., 2015; Koocheki et al., 2019).

The consequences of climate change have largely focused on global warming (Ming et al., 2014; Wernberg et al., 2011). Global warming, due to increased anthropogenic greenhouse gas emissions (Guardia et al., 2016; Zhao, 2011), may also have a negative impact on the flowering process of saffron (Jafarzadeh et al., 2015; Koocheki et al., 2010).

As mentioned earlier, the physiological and biochemical mechanisms associated with bud stimulation (during flower induction until flower appearance) are basically influenced by temperature (Abrishamchi, 2003). Hence, an increase in the relative environmental temperature could possibly disrupt the process of differentiation in vegetative-reproductive sprouts (Arsalani et al., 2015; Fernandez, 2004; Molina et al., 2005b). Saffron flower emergence may be delayed due to an increase in average air temperature during autumn (Koocheki and Seyyedi, 2015a). Due to an increase in the average air temperature (between 1.5°C and 2°C, Table 7.7), the date of saffron flower appearance (about mid-October)

TABLE 7.7 Increasing the air temperature and possible dates for flowering in saffron based on climatic conditions in Khorasan-Razavi province, Iran.

An increase in average air temperature (°C)	Possible dates for flowering in saffron	
	Minimum date	Maximum date
0.5	20th of October	1st of November
1.0	3rd of November	14th of November
1.5	16th of November	28th of November
2.0	30th of November	13th of December

Source: From Koocheki, A., Nassiri, M., Alizadeh, A., Ganjali, A., 2010. Modelling the impact of climate change on flowering behavior of Saffron (*Crocus sativus* L.). Iran. J. Field Crop. Res. 7, 583−594 (in Persian).

in Khorasan-Razavi Province, Northeast Iran is postponed until late December (Koocheki et al., 2010). This postponement can also occur in other areas with similar climates.

Furthermore, saffron is known as a hysteranthous plant, so that under optimal temperature conditions, its flowers start to appear before the leaves emerge (Koocheki et al., 2016a). Nevertheless, a relative increase in air temperature causes the saffron flowers to appear after the leaves emerge (Koocheki and Seyyedi, 2015a; Molina et al., 2005b). As a result, this phenological undesirable process can disrupt the flower picking through the growth of leaves at inappropriate times (Jafarzadeh et al., 2015; Koocheki et al., 2019). The length of the vegetative growth period will be shortened by any delay at the beginning of the reproductive growth period (Koocheki and Seyyedi, 2015a). Hence, reduced saffron corm weight can be considered as another consequence of climate change. Fluctuations in precipitation patterns (Djebou and Singh, 2016), reducing water resource quality (Bazrafshan et al., 2019; Fan and Shibata, 2015), and drought-induced water scarcity (Kahil et al., 2015), other negative climatic and environmental outcomes, can reduce saffron flower and corm yields.

The adoption of strategies to reduce the negative effects of climate change and adaptation to climatic conditions in the areas of saffron cultivation could be effective in reducing these adverse effects (Jafarzadeh et al., 2015; Koocheki et al., 2010).

7.5 Conclusion

Saffron, a perennial and autumn-flowering geophyte plant under field conditions, is a crop suitable for arid and semiarid areas that survives for 6−8 consecutive years, depending on agronomic management or climate parameters. A variety of factors can affect the multiyear production cycle of saffron. In addition to optimal temperature conditions for differentiation of reproductive organ and flower emergence, saffron yield is fundamentally determined based on correct agronomic management and includes: (1) selecting the appropriate mother corms; (2) selecting healthy saffron corms without symptoms caused by physical damages, pests, and pathogens; (3) reducing storage period from harvesting to replanting; (4) properly storing corms in terms of controlling temperature, humidity, and pest and pathogen activity; (5) planting corms at the beginning of the true dormancy period; (6) paying attention to the benefits of dense corm planting; (7) preparing soil based on organic fertilizer application; (8) retaining green cover or plant residue on the soil surface during summer; (9) produced saffron based on intercropping patterns; and (10) using modern aspects of saffron production based on soilless plant culture.

The above can play an indelible and irrefutable role in increasing the production and profitability of saffron. It is also important to change the view of saffron producers. While dried stigma is sold as the main product of saffron in commercial markets, all agronomic practices under field conditions should focus on the production of standard corms. Consequently, the production of standard corms should be recognized as the final product of the saffron perennial lifecycle.

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