Chapter 11

Mechanization of saffron production

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Chapter Outline

11.1 Introduction

11.1.1 The role of mechanization in agricultural development

For modern agriculture, it is essential to use implements and machinery. Arguably, these are the most important inputs for the agriculture sector. The goals of mechanization include (Sims and Kienzle, 2006):

1. increased productivity per unit area due to improved timeliness of farm operations;
2. an expansion of the area under cultivation where land is available;
3. accomplishment of tasks that are difficult to perform without mechanical aids;
4. improvement of the quality of work and products; and
5. a reduction of drudgery in farming activities, thereby making farm work more attractive.

Mechanization systems are categorized as human, animal, and mechanical technologies. Based on the source of power, the technological levels of mechanization have been broadly classified as hand-tool technology, draught animal technology, and mechanical power technology (Sims and Kienzle, 2006). The correct choice of and use of machinery and equipment has a direct effect on yield and income. In general, If development is not restricted in other fields, the use of agricultural machinery can be promoted. Besides the technological development of farm machinery, new technologies should be used in other fields such as seed improvement, irrigation, fertilizers and pesticides, and land consolidation in the agricultural sector. It is only in these cases that agricultural technologies can be used to increase yield, reduce costs, reduce labor, and enhance sustainable agriculture.

Saffron: Science, Technology and Health. DOI: https://doi.org/10.1016/B978-0-12-818638-1.00011-3

11.1.2 Economic advantages of saffron mechanization

Saffron production is labor-intensive and is the world's most expensive spice. Saffron cultivation methods have remained almost the same over the last few centuries and thus its production requires high labor hours due to low mechanization of farms (Alonso Diaz-Marta et al., 2006).

In addition to the specific climatic requirements for saffron cultivation, labor is another restriction on saffron production in many countries. In fact, 23% of the total energy used to produce saffron is related to manpower. The corm planting, flower picking, and stigma separation are the most important steps in saffron production, and all these steps require a great deal of labor. In a manual harvesting system, 400 and 900 man-hours per hectare are needed for flower picking and stigma separation, respectively (Moayedishahraki et al., 2010).

For soil bed preparation before planting, weeding, and crust breaking, equipment available can be used, but planting and harvesting require invention and manufacturing of special equipment and machines. Use of machinery for planting saffron corms can lead to reduced production costs, cultivation of corms in rows and at an appropriate depth, and reduced corm requirement. Mechanization of the saffron harvesting process (flower picking and stigma separation) can reduce microbial contamination of stigmas in addition to lowering production costs. Moreover, yield loss can be avoided due to the shortened harvesting time and reduced need for labor.

11.2 Machines for corm production

11.2.1 Physical properties of saffron corms

Saffron corms are spherical with a hard fleshy white texture. Corms are covered with thin brown fibers with thickness increasing toward the outer layers. These thin layers are for corm protection.

Saffron corms come in different sizes, and their weight varies from 2 to 40 g (for more information refer to Chapter 7: Saffron corms). Table 11.1 shows the physical properties of saffron corms from different parts of Khorasan province in Iran. Their physical properties including dimensions, geometric diameter, arithmetic diameter, sphericity, particle and bulk density and also static coefficient of friction are given (Bakhtiari-Konari et al., 2013).

11.2.2 Corm digging

The flowering life of saffron fields varies from 5 to 10 years depending on the initial corm planting density. By the end of this period, the yield sharply drops due to extensive corm propagation, insufficient space for vegetative growth of the corms, and weak performance of the soil. At this point, saffron corms should be dug out and transferred to a new field. On average, 20−30 tons of corms can be harvested from 5- to 10-year-old fields.

Since corms are planted at a relatively large depth (15−20 cm), they are dug out by moldboard plows. Following deep plowing, corms can be separated from soil aggregates by breaking down the latter using hand tools. The mean required tractor working hours and number of workers are 50 hours and 50 persons per hectare, respectively (Saeidirad et al., 2014).

TABLE 11.1 Physical properties of saffron corms.

Physical properties	Lowest	Highest	Mean
Weight (g)	3.85	14.82	7.77
Geometric diameter (mm)	18.34	27.17	22.96
Arithmetic diameter (mm)	18.42	27.49	23.20
Sphericity (dimensionless)	0.83	0.91	0.86
Particle density (g cm^{-3})	1.04	1.22	1.19
Bulk density (g cm^{-3})	0.45	0.51	0.48
Static coefficient of friction	0.65	0.73	0.70

Source: From Bakhtiari-Konari, F., Saeidirad, M.H., Garazhian, H., Sahrayei, P., Arianfar, A., 2013. Investigation and comparison some physical properties of saffron corms. J. Res. Innov. Food Sci. Technol. 2, 69−81 (in Persian).

FIGURE 11.1 Single-bottom moldboard plow for digging out saffron corms.

For example, in most parts of Khorasan province in Iran, a single-bottom moldboard plow is used for this purpose. The tractor passes in a vertical way to the planting direction and makes a 25–30 cm deep furrow. A number of workers follow the tractor and pick up the corms and put them in bags. In this method, the tractor stops at the end of each pass since it moves much faster than the workers, and waits for them to finish picking up the dug-out corms (Fig. 11.1). The low efficiency, high labor requirement, and high labor costs are the main problems of this method. Since the dry conditions of the land at the time of harvest makes it impossible to use tuber harvesters, growers have no choice but to use this method, which is relatively superior to the traditional method that uses shovel and hand tools instead of tractor power.

11.2.3 Corm sorting

The harvested corms are attached to each other around the residue of parent corms, which should be separated, and their extra fiber layers must be removed. The corms must then be graded. Since corms weighing less than 6 g are not capable of flowering in the first year, it is thus recommended to separate them from heavier corms. In most regions, saffron corm cleaning and separation are carried out by laborers, which is very time consuming and costly considering the large number of corms produced.

Most of the apparatuses designed and developed for corm grading use the cylindrical sieve mechanism, where smaller corms pass through the rotating cylinder bars, and the larger corms roll out of the cylinder along its slope (Fig. 11.2).

11.3 Tillage

11.3.1 Bed preparation for corm planting

Bed preparation and planting are important operations, and consume more than 60% of the total energy requirement of the mechanization sector. Therefore, its proper management can play an important role in reducing energy consumption.

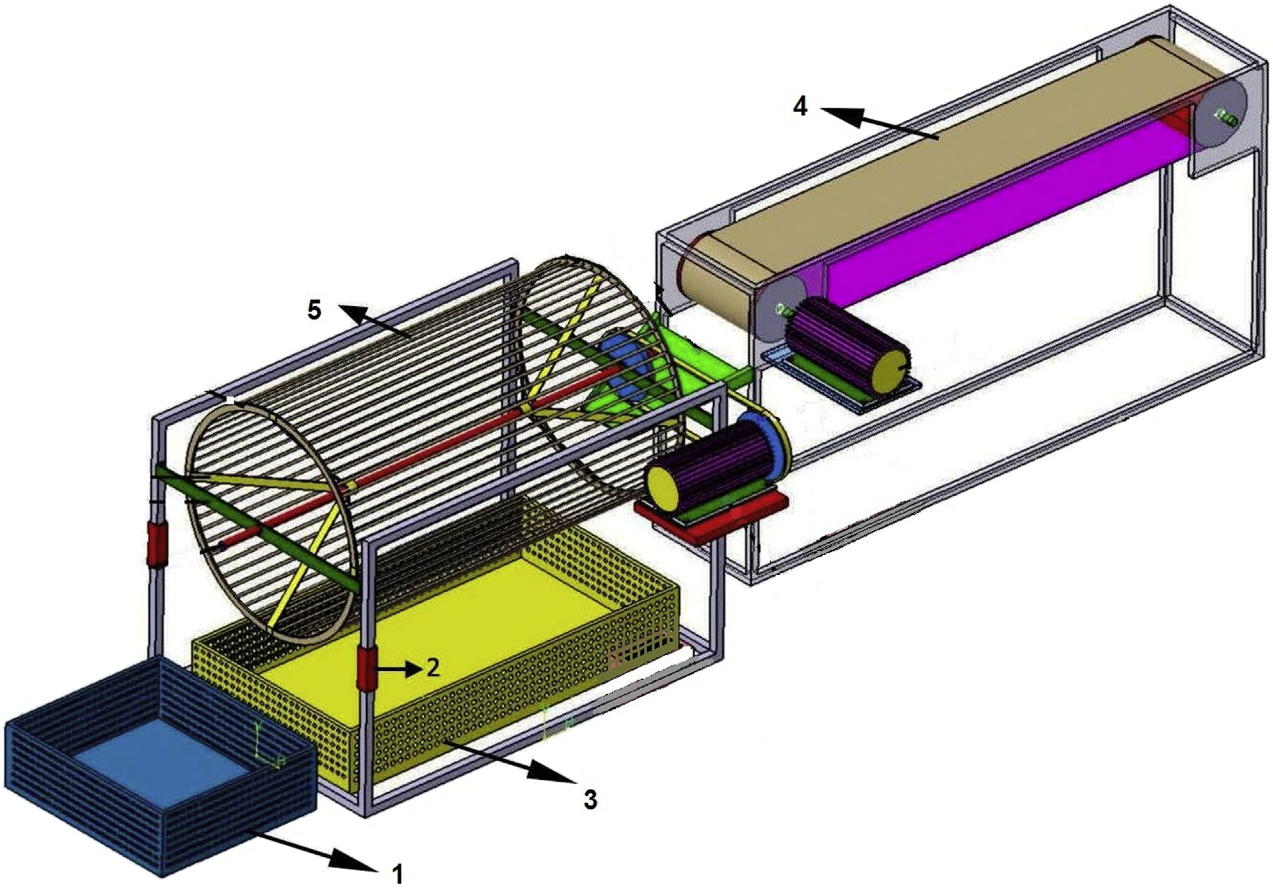

FIGURE 11.2 Schematic view of a saffron corm sorter.
1, Large corms basket; *2*, cylinder slope adjustment; *3*, small corms basket; *4*, feeding conveyor; *5*, rotating cylindrical sieve. *From Ghanbarian, D., 2012. Design and development of a drum type saffron corm sizing-machine. Agric. Eng. 35(2), 83−96 (in Persian).*

Considering the adverse effects of extensive tractor passes on fields during bed preparation, such as soil compaction and erosion, research interest in selection of appropriate implements and increased farm efficiency is growing every day (Tabatabaeefar et al., 2009).

Saffron can be planted in most types of soil, whether lightweight sand or heavy clay. However, this plant grows best in medium loamy-texture soils containing humus. Bed preparation for saffron planting requires plowing at a 25−30 cm depth, with the diameter of soil particles ranging from 10 to 15 mm following the tillage practice. This can be done by a chisel plow in mid-April when spring rains are over (Fig. 11.3). Plowing at this time not only is considered as primary tillage but also plays a significant role in weed control. If this is performed at proper moisture content (12%−15%), secondary tillage can be eliminated or at least minimized. It is recommended to spread 20−40 tons of composted manure per hectare before planting and mix it with the soil using secondary tillage implements and machinery such as a cultivator or disc harrow (Behdani and Fallahi, 2016).

11.3.2 Crust breaking

Crust breaking is carried out following the first irrigation of the saffron field in the growth season (from late September to mid-November) and when the soil moisture content is 15%−18%. This operation is needed to crush the hardened layer above young saffron sprouts and facilitate their emergence from the soil. Crust breaking in saffron fields during the early growth season must be performed carefully as saffron sprouts have reached near the soil surface (Saeidirad et al., 2007).

The tillage depth for crust breaking depends on the distance of the sprouts from the soil surface, which in turn is a function of irrigation time and weather conditions in the region. The later the first irrigation, the closer the saffron

FIGURE 11.3 Chisel plow equipped with a roller for primary tillage.

sprouts to the soil surface (due to the approaching time of harvest), and thus the crust-breaking operation must be performed with extra care. Growers break crusts using different means and methods such as a tractor-drawn spring-loaded cultivator, rotavator, and powered rotavator. Small tractors (<45 hp) are recommended to be used for drawing cultivators or rotavator. Big and heavy tractors can cause serious damage to crops. Currently, horticultural tractors are common due to their lightweight and high maneuverability in small pieces of land (Sheykhdavodi et al., 2010).

A powered cultivator operated by an on-foot user is an example of a machine used for breaking crusts in saffron fields. In this self-propelled tillage implement, the rotavator's axis where blades are mounted serves as the drive wheel. During road transportation, two wheels replace the rotavator's two axes. The engine power is transferred through a gearbox to the axes. In crust breaking for saffron, growers have creatively circumvented the possible damage of L-shaped blades to saffron sprouts by replacing them with vertical dual-spike blades (Fig. 11.4). If the first irrigation is performed later than recommended time, which is usually inevitable due to water scarcity, this implement can cause extensive damages to the crops by destroying the saffron sprouts. Therefore, under these circumstances, growers are forced to use traditional methods for crust breaking (Saeidirad et al., 2007).

11.4 Corm planting

11.4.1 Planting patterns

Saffron corms can be planted from the end of the growth period in mid-May until early October. It is recommended to plant saffron corms in a new field within a week or two after they are dug out because both air and soil are very warm and the relative humidity of the air is very low causing the corms to incur damage due to moisture loss. Delay in planting corms may lead to emergence of roots in storage and damage during planting, prevented their optimal growth. Digging out corms in warm months (June–August) is not recommended; instead, it should be performed in May or September.

Uniform planting of corms in rows can help save more corms. It can also increase yield and facilitate the execution of other field operations, particularly flower harvesting. The planting pattern of saffron in Iran is normally in flat rows. The row spacing varies between 20 and 30 cm. The density of corms per unit area has a direct relationship with its yield and an indirect relationship with the number of the flowing years (age) of the saffron field. As a result, the age of saffron fields ranges between 4 and 10 years depending on the planting density (for more details refer to Chapter 7: Saffron corms).

FIGURE 11.4 Left, replacement tines for breaking crusts in saffron fields; right, powered tiller rotavator.

It is recommended to mechanize corm planting in order to reduce labor, save the amount of corm required for planting, increase performance speed, and provide agreeable conditions for other mechanized process such as crop protection and harvesting.

11.4.2 Traditional planting methods

In traditional planting, growers use single-bottom moldboard plows and tractor-mounted furrow openers to dig furrows with 20−30 cm spacing and a depth of 15−20 cm. A number of skilled workers plant corms in rows with 5−10 cm spacing (Saeidirad et al., 2014). Considering the low row spacing (20 cm) and the fact that corms are planted manually following a tractor pass, two furrow openers cannot be used simultaneously as the soil turned by the furrow openers will pour into the adjacent furrow. This reduces planting speed. In different parts of Khorasan province in Iran, growers have built creative implements and equipment for semimechanization of saffron corm planting. Fig. 11.5 shows a single-bottom moldboard plow equipped with corm hopper. It is drawn by a tractor to open a furrow in the soil. The worker throws corms in a free-fall tube and plant in the freshly opened furrow. The soil from each furrow is then rolled into the previous furrow and thus covers up the corms. The in-row spacing of corms is an effective factor in density and uniformity of the planting operation, which cannot be controlled precisely due to use of labor and its inherent human error.

Fig. 11.6 shows a six-row corm planter invented by local farmers used in some parts of Khorasan province. It has a corm box, from which three workers simultaneously pick corms and release them in six free-fall tubes. Its advantage over a one-sided plow is the simultaneous planting of six rows, which increases performance. Similar to the previous method, it requires high labor and is affected by human error in corm spacing.

11.4.3 Automatic planting machines

Several implements have been developed for mechanized row planting of saffron corms, most of which use spoon/cup seed metering devices similar to those used in potato planters. Fig. 11.7 is a two-row saffron corm planter capable of planting corms at 20 cm row spacing, up to 5 cm distance between corms. Use of spoon/cup seed metering devices can cause limitations for planting density, and thus are not capable of planting more than 3 tons ha^{-1} of saffron corms. It can plant 0.12 ha h^{-1} with a working speed of 3 km h^{-1} (Saeidirad and Akram, 2006).

FIGURE 11.5 Single-bottom moldboard plow equipped with corm hopper. *From Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on mechanization development possibility and providing the most optimum method to saffron harvesting mechanization. Final Research Report, No. 44678, Agricultural Engineering Research Institute (in Persian).*

FIGURE 11.6 Semiautomated six-row corm planter.

FIGURE 11.7 The two-row saffron corm planter. *From Saeidirad, M.H., Akram, A., 2006. Design and development of two-row saffron bulb planter. AMA-Agr. Mech. Asia Af. 37(2), 48–51.*

In Fig. 11.8 a fully automated seven-row corm planter is presented, which was designed and developed at the Khorasan Razavi Agricultural and Natural Resources Research Center, Iran. It is capable of planting 7–10 tons ha^{-1} of saffron corms with 25–30 cm row spacing. Its working width is 210 cm and it can plant 0.8 ha h^{-1} with a working speed of 4 km h^{-1}.

This seven-row saffron planter consists of a corm container, roller-type seed metering device, furrow openers, corm covering packer, carrying wheels, and power transmission system. This planter can be attached to a tractor by a three-point hitch, and the seed metering device is driven by the ground wheel. There are two seed metering rollers, driven by the ground wheel, at the bottom of the container that ensures the consistent continuous flow of corms from the container to the openers. Saffron corms are uniformly distributed between the seven openers, and the openers (30 cm apart from each other) are arranged in a nonlinear formation and release the corms at a depth of 20 cm (Saeidirad et al., 2018).

11.5 Harvesting saffron flowers

11.5.1 Traditional method of harvesting saffron flowers

Seven to 10 days after the first irrigation (mid-October to mid-November), saffron flowers start to appear on a daily basis. The flowers emerge gradually within a 15–20 day period. The height of the flowers from the soil surface varies from 20 to 120 mm, and reaches 50–160 mm above the petals. Saffron flowers emerge in the early morning hours and grow taller as the day advances and becomes warmer. But the flower height can be affected by other factors such as field age, first irrigation time, and also the quality of the soil and its organic content. The main challenges facing the

FIGURE 11.8 Fully automated seven-row saffron corm planter. *From Saeidirad, M.H., Zarifneshat, S., Nazarzadeh, S., Mehrabi, E., 2018. Design, development and evaluation of 7 rows saffron corm planter. Final Research Report, No. 53999, Agricultural Engineering Research Institute (in Persian).*

use of machinery for harvesting are the low height of the flowers from the soil surface and the presence of leaves, which in some cases, particularly when the first irrigation is delayed, emerge simultaneously with the flowers (Saeidirad et al., 2014).

In the manual method, the growers harvest flowers in the early morning on a daily basis because the weather is cooler and the flowers are just buds. On the other hand, it is much easier and faster to harvest saffron buds, as in the presence of leaves, it requires more time and effort to harvest the full-blown flowers. Buds are also easier to handle and need less space. However, harvesting buds is more beneficial in that they have longer storage life. Late harvested and full-blown flowers should be rapidly prepared for other operations (separation of stigmas), whereas buds can be storage and wait for 2−4 days under cool conditions and away from sunlight.

Buds start to open with sunlight and as the day becomes warmer. As a result, stigmas lose their protective layer of (the petals) and are exposed to sunlight and wind, which may affect quality. Considering the huge workload and insufficient labor of the harvesting process, it is possible to harvest only a part of the flowers as buds (Fig. 11.9). In this case, the buds and flowers should be separated into different containers to help prioritize the next harvest operations in order of storage life.

The required labor for harvesting one hectare of saffron depends on the flower density per unit area. Flower density per unit area is itself a function of field age and corm planting density. Flowering is very limited in the first year, and it increases gradually to reach its maximum in the third and fourth years. From this point on, the field yield and flowering rate are reduced. Although the flowering period of a saffron field is 15−20 days long, the peak flowering period lasts no more than 3−5 days; more than 75% of the flowers emerge in this short period and should be picked (Saeidirad et al., 2014) (Table 11.2).

11.5.2 Invented picker machines

An important limitation of saffron harvesting machines is the close gap between the flower and soil. Another challenge is the growth of leaves simultaneously with flowers. Emergence of saffron leaves is a function of local weather conditions and also the time of the first irrigation. Delayed growth of leaves after the harvest period is ideal for easy harvesting of saffron flowers. Although the emergence and growth of leaves can be partly delayed by a late first irrigation,

FIGURE 11.9 Saffron flowers harvesting by hand.

TABLE 11.2 Flowering rate of saffron fields and required labor for flower picking from field.

Field age (year)	Saffron stigma (kg ha^{-1})	Saffron flower (kg ha^{-1})	Saffron flower (number m^{-2})	Labor (man-hours ha^{-1})
1	2–3	150–250	40–60	75–100
2	6–8	500–700	70–170	180–240
3	8–10	700–800	170–200	240–300
4	9–12	750–1000	185–250	300–400

Source: From Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on mechanization development possibility and providing the most optimum method to saffron harvesting mechanization. Final Research Report, No. 44678, Agricultural Engineering Research Institute (in Persian).

flowering will also be delayed if the autumn's cold weather arrives with a delay allowing the leaves to emerge before the flowers.

Numerous machines and devices have been designed and developed with this aim. Some the machines are known as hand-supported machines and help workers harvest flowers easier and with less effort.

In Spain, in order to make this task easier, a self-propelled machine was developed that allows workers to harvest flowers while sitting (Alonso Diaz-Marta et al., 2006). Also, in Iran, a kind of trolley was introduced to reduce the mechanical damages on the body of labors during saffron harvesting (Fig. 11.10).

Another implement known as "Saffron All In One" (SAIO) was also designed and developed that allows four users to perform saffron corm planting, removal of weeds, and harvesting operations while in the prone position (Fig. 11.11).

Mechanized flower harvesting is aimed at cutting or picking. Accordingly, several machines have been designed and developed. The cutting mechanism is not applicable when saffron leaves have also emerged with the flowers. This is only useful when leaves grow with delay. The currently available flower harvesting machines can be divided into portable and self-propelled groups. In portable machines, the harvesting head is moved across the field by an operator, and the cut flowers are sucked into a container carried on the shoulders of the operator.

Fig. 11.12 shows a portable device for harvesting saffron flowers. The flowers are cut by a cutter operated by the operator and are then transferred into the back-carried container by a suction mechanism. The cutting head consists of two rotary blades rotating in opposite directions. The suction unit has a suction pump powered by a single-cylinder gasoline engine (1 hp). This machine is capable of harvesting 5.5 kg h^{-1} of saffron flowers (Saeidirad et al., 2014).

FIGURE 11.10 Saffron harvesting with trolley. *From Abbaspour-Fard, M.H., Yousefzadeh, H., Azhari, A., Ebrahimi-Nik, M.A., Haddadimoghaddam, M., 2018. Ergonomic evaluation of conventional saffron harvesting versus using a trolley. Saffron Agron. Technol. 6(2), 253−267 (in Persian).*

FIGURE 11.11 Saffron All In One (SAIO). *From ABAC Holland, 2016. ABAC Holland develops Saffron All-in-One planting and harvesting machine report on prototype II.*

Two saffron-picking mechanisms are shown in Figs. 11.13 and 11.14. These devices are still in the research stages and have not been produced commercially. As shown in Fig. 11.13 a prototype based on a cam-strike system was developed for harvesting saffron. This cam-strike system detaches the goblet with no damage to the foils. The cutting process has two stages: First, the two components move toward each other, and second, the flowers and the leaves are caught

FIGURE 11.12 Portable saffron harvesting device. *From Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on mechanization development possibility and providing the most optimum method to saffron harvesting mechanization. Final Research Report, No. 44678, Agricultural Engineering Research Institute (in Persian).*

between these components. Through a linear oscillation, the flower is cut by a series of torsional loads applied to its stem. The cutting process is facilitated by the leaves and their rough surfaces (Gambella et al., 2013).

Another prototype uses a two-finger pneumatically powered gripper equipped by a suction (vacuum collection) device. Using the structure of the stem and foils, the gripper detaches the flowers from their stem: it breaks the stem while causing no damage to the detached goblet and the foils. The gripper detaches the flower with its two fingers. It is also made of a body, including the electric motor for powering a fan that sucks in the detached flowers through a vacuum tube, and also a handle equipped with a manually operated pneumatic valve to control the pneumatic gripper. The harvester was experimentally tested on the field for picking saffron flowers in the open fields of San Gavino Monreale, Sardinia, Italy (Manuello Bertetto et al., 2014, 2011).

11.6 Saffron stigma separation

11.6.1 Physical properties of saffron flowers

Each saffron flower comprises six petals, three stamens, one triple-filament stigma, and a peduncle. The flowers weigh between 0.35 and 0.45 g with an apparent density of 0.90−0.95 g cm^{-3}. Each kilogram of saffron flower contains 2400−2700 flowers. The mechanical and aerodynamic properties of the saffron flower and its parts are given in Table 11.3. The differences in the density and aerodynamic properties of the different parts of the flower allow for solutions for separating them from each other. Most devices and machinery designed and developed for this purpose use these differences.

11.6.2 Traditional stigma−flower separation method

The most delicate and time-consuming phase of saffron harvest is the separation of stigma from flowers. The short flowering period in each region makes it impossible to find sufficient labor and time to separate stigma from all harvested flowers on a daily basis. As a result, the growers are forced to store the flowers for a few days. This results in quality degradation and sometime flower spoilage. To achieve high-quality products, the recommendation is to separate stigma no later than 1 day after harvest. The traditional method requires three man-hours for separating the stigmas of 1 kg saffron flower (Saeidirad and Mahdinia, 2014).

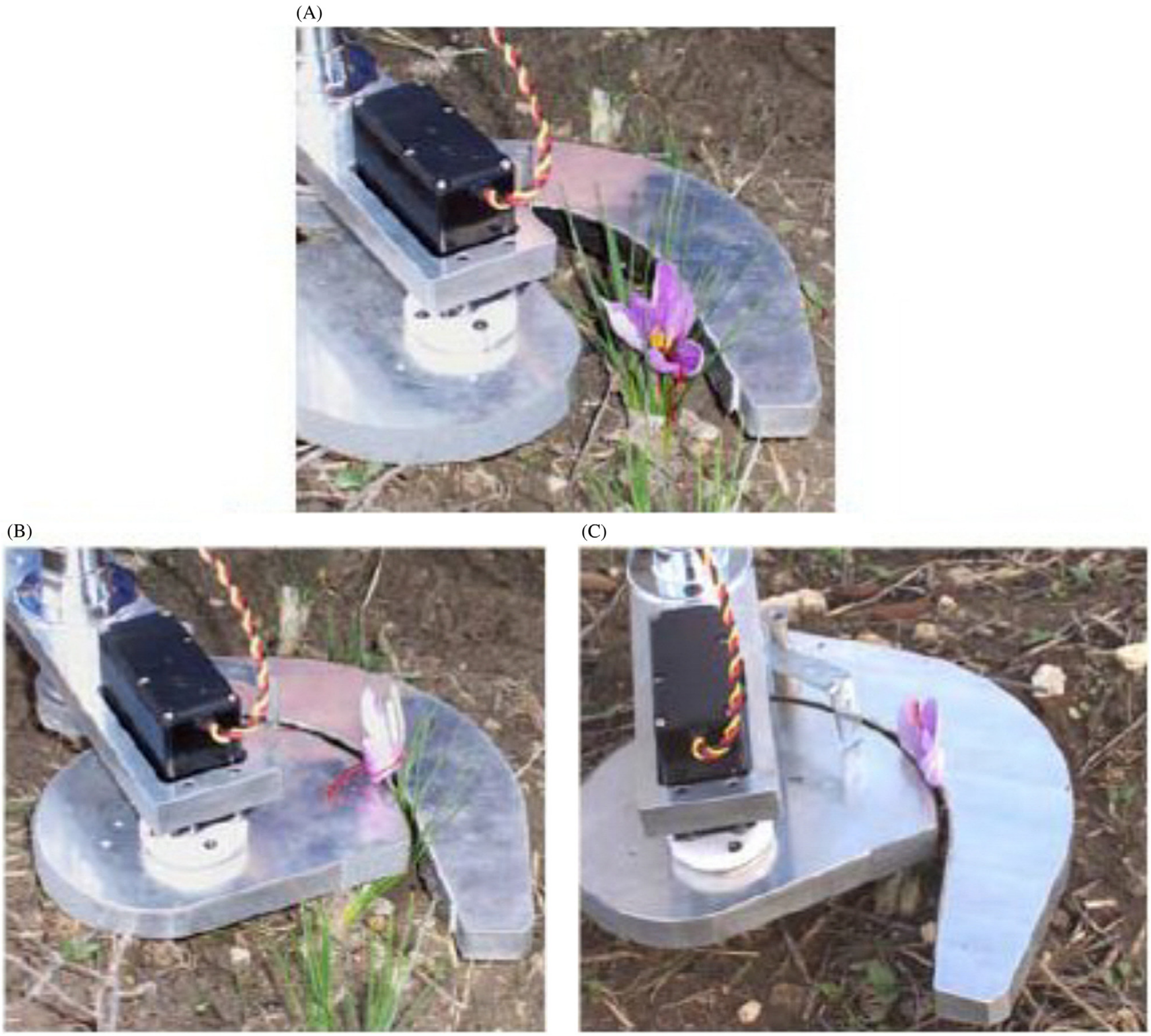

FIGURE 11.13 The field operation of the cam-strike harvesting machine: (A) approaching, (B) gripping, and (C) detaching. *From Gambella, F., Paschino, F., Manuello Bertetto, A., 2013. Perspectives in the mechanization of saffron (*Crocus Sativus *L.). Int. J. Mech. Control 14 (2), 3−8.*

FIGURE 11.14 The harvesting device. *From Manuello Bertetto, A., Ricciu, R., GraziaBadas, M., 2014. A mechanical saffron flower harvesting system. Meccanica 49, 2785−2796.*

TABLE 11.3 Physical and aerodynamic properties of saffron flower parts.

Property	Weight (g)	Gravity (g cm^{-3})	Moisture content (%)	Terminal velocity (m s^{-1})
Flower	0.35–0.45	0.90–0.95	88–93	3–3.5
Stigma (three filament)	0.026–0.035	0.90–0.95	72–77	2.8–3.4
Stigma (single filament)	0.008–0.012	0.88–0.94	72–77	3–3.5
Stamen	0.006–0.01	1.10–1.20	84–87	2–2.5
Petal	0.027–0.03	0.82–0.88	88–90	1–1.5
Peduncle	0.1–0.17	0.95–0.99	88–92	3.5–4

Source: Data from Emadi, B., Saeidirad M.H., 2011. Moisture-dependent physical properties of saffron flower. J. Agr. Sci. Tech. 13, 387–398; Sanabadi-Aziz, M., Mostofi, M.R., Faridi, H., 2015. Design and construction of a mechanical machine for separating stigmas from the saffron's petals. J. Multidiscip. Eng. Sci. Technol. 2(9), 2408–2416; Valeghozhdi, H., Hassanbeygi, S.R., Saeidirad, M.H., Kianmehr, M.H., 2010. Determining coefficient of friction and terminal velocity of saffron flower and its components. Iran. J. Food Sci. Technol. 7(25), 121–133 (in Persian).

FIGURE 11.15 Left, Mancha saffron; right, Bunch saffron.

In Khorasan province, Iran, saffron stigmas are separated through two traditional manual methods resulting in two types of products: Bunch saffron and Mancha saffron (Fig. 11.15). To product of Bunch saffron, the worker cuts open the stem and pulls out the triple-filament stigma along with the white style at the end of it. The stigmas are then placed on one another with their white style. However, to produce Mancha saffron, which is the export-grade product, the flowers are cut from their collar and the triple-filament stigma is then separated from the rest of the flower.

11.6.3 Invented separators

As mentioned earlier, cutting should be performed at the peduncle in order to separate the stigma from the flower. In this method, the flower components are dismantled and then the stigma can be separated from the rest of the plant. Therefore, to achieve mechanized separation of stigma from flower, the machine should be able to perform three main steps: flower sorting, cutting, and stigma separation.

Fig. 11.16 shows a laboratory-scale sorter for saffron flower developed for a more accurate study of the flower-sorting process and possibility of an automated flower-feeding line. It has a cylindrical picker featuring vacuum tines. With every rotation of the cylinder, each vacuum tine picks a flower and releases it on a sloped surface when the vacuum suction is ceased along the way. Due to the asymmetrical center of gravity of the flowers, their peduncle is oriented downward during the free fall. Thus, all flowers are placed individually on the sloped surface and are fed from the peduncle to the conveyor belt (Bakhshi et al., 2018).

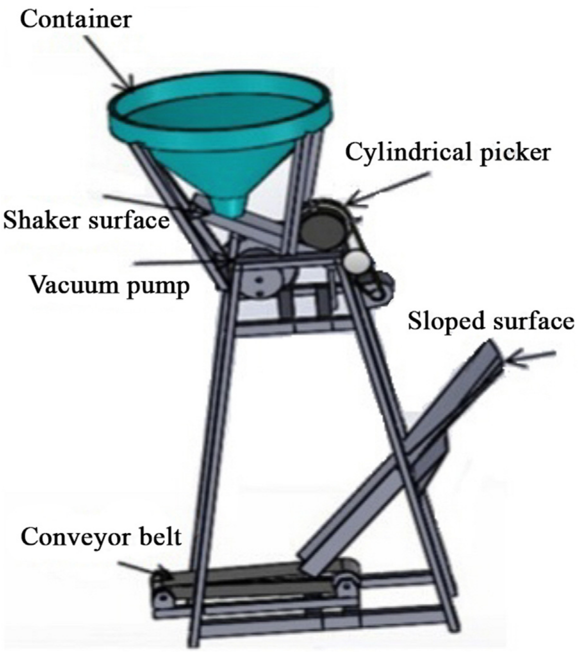

FIGURE 11.16 Saffron flowers sorter. *From Bakhshi, H., Abbaspour-Fard, M.H., Saeidirad, M.H., Aghkhani, M.H., Pourbagher, R., 2018. Design construction and evaluation of a row singulator for saffron flowers. Saffron Agron. Technol. 5(4), 361–371 (in Persian).*

FIGURE 11.17 Correct cutting point.

Accurate and correct selection of the cutting point is an important technical issue at this stage. Otherwise, loss will increase. The peduncle-petal joint is the best cutting point. By displacing this point, the amount of the white style attached to the triple-filament stigma may increase or decrease (Fig. 11.17). Most researchers use image processing systems to select the cutting point. The change in the color of peduncle from pale purple to deep purple at the cutting point is the main characteristic of automated detection.

A schematic view and the operation of the automated cutting device is presented in Fig. 11.18. The device features an automated cutter to separate stigma from the saffron flower and uses image processing to find the right cutting spot. Cup-shaped containers are arranged to collect the flowers and take them to the main system. At the end of the path, the flower is picked up from the cups by two pulleys and is passed through the imaging chamber. The image of each flower is then processed to find the best cutting point. Once the point is determined, the height of the cutting system (at the end of the device) is adjusted according to a computer command, and the flower is finally cut. Following the cutting stage, the vacuum system transfers the stigma and the flower to the storage tank. The results showed the efficiency and high rate of the cutting operation regardless of the shape, size, travel speed, and orientation of the flowers. The efficiency of the device was eight times higher than the manual method (Gracia et al., 2009).

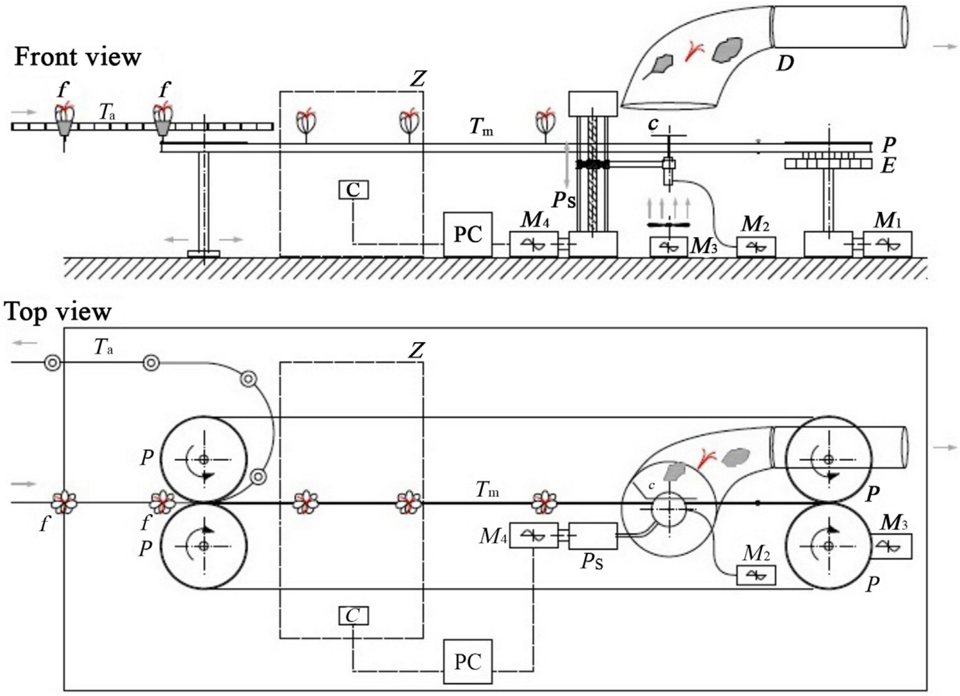

FIGURE 11.18 Schematic view of the automated cutting machine. *C*, camera; *c*, cutting disc; *D*, air separator; *E*, transmission gear; *f*, saffron flowers; *M1*, *M2*, *M3*, *M4*, motors of the transporter, cutting system, fan and positioning system; *P*, transmission pulleys; *PC*, computer; *Ps*, linear positioning system; *Ta*, *Tm*, conveyor belts or flower transporters; *Z*, area with controlled illumination. *From Gracia, L., Perez-Vidal, C., Gracia-López, C., 2009. Automated cutting system to obtain the stigmas of the Saffron flower. Biosyst. Eng. 104(1), 8–17.*

FIGURE 11.19 Saffron flower cutting device with manual feeding. *From Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on mechanization development possibility and providing the most optimum method to saffron harvesting mechanization. Final Research Report, No. 44678, Agricultural Engineering Research Institute (in Persian).*

A saffron flower cutter developed by an Iranian inventor is shown in Fig. 11.19. Its operation is based on manual feeding by an operator. Flowers are separately fed from their peduncle to the feeding inlet. The flowers pass through two counter-rotating rollers and are cut at the petal–peduncle joint by a vertically moving guillotine-like blade. An important feature of this device is its adjustable blade speed by a central processing system, through which the device can change the cutting point and thus adjust the length of the style attached to the triple-filament stigma. The device features four cutting units and requires three operators. Its capacity with four cutting units is 5 kg h^{-1} of saffron flower, and its mean cutting error, including uncut flowers, is 2.5% (Saeidirad et al., 2014).

The same inventor designed and developed a saffron flower separator (Fig. 11.20). The cut pieces (i.e., petals, stigmas, peduncles, stamens) are placed on the conveyor by the operator. The different parts of the flower are separated using airflow, sieve drums, and a magnetic field. It is capable of separating 50 kg h^{-1} of flowers with a separation accuracy of 3% (impurities in cleaned stigmas) (Saeidirad et al., 2014).

FIGURE 11.20 Saffron flower separator. *From Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on mechanization development possibility and providing the most optimum method to saffron harvesting mechanization. Final Research Report, No. 44678, Agricultural Engineering Research Institute (in Persian).*

FIGURE 11.21 Saffron processing device.

The inventor combined the two cutter and separator devices and introduced a saffron processing device in one bundle (Fig. 11.21) made of flower cutter, separator, and stigma dryer units. The dryer is a conveyor type with a netted fabric belt. The heat is supplied by four electric heating elements inside aluminum tubes. The stigma-carrying conveyor travels very slowly on aluminum tubes and the heat from the elements is blown by a fan toward the stigmas and dries them.

11.7 Conclusion

This chapter set out to explore the importance of saffron mechanization, the reasons and motivation for development of machine use in saffron production and the role and impact of intervention on the yield increasing, costs, labor and microbial contamination of stigma reducing. It also sought to show the correct choice and use of machineries and power supplies in different stages of saffron production. Moreover, all implements and equipment currently developed that are available for soil bed preparation, corm digging and sorting, corm planting, crop protection, and saffron harvesting process (flower picking and stigma separation) were introduced.

References

ABAC Holland, 2016. ABAC Holland develops Saffron All-in-One planting and harvesting machine report on prototype II. Available from: <http://abacholland.com/wp-content/uploads/2012/09/Report-SAIO-2-1.pdf>.

Abbaspour-Fard, M.H., Yousefzadeh, H., Azhari, A., Ebrahimi-Nik, M.A., Haddadimoghaddam, M., 2018. Ergonomic evaluation of conventional saffron harvesting versus using a trolley. Saffron Agron.Technol. 6 (2), 253−267 (in Persian).

Alonso Diaz-Marta, G.L., Arghittu, A., Astrka, K., Betza, T., Camba, E., Canadas Sanchez, W., et al., 2006. Saffron in Europe (Problems and Strategies for Improving the Quality and Strengthen Competitiveness). Technical Institute for Agriculture (ITAP), Region of Western Macedonia (RWM), Regional Organisation for Agricultural Development and Technical Support (ERSAT), University of Castilla La Mancha (UCLM), Agricultural University of Athens (AUA). Available from: <http://www.europeansaffron.eu/archivos/White%20book%20english.pdf>.

Bakhshi, H., Abbaspour-Fard, M.H., Saeidirad, M.H., Aghkhani, M.H., Pourbagher, R., 2018. Design construction and evaluation of a row singulator for saffron flowers. Saffron Agron. Technol. 5 (4), 361−371 (in Persian).

Bakhtiari-Konari, F., Saeidirad, M.H., Garazhian, H., Sahrayei, P., Arianfar, A., 2013. Investigation and comparison some physical properties of saffron corms. J. Res. Innov. Food Sci. Technol. 2, 69−81 (in Persian).

Behdani, M.A., Fallahi, H.R., 2016. Saffron: Technical Knowledge Based on Research Approaches. University of Birjand Press, Birjand, p. 412 (In Persian).

Emadi, B., Saeidirad, M.H., 2011. Moisture-dependent physical properties of saffron flower. J. Agr. Sci. Tech. 13, 387−398.

Gambella, F., Paschino, F., Manuello Bertetto, A., 2013. Perspectives in the mechanization of saffron (*Crocus Sativus* L.). Int. J. Mech. Control 14 (2), 3−8.

Ghanbarian, D., 2012. Design and development of a drum type saffron corm sizing-machine. Agric. Eng. 35 (2), 83−96 (in Persian).

Gracia, L., Perez-Vidal, C., Gracia-Lo´pez, C., 2009. Automated cutting system to obtain the stigmas of the Saffron flower. Biosyst. Eng. 104 (1), 8−17.

Manuello Bertetto, A., Falchi, C., Pinna, R., Ricciu, R., 2011. Laboratory test for an integrated device in agricultural applications. Int. J. Mech. Control 12 (1), 105−112.

Manuello Bertetto, A., Ricciu, R., GraziaBadas, M., 2014. A mechanical saffron flower harvesting system. Meccanica 49, 2785−2796.

Moayedishahraki, E., Jamialahmadi, M., Behdani, M.A., 2010. Efficiency evaluation of saffron cultivation energy In South Khorasan province. Agroecology 2 (1), 55−62 (in Persian).

Saeidirad, M.H., Akram, A., 2006. Design and development of two-row saffron bulb planter. AMA-Agr. Mech. Asia Af. 37 (2), 48−51.

Saeidirad, M.H., Mahdinia, A., 2014. Compaction and impaction forces from loading mechanisms for separation of stigmas from dried saffron flowers. J. Agric. Eng. Res. 15 (1), 1−10 (in Persian).

Saeidirad, M.H., Mansoorian, N., Behdad, M., 2007. Technical and economical comparision of tillage emplements used for crust breaking of saffron cultivation at different irrigation times. J. Agric. Eng. Res. 8 (2), 93−104 (in Persian).

Saeidirad, M.H., Zarifneshat, S., Mahdinia, A., Nazarzadeh, S., Mazhari, M., Mostafavand, H., et al., 2014. Investigation on Mechanization Development Possibility and Providing the Most Optimum Method to Saffron Harvesting Mechanization. Final Research Report, No. 44678. Agricultural Engineering Research Institute (in Persian).

Saeidirad, M.H., Zarifneshat, S., Nazarzadeh, S., Mehrabi, E., 2018. Design, Development and Evaluation of 7 Rows Saffron Corm Planter. Final Research Report, No. 53999. Agricultural Engineering Research Institute (in Persian).

Sanabadi-Aziz, M., Mostofi, M.R., Faridi, H., 2015. Design and construction of a mechanical machine for separating stigmas from the saffron's petals. J. Multidiscip. Eng. Sci. Technol. 2 (9), 2408−2416.

Sheykhdavodi, M.J., EbrahimiNik, M.A., PourrezaBilondi, M., Bahrami, H., Atashi, M., Seyedian, S.M., 2010. Mechanization planning for tillage of saffron fields using multiple criteria decision-making technique as a policy framework in Iran. Aust. J. Crop Sci. 4 (5), 295−300.

Sims, B.G., Kienzle, J., 2006. Farm Power and Mechanization for Small Farms in sub-Saharan Africa. Agricutural and Food Engineering Technical Report (3). FAO, Rome, 2006. Available from: <http://www.fao.org/3/a-a0651e.pdf>.

Tabatabaeefar, A., Emamzadeh, H., Ghasemi-Varnamkhasti, M., Rahimizadeh, R., Karimi, M., 2009. Comparison of energy of tillage systems in wheat production. Energy 34, 41−45.

Valeghozhdi, H., Hassanbeygi, S.R., Saeidirad, M.H., Kianmehr, M.H., 2010. Determining coefficient of friction and terminal velocity of saffron flower and its components. Iran. J. Food Sci. Technol. 7 (25), 121−133 (in Persian).