



History, biology, and culture of *Crocus sativus*: Overview and perspectives

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Abstract

SAFRAN (*Crocus Sativus* L.) is an autumnal flowering plant of great nutritional, economic and environmental value. It is a triploid species ($2N = 3x = 24$) that fails to produce seeds and therefore it spreads exclusively by corms. Although the demand for Safran on the international market has increased in recent years, the cultivation zone of this spice is concentrated in some terroirs with primitive agronomic practices. The reason which research activities have been launched to develop new spice production technologies in many countries. Indeed, the quantitative and qualitative production of saffron is influenced by several factors such as soil, climate, and anthropogenic operations. This bibliographic review deliberates on the latest agronomic works done on Saffron for the promotion of this culture as a profitable, viable, and sustainable culture.

Keywords: production technology, triploid, anthropogenic operations, quantitative and qualitative production.

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1. Introduction

Saffron is the spice derived from the plant botanically known as *Crocus sativus* L. from time immemorial, saffron has certainly represented the most interesting and attractive species, for the coloration, bitterness, and aromatic power of its dried stigmas [1]. It is the most expensive spice in the world [2] because the main management techniques such as planting, maintenance, and harvesting flowers are carried out manually. This is in addition to the low yield of this spice, which is attributed on the one hand to primitive agronomic practices and the other hand to genetically uniform planting material [3]. For a long time, Saffron was abandoned by researchers and farmers because it was considered a minor crop used only for agricultural diversification. However, in recent years, it has acquired a more interesting role in low-input agricultural systems such as the organic farming system. In the literature, several reviews are available on various aspects of saffron such as its biology [4,5] its history [3], its origins [6,7], its constituents, its uses [8] and its production chain [9] [10]. The purpose of this article is to summarize the work on agronomic aspects including plant requirements, technical route, and pests of the crop.

2. Presentation of the species: Etymology, Karyotype, Distribution Area, Biology, and Ecological Requirements.

2.1. Etymology

Crocus Sativus is the scientific name given by Linné in 1754, commonly called saffron. The terms of Safran and Crocus have undergone a different etymological evolution: the word Crocus is the Latin transcription of the Greek word "Krokos", to which we can find Assyrian or Hindu roots. "Krokos" in Greek means wire, filament, hair and originally referred to the stigma of the plant. The term sativus, when to it, means "cultivated" because the *Crocus sativus*, by its vegetative reproduction, can not multiply without the hand of man, [1]. The word saffron comes from the Latin saffranum, itself inspired by Arabic: Zaferân, which means the yellow, testimony of the strong symbolic around the color of this spice [11,12]. It is interesting to note that there is a common etymological origin in the designation of the word saffron in different languages [13].

International denominations

* French : saffron /English : saffron /Italian : zafferano /Portuguese : açafreão / Arabic: الزعفران

2.2. Origin and distribution

Saffron is one of the oldest spices, even though many legends surround the origin of saffron. The first detailed historical information goes up to Papyrus Ebers (1550 years before JC) which documents the use of Safran for medicinal purposes [14]. Concerning the origin and domestication of Saffron: Vavilov

indicates that its origin in the Middle East, while other authors suggest central Asia or the islands of southwestern Greece [15,3]. Also, Negbi [16] proves that the *Crocus sativus* has probably been selected and domesticated in Crete during the Bronze Age. From this primary area, it would have spread to India, China, and the Middle East countries. It is from the latter country that the Arabs spread the saffron throughout the Mediterranean basin [17], as in Morocco, where it was probably introduced to the 9th century [18].

Due to the small area of culture and the small importance given to this species, the information on its spreading in the world is uncertain [19]. Total global production of Safran is estimated at about 475 tons per year that is generally important in countries where labor is cheap, such as Iran, India, and Morocco, but it is also produced in Countries like Greece, Spain, Argentina, and the United States and more recently this culture has been introduced in some countries such as China and Japan [12]. Today, with more than 85% of the world's production, Iran is considered the world's leading producer of saffron [20], with an area of 115,000 ha and 405 tons of annual production. Next came India and Greece. Morocco is the fourth largest producer in the world with a production of 6.8 tons in 2018 for an area of about 1,800 hectares [21] (Table 1). In Morocco, the traditional saffron production area is located in the Taliouine and Taznakht region located respectively in the provinces of Taroudant and Ouarzazate [22]. However, given the importance of this species, Morocco has allocated particular attention, within the framework of the Green Morocco Plan, to the development of the saffron sector through the use of modern production techniques and the search for areas favorable to the introduction of saffron cultivation such as Ourika, Chefchaouen, Midelt, Oujda, sefrou, Bouchaoun, Tinghir, Errachidia.

Table 1. Saffron Production in Morocco and around the World (2018).

Country	Average annual production (Ton)	Percentage share of world production (in 2018)
Iran	405	85.2
India	22	4.6
Greece	7	1.5
Morocco	6,8	1.4
Other countries (Afghanistan, Spain, etc.)	34.2	7.3
Total Production	475	100

2.3. Genetic traits ' karyotype'

Saffron (*Crocus sativus* L.) belongs to the large family Iridaceae and the genus *Crocus*. This genus is characterized by a great diversity of species that have been described by several authors: [23]; 81 species, [24] 8 species, [25] 100 species. Morphological, karyological, and molecular studies conducted in recent

years [26,27,28] have shown that the number of *Crocus* species is likely to exceed 160 [29] (Fig 1). Crocuses have enormous cytological variation, with some species even showing interspecific chromosomal variation [30]. The following chromosome numbers have been reported: $2n = 6, 8, 10, 11, 12, 14, 16, 18, 20, 22, 23, 24, 26, 27, 28, 30, 32, 34, 44, 48$ and 64 [31]. This great morphological and cytological diversity of the genus *Crocus* is the result of massive hybridization, and the Inter-and intra-specific variation suggests that the genus has been exposed during its evolution to massive adaptation requirements and natural selection pressure [7].



Fig 1. Some species of the genus *Crocus*. (Botany Section 2011)

- Karyotype of *Crocus sativus*

Several studies have addressed the issue of karyotypic variability in saffron (Table 2). The first cytological studies to study the number of chromosomes date back to 1931, Morinaga and Fukushima reported $2N=24$ chromosomes while the results of various recent studies confirmed that *C. sativus* is triploid with $2n=3x=24$. The genetic origin of *Crocus sativus* is unclear and several hypotheses are put forward. Some authors believe that the species is probably the result of autotriploidy of a wild crocus, probably by fertilization of an unreduced diploid egg cell by a haploid gamete, or fertilization of a haploid egg cell by two haploid gametes [32,33]. Another hypothesis relates the origin of saffron to polyploidy resulting from the hybridization of *Crocus cartwrightianus* and *Crocus hadriaticus* [34]. Information about saffron's ancestors is not as unambiguous: classical botanical studies based on morphological aspects have suggested that *C. cartwrightianus* may be the closest relative of *C. sativus*.

Moreover, *C. sativus* and *C. cartwrightianus* are morphologically almost identical with the largest difference in size: the flowers of *C. sativus* have a double size compared to those of *C. cartwrightianus* [35]. The analysis RADP (random amplification of polymorphic DNA) and AFLP (length polymorphisms of amplified DNA fragments) were performed to look for the putative ancestors of *C. sativus* and which confirmed that the quantitative and qualitative DNA traits of both *C. cartwrightianus* and *C. thomasii* species are compatible with those of *C. sativus* [36,32]. Alsayied [37] reported that according to IRAP data (inter-retroelement amplified polymorphism), *C. sativus* had minimal genetic variation and that its ancestors were *C. cartwrightianus* and *C. pallasii* subsp. *pallasii*.

Table 2. Chromosomal number of *Crocus sativus*. L

Chromosome	References
2n=24	[38]
2n=14,15	[39]
2n=3x=24	[40, 41]
2n=20,22,28	[42]
2n=3x=24 ;x=8	[43, 44, 45]

2.4. Plant biology

Saffron with sub-hysteranthe behavior is a perennial herb growing to a height of 25-40 cm. The corms, leaf structure, and floral organs are the main parts of saffron plants [46] (Fig 2).

a. Flower

The flower, usually one or more, even up to 12, is composed of a perianth of 6 purple tepals (perigone) conned at the base in a long and narrow tube. The pistil is composed of a lower ovary from which arises a slender style 9-10 cm long. Three sterile stamens with two-lobed anthers each are also present [1]. The style ends with a single stigma consisting of three filaments of intense red color, which are the part of the plant interesting for humans from the point of view of culture (Fig 2). Some variations with a greater number of stigmas have been reported by [47,48,49]. However, they do not reappear the following year and should therefore be considered as somaclonal variations that are not passed on to subsequent generations.

b. Sheet

The leaves vary from five to eleven per bud; they are very narrow and measure between 1.5 and 2.5 mm of green color, they measure from 20 to 60 cm in length [9] with a whitish band in the inner part and a rib on the outside. This anatomical device allows the sheet to wind on its main axis and to be enclosed in a tube which limits evaporation when needed [50].

c. Corms

The corm of saffron is an organ derived from the stem, formed by shortened nodes and internodes. the corms are 3-5 cm in diameter and covered with tunics [1]. Mature saffron corms typically have one to

three dominant apical buds that will germinate the following season, as well as many dormant axillary buds [51] (Fig 1). Each axillary Bud has the same developmental potential as the primary apical shoot. However, axillary buds enter a dormant state after forming only a few leaves [52]. A large number of axillary buds in the corm system allows the plant to quickly recover damage and adjust growth based on environmental factors. Each mother corm produces from the apical buds, 1-3 large daughter-corms, and several small corms are born from the lateral buds [53]. Saffron also has two types of roots: fibrous and thin roots at the base of the mother corm, and contractile roots formed at the base of the lateral buds [54]. They are thicker than the former with a tuberous organ appearance that gives the corm the ability to maintain depth in the soil [55].

2.5. Development cycle

Saffron blooms in the fall when other plants are preparing to protect themselves from the rigors of winter, and unlike others, its activity slows down in the spring [56]. The life cycle begins with aerial vegetative growth during the first autumn rains with the emission of leaves and flowers and ends with the production of replacement corms in about 220 days. From september, the metabolic activity of the plant resumes, the leaves and floral primordia develop until flowering in october-november. Flowering induction is a process influenced by environmental factors such as temperature [57] and pre-treatment of mother corms [58,59]. Indeed, the phenological sequence of the different phases is not predetermined: flowers can appear before, at the same time or after the appearance of leaves. Then, as a result of flowering, the vegetative period is characterized by the development of roots, leaves, and corms whose average size of the corms is inversely proportional to their number [60]. The arrival of relatively high spring temperatures causes a gradual slowdown until almost complete cessation of the metabolic activity of the plant. The plant thus enters a dormancy phase [61]. During dormancy, flower buds begin to differentiate [62].

2.6. Reproductive biology

a. Sexual Multiplication

Saffron is an auto and allo sterile and mostly male-sterile species [33]. It is therefore unable to produce seeds. Its sterility results from irregular triploid meiosis, with many abnormalities in gametophytic development [63,33] and therefore an abnormal pollen production. For this reason, saffron exhibits sterile self-pollination. Seed production has been reported only once [64]. *In vitro* cross-pollination of the ovary of *Crocus sativus* with pollen from *Crocus cartwrightianus* [6] and *Crocus tomasii* (self-incompatible, but Allo-fertile species) [19] resulted in the production of viable capsules and seeds (Fig 3). *Crocus hadriaticus* can also fertilize *Crocus sativus* [65]. Conversely, pollination of other species of the genus *Crocus* with the pollen of *Crocus sativus* produced no seeds [33].

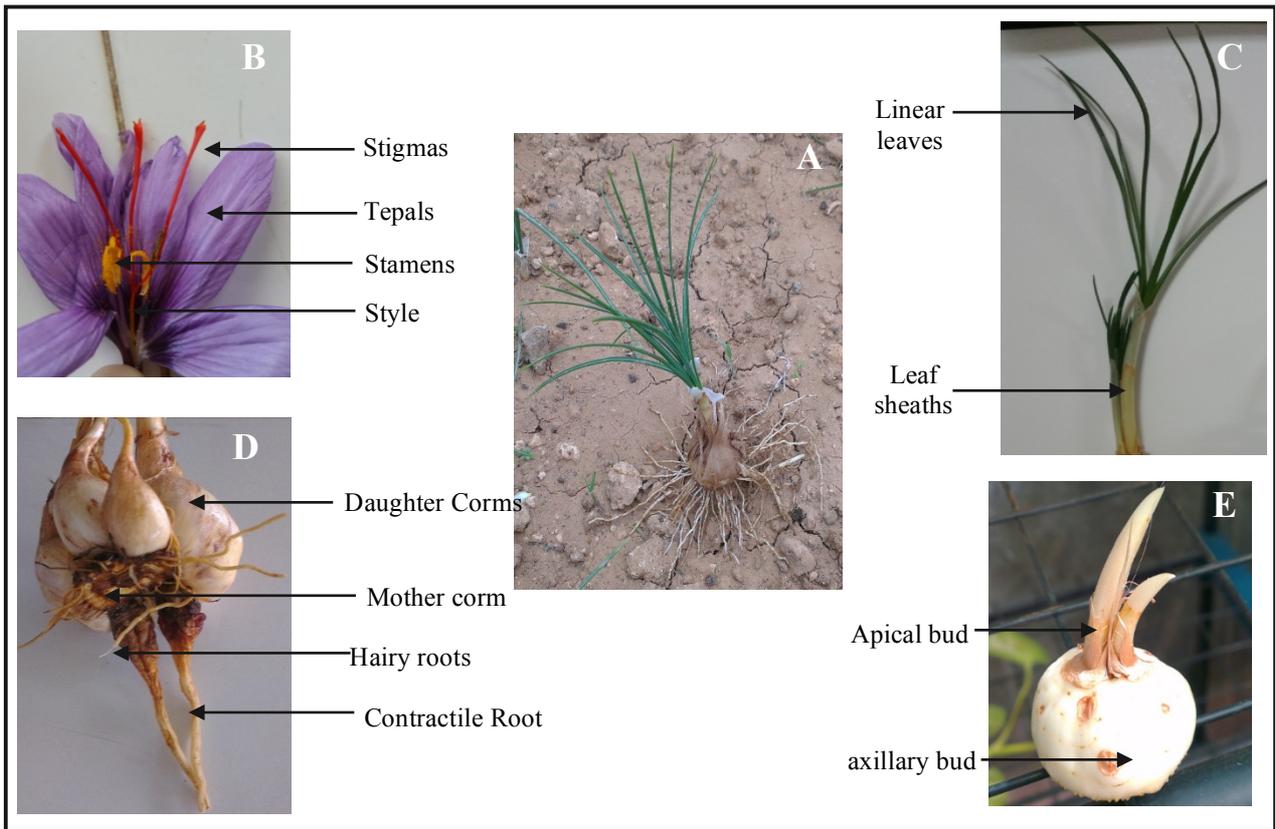


Fig 2. Saffron plant (A) details of the saffron flower (B) details of the leaves showing the sheath that connects the leaves (C) bottom view of the corm showing the mother corm surmounted by the son corms, as well as the two types of roots: hairy and contractile (d) top view of the corm showing the apical buds and axillary buds located in the different nodes (E).

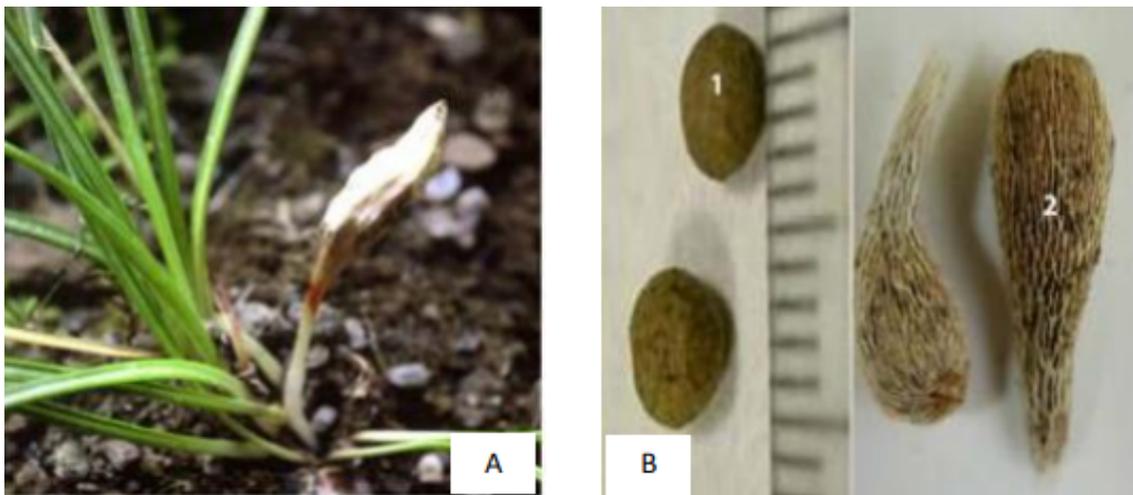


Fig 3. A; capsules of *C. sativus* × *C. cartwrightianus*. B; corms from sprouted seeds of *C. sativus* x *C. cartwrightianus* 1.1-year-old corm 2.3-year-old corm [6].

b. Asexual reproduction

Saffron corms are underground organs, which store reserves allowing the species to overcome the bad season and ensure its sustainability. The development of a corm goes through the following stages [66]:

start of apical buds, latent on the surface of Mother corme, towards the end of august or early september, with the first autumn rains; Consumption of stored reserves in the mother corme for the formation of flowers and leaves and the beginning of the accumulation of new reserves in preformed daughter-cormes, maturation of new strains and senescence of mother corme [62]. The number of shoots per corme is a critical factor, as it affects flower production as well as the number of corms of the next generation. The number of shoots can be affected by the size of the corms [67] and the depth of planting [60]. Similarly, micropropagation protocols using corme tissue explants, lateral or apical buds, leaves, and different floral parts were used for in vitro regeneration of saffron [68,69,70,1,71,72].

2.7. Conservation, characterization, and use of *Crocus* genetic material

To date, no saffron variety is available to confirm productivity gains. Due to the triploid nature of saffron, conventional breeding methods offer limited scope for saffron enhancement. Therefore, the clonal selection offers a maximum opportunity to capitalize genes for high yield, integrated tolerance to diseases and pests, and better quality. In 2005, the European Commission launched a program for the conservation, characterization, collection, and use of genetic resources in agriculture, AGRI Gen RES. A consortium of 14 groups from 9 countries. The collection of mother plants is in the plant material Bank of Cuenca (Spain), where 384 accessions of saffron and wild *Crocus* are preserved, multiplied, and particularly characterized [73]. For genetic conservation and use, Work is also being carried out in Azerbaijan [74], Iran [75], Greece [6] and Kashmir [76,77].

2.8. Edapho-climatic requirements

a. Climate

Saffron is successfully grown in various environments around the world. The range of *Crocus spp.* is between 10 ° W and 80 ° E longitude, 30 and 50 ° latitude N [23] (Table 3). Saffron can be grown at altitudes ranging from 50 m above sea level, as in Italy (Sardinia), to more than 3000 m for the case of India (Kargile). It adapts to both the temperate subtropical climate and the continental Mediterranean climate, with cool winters and hot, dry summers, in a humidity regime typical of the dry Mediterranean climate [53]. Rainfall in saffron growing areas is highly variable. It is less than 200 mm/year in Taliouine, Morocco, while in Navelli, Italy it reaches 700 mm [21].

Temperature is the most important environmental factor controlling the growth and flowering of *Crocus* species [83]. the average annual temperature of 16 saffron growing sites worldwide ranges from 5.9 to 18.6 ° C and precipitation from 200 to 700 mm (Table 4). The crop can withstand very severe temperatures, up to 40°C in summer and -18°C in winter [5] (Fig 4). The optimum temperature for flower initiation should be lower than for flower formation [84]. This fact explains the difference in the timing

of the emergence of flowers in places with contrasting climates. The photoperiod has a considerable influence on the flowering of saffron. A lighting period of 10 to 11 h is desirable [85].

Table 3. Some places where saffron is grown

Location	Latitude	Longitude	Altitude	References
LaMancha (Spain)	39° 10'N	02°54' W	610 m	[3]
Navelli (Italy)	42° 14'N	13°44'E	650 m	[15]
Oujda (Morocco)	34°40'N	1°54'W	661 m	[21]
Taliouine (Morocco)	30° 36'N	08°25'W	1200-1400 m	[78]
Ferdows (Iran)	34° 16'N	58°10'E	1213 m	[79]
Sahr-kord (Iran)	32° 19'N	50°51'E	2066 m	[80]
Sangla (India)	31° 25'N	78°25'W	2680 m	[81]
Kargil (India)	34° 32' N	76° 08'E	3200 m	[82]

Table 4. Climate characteristics of major saffron cultivation areas.

Location	Maximum temperature (°C)	Minimal temperature (°C)	Average temperature (°C)	precipitation (mm)	References
La mancha (Espagne)	25	5.7	16-20	---	[15]
Ferdows (Iran)	49.6	-12	18.8	158.8	[79]
Navelli (Italie)	22.5	2-5	11.3	700	[15].
Taliouine (Maroc)	25-30	-	-	100-200	[78]
Sangla (Inda)	32.9	-4.3	14.3	104	[86]
Oujda (maroc)	45	-0,4	20.1	251.2	[87]



Fig 4. Saffron plant under the snow at the FSO Experimental station (Morocco)

b. Soil

Saffron grows on a wide range of soil types [53]. Reviews are controversial in the literature about the best type of soil for saffron. Some authors report that the best soils are deep and well-drained clay and

clay-limestone soils [85] and [2] and others suggest that saffron grows well on well-worked and well-drained loamy or sandy soils [88]. However, since the commercial product of saffron (stigmas) is not a storage structure as for the majority of cultivated plants, the need for fertilizers for the production of stigmas is low and therefore the crop adapts well to poor soils [89]. According to Mollafilabi [85], saffron grows well on saline soils, but calcium carbonate deficiency on these soils may be a limiting factor. The soil pH for saffron cultivation should be neutral to slightly alkaline [90,53].

3. Cultivation of saffron: planting, maintenance, pest, and post-harvest treatment.

Most crop maintenance techniques, especially planting, weeding, picking, and separating flowers, are hand-made worldwide [91] making this species among the most labor-intensive crops (Fig 5).

3.1. Soil preparation

Good soil preparations are needed to have a friable texture for growing saffron. The field is plowed 2-3 times to a depth of 30-35 cm. This is followed by cover cropping and leveling. The plot must be cleared of any growth of weeds, penetrating roots, and stubble. To facilitate weeding, hoeing, and irrigation, appropriately sized raised beds, preferably 1.2-1.5 m wide and 15-20 cm high, should be developed [5]. Paths can be 30 cm wide between the beds, which act as drainage channels. This avoids a high content of unwanted moisture in the upper 15-20 cm of the soil. In Sandy to loamy sandy soils in dry temperate regions where precipitation is of low intensity, a raised bed may not be required.

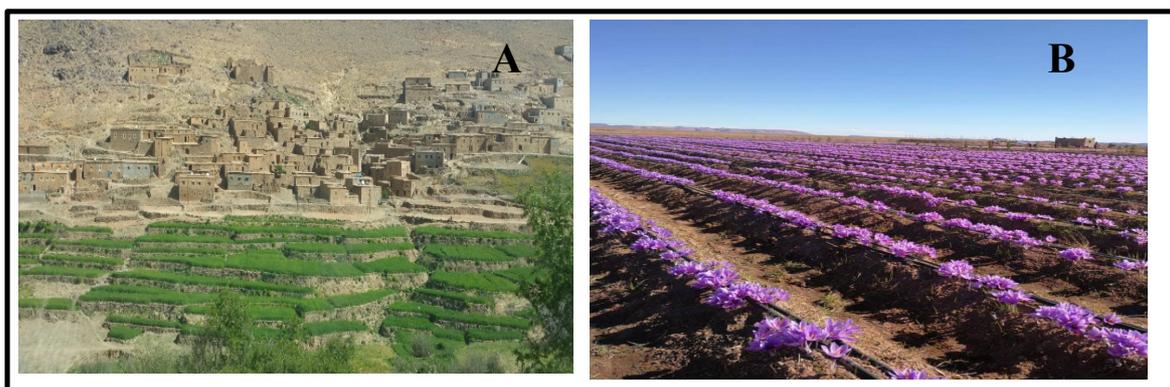


Fig 5. Old terrace planting system (Morocco) (A), billion planting in extension areas (Talakht, Morocco)

In Iran, [92] have grown saffron in various media (1) in the pot containing topsoil; (2) in semi-liquid agar medium; and (3) in a liquid medium; the results showed that root elongation was four times higher in the soil compared to other media. Similarly, [89] tested the effect of the different substrates (peat and perlite) and found that the best yield of saffron was obtained in the case of perlite compared to the peat/perlite mixture.

3.2. Plantation

a. Choice of corms

The size of the corms has a decisive influence on the yield especially during the first year of planting because of their impact on the number of flower buds. Generally, a diameter of 2.5 cm is considered the smallest size below which bulbs must be placed in the nursery for magnification [5].

b. Planting depth

Planting saffron corm at an appropriate depth influences the yield of saffron. When the bulbs are planted shallow (<8-10 cm), the contractile roots become large and fleshy, in which case the daughter corms do not grow, as reserves are stored in the roots [93]. In sandy soils, saffron has been shown to be able to emerge from plantations 30 cm deep [94], while Nazir [95] has reported longer leaves (48.70 cm), a higher number of corms/plant (29.24) by planting saffron at 7.5 cm deep. However, Dhar [90] argued that shallow planting is undesirable because the bulbs are exposed to freezing cold in winter and high temperatures in summer, which adversely affects growth. Recommended planting depths for bulbs vary from 7.5–10 to 15-22 cm in different regions depending on the texture of the soil. In Italy, planting depths of 15 cm gave a better yield than a shallower or deeper planting.

c. Planting period

The planting period of saffron varies from region to region depending on climatic conditions. Rehman [96] reported that corm yields were highest when corms were planted from mid-July in the Balochistan region of Pakistan. In Iran, [97] concluded that the best time for planting is from mid-May and especially early June. In Italy, saffron is planted in the second half of August, in Spain from 15 to 30 June, in Greece before mid-September, and in India from mid-July to August [15] and between late August and early September in Morocco [15].

d. Planting spacing and density

Spacing is a parameter decided by the distribution of the crop so as not to hinder the development of the adjoining corms. Under the temperate Sangla conditions in India, a spacing of 20 × 20 cm is ideal [98] when cultivation is conducted over 10 years. However, Badiyala [99] observed that a narrower row spacing of 10 × 7.5 cm gives higher yields in the early years. In Morocco, 2 × 2 m raised beds were made with rows spaced 20 cm apart and clusters of 2-3 bulbs were planted 10-15 cm apart in the rows [100]. The number of corms/ha depends on the size and weight of the corms, the duration of cultivation, and the spacing is chosen. A larger size of corm has a positive effect on spice production [101]. Increasing the size of corms leads to a higher number and weight of corms [102]. About 25 to 30 quintals of corms or 500,000 corms with an average diameter of 2.5 cm are needed to plant a 1 ha of saffron [103]. While Ram [104] reported that about 40 q of appropriately sized corms (2.5 cm in diameter) with

an average weight of 10 g are needed to plant 1 ha of land in Kishtwar, India. In Greece, 20-30 q of saffron bulbs or about 230,000 - 250,000 bulbs with an average diameter of 2.2–2.5 cm are used / ha. [105]. In Morocco, 30 q of corms are used / ha. [78].

3.3. Irrigation

The water requirements for Saffron are low and can be met by precipitation in some areas in semi-arid conditions. Some authors [106,107] report that flood irrigation inputs of up to 3000 m³ per year in Iran. So in Morocco, the volume brought for irrigation does not exceed 500 m³ / ha [78]. Experiments carried out in Greece Skrubis [108] have shown that irrigation in early september promotes early flowering [109], while irrigation in late september and during the month of october leads to an increase in yield. The critical stages of saffron irrigation are flowering in autumn and the reproductive period in spring (March) [110,111]. The vegetative period coincides with the winter season, characterized by low climatic demand and water supplies by rain, therefore it is important to limit water supplies by irrigation during this phase. Irrigation of saffron in the summer (dormancy) is not recommended because of the high risk of fungal infection of the corms [112]. In general, three systems are used for irrigation: surface irrigation, sprinkling, and drip irrigation (Fig. 6). From the point of view of irrigation water quality, the saffron plant has a high tolerance to salinity [113].

3.4. Fertilization

Saffron is not very demanding on fertilizers. Manure as a substantive amendment is recommended at a rate of 20 tons in Greece [114], 15-20 tons in Kashmir [115,116], 30 tons in Sangla, India (Rana et al., 2003), and Italy [117], and 40 tons in Iran [118]. Sadeghi [119] reports promising results of chemical fertilizer application. Under Iranian conditions, the yield of saffron increased by 33% by applying 46 kg N / ha in the form of urea and 30 tons of manure/ha. [120]. Under rain conditions in Kashmir, N and K at 30 kg and P at 40 kg/ha were considered ideal. (113,144). Fertilizers were applied in two equal slices, one during the first week of september and the other during the third week of november. Similarly, [121] also reported that fertilizer spraying during March increased the number of flowers by 33 %. Foliar fertilization of urea on saffron in winter (January-March) resulted in a significant increase in the number of flowers in a two-year experiment conducted in Iran [121]. In addition, because of the soil that is depleted of potash and phosphorus, elements necessary for the growth of the bulbs, it is essential to carry out sorting and grubbing of the corms every four to five years.

3.5. Weed control

Saffron is a low crop that has a low competitive ability against weeds for water, mineral elements, and especially for light [122]. Because of this, weeds are the main problem and the formidable enemy for

saffron (Fig 7). They negatively affect bulb growth and development (bulb size and number) and therefore cause significant yield loss [123].



Fig. 6. Irrigation systems used for saffron in Morocco: sprinkler irrigation (a), surface irrigation (B), drip irrigation (C)

Several weeds like *Anagalis arvensis*, *Avena fatua*, *Digitaria sanguinalis*, *Equisetum sp.*, *Cyperus rotundus*, *Malva parviflora*, *Malva verticillata*, *Gallinsoga parviflora*, *Chenopodium album*, *Chenopodium murale*, *Stellaria media*, *Echinochiumloa Walla annichi*, *Echinochiumloa Walla annichi*, and *Medicago falcata* are present in succession during the saffron cultivation cycle [124,122]. According to the agronomic diagnosis carried out in the Taliouine-Taznakht region (Morocco) [125], weeds are controlled manually, since the use of chemical herbicides is not justified due to the small size of the saffron plots. However, in Greece Negbi [16] achieved the best weed control by using simazine and atrazine herbicides at a rate of 1.0 kg/ha. Fusilade and betanal are also reported to be effective in controlling broadleaf grassy weeds. Pruthi and Yau [126,127] observed that chlorthal and glyphosate provided promising weed control between crocus rows in Sardinia, Spain.

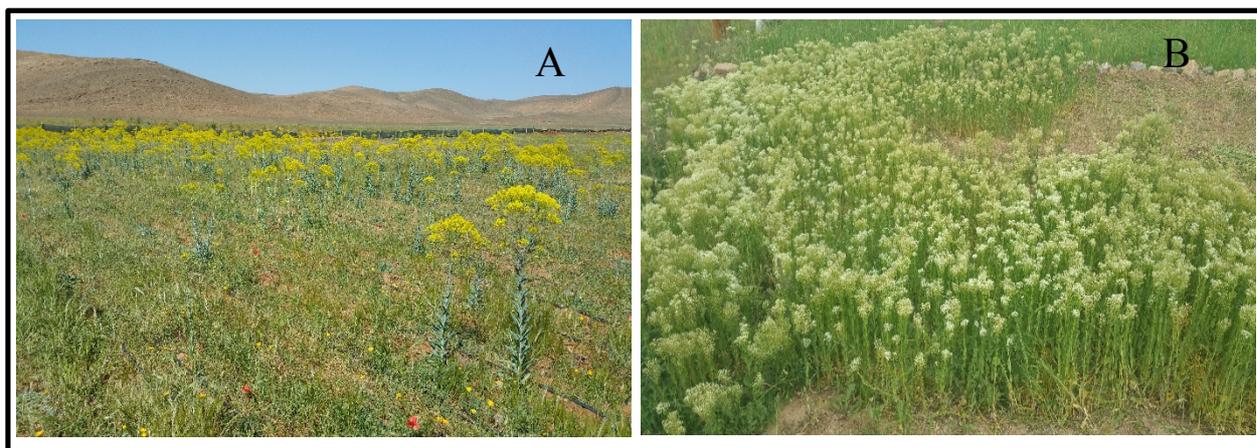


Fig 7. Infestation of the Fields of Saffron by weeds (A) *Isatis Tinctoria*, (b) *Cardaria Draba* (Morocco).

3.6. Biotic stresses

The saffron harvest is affected by several biotic stresses of which the rot of the corms is the most serious disease, caused by telluric fungi, namely. *Rhizoctonia violacea*, *Pythium irregulare*, *Fusarium solani*, *Phoma crocophila*, *Macrophomina phaseolina*. [9,128,129]. Infected corms developed symptoms of red, brown, black, and white color. To avoid fungal infection, practices such as crop rotation, removal, and burning of infected plants, as well as treatment of corms before planting with antifungal products such as Benomyl or copper-based solutions. Saffron is infested with different types of viruses, namely yellow bean mosaic virus (BYMV), tobacco rattle virus (TRV), cucumber mosaic virus (CMV), tomato tanned disease virus (tswv), and tobacco necrosis virus (TNV). [130,131]. Moles, rats, and rabbits can easily damage the corms or eat the leaves. Crows also inflict damage to sprouting flowers causing great loss [90]. An unusual pest in *C. sativus* is the cantharidine beetle, which attacks the flower at the beginning of the day in search of honey which damages the stigmas [132].

3.7. Intercropping and crop rotation

Cultivation of saffron must be included in a rotation program. A ten-year experiment [33] observed that bulbs left in the soil without management techniques continue to produce daughter bulbs for 3-5 years, then they degenerate and are no longer able to reproduce vegetatively. Feizi and Tammaro [133,134] reported similar results. In India, the cultivation of saffron with cereals such as wheat and mustard is usually followed by farmers. In central Italy, saffron is profitably rotated with legumes and wheat [86]. Saffron can also be planted in intercalary with other speculations whether arboreal or herbaceous (Fig 8). Some authors have reported that saffron cultivation can be successfully resumed between almond or apricot plantations. So, in Apple plantations, the cultivation of saffron is successful only during the first stages of establishment. Similarly, Koocheki [135] reported that the interaction of saffron culture and cumin culture induced a significant increase in flower numbers and therefore saffron yield.



Fig 8. Saffron cultivation systems in Morocco: monoculture (A), intercropping (B).

3.8. Harvest and yield

Harvesting flowers and separating stigmas are considered among the most difficult operations. Picking 1,000 flowers requires 45-55 min, and an additional 100-130 min to remove the stigma. Thus, 370-470 h is required to produce 1 kg of dried saffron [136]. The saffron flower is highly ephemeral, it should be harvested on the day of its appearance and placed in baskets [53]. Harvesting should begin shortly after dawn. If exposed to the sun, saffron quickly loses its color and flavor and wilts under the light. Immediately after harvesting, the flowers are brought inside for the separation of stigmas (pruning). The collected filaments must be protected from light and various contaminations before drying.

Yield is a rather difficult parameter to predict for saffron cultivation because it depends on many environmental, biological, and anthropogenic factors [16]. One kilogram of intact flowers gives 72 g of fresh saffron (stigmas), which in turn gives 12 g of dry saffron. the yield is relatively low in the first year and maximally increases in the third and fourth year after planting. Saffron yield (kg ha⁻¹) varies considerably from country to country. In Iran, the average yield ranges from 4 to 6 kg ha⁻¹ [137,20]. Yields of 8.4 and 6.5 kg ha⁻¹ were obtained respectively in Italy and Spain [138], while yields under unfertilized and rain-fed conditions in Kashmir reach only 1.57 to 3.74 kg ha⁻¹ [48]. In New Zealand, a yield of 24 kg ha⁻¹ was produced [139]. In Morocco, yields vary between 2 to 6 kg ha⁻¹ depending on the growing season [140].

3.9. Drying

Drying is a crucial operation that determines the quality of saffron and its components. During the process of dehydration, stigmas lose 80% of their weight. The drying process differs from country to country. In Morocco, stigmas are spread on fabric in a very thin layer and dried in the sun for several hours or in the shade for 7-10 days [141]. For villages with an electric current, drying is carried out using dryers (Fig 9). Sampathu [142] confirmed that the traditional method of sun drying in India takes about

27 to 53 h, which could be responsible for the enzymatic degradation of Crocin [143,144]. Compared different drying methods, namely shade drying, sun drying, electric oven drying, cross-flow drying, vacuum oven drying, and dehumidified drying and they observed that a method using $40 \pm 5^\circ \text{C}$ (solar dryer/oven drying) is the best technique for maintaining high-quality saffron and saves a lot of time compared to traditional drying in the sun.



Fig 9. Saffron stigma drying techniques in Morocco: in the Shade (A), by electric dryers (B).

Conclusion

Saffron, the legendary culture, is a very unusual plant for its agrolological and ecophysiological characteristics. It has an annual cycle, but the culture is perennial, due to its vegetative propagation. Besides, it is considered a hysterical plant. Indeed, the phenological sequence of the different phases is not predetermined: the flowers can appear before, at the same time, or after the appearance of the leaves. The water consumption of the crop is reduced with a very low harvest index [2]. The sterility of saffron limits the application of conventional selection approaches for its improvement. However, vegetative propagation offers the major advantage of maintaining the genetic characteristics of the plant but does not allow any genetic improvement. Also, the use of biotechnology tools, such as the induction of artificial variability to achieve yield improvements could be considered with colchicine [145,146] or physical irradiation [147,148]. The improvement of production could also be achieved through the use of appropriate cultivation techniques such as seed selection, the use of mulch, the improvement of the physicochemical properties of the soil through the incorporation of biofertilizers, establishment of mycorrhizal associations, and irrigation planning during critical stages of cultivation. In addition, given the importance of labor in the production chain of this crop, genetic studies (selection) and biological (storage conditions) devoted to prolonging the appearance of leaves at the end of flowering, could prove an important step towards mechanization. In general, a synergy between the empirical knowledge of producers and scientific knowledge can generate new agronomic knowledge especially since technical management represents a major obstacle to the development of the production chain of this crop.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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