ISSN NO: 2770-0003
Date of Publication: 16-11-2021

Bioecology And Introduction of Saffron (Crocus Sativus L.)

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Abstract: Saffron (*Crocus sativus L.*) is an autumnal flowering geophyte whose dried stigmas, well known for their aromatic and coloring power, have been used since immemorial time as a spice in human nutrition, for medicinal purposes and as a dye. Many doubts remain on its origin; it was probably selected and domesticated in Crete during the Late Bronze Age. It has a reverse biological cycle compared with the majority of cultivated and spontaneous plants: flowering first in October-November, then vegetative development until May, which means that the vegetative development is not directly important for production of stigmas, but for the production of new corms. It is a representing an alternative viable crop for sustainable agriculture. Here we review the main biological, genetic and ecological traits associated with agronomic management techniques of saffron in relation to environmental conditions.

Key Words: Crocus sativus L, morphologically saffron, origin and distribution, Soil, Fusarium

Introduction:

Saffron (*Crocus sativus L.*) belongs to the large family of Iridaceaeand to the genus Crocus, which includes about 80 species distributed primarily in the Mediterranean and south-western Asia (Fig. 1). Among these, saffron, recognized as the most expensive spice in the world (winter halter and Straubinger, 2000; Fernandez, 2004), certainly represents the most interesting and attractive species, for the coloring, bitterness and aromatic power of its dried stigmas. Saffron is a geophyte herbaceous plant, whose stigmas have been used from ancient times as a spice in food, as a dye, in perfumes and cosmetics preparation and for medicinal purposes (Basker and Negbi, 1983). Nowadays, it is almost used for food coloring and flavoring, even though recent studies are boosting interest in its medical properties. Saffron is known only as a cultivated species; it propagates solely vegetatively by means of corms, underground stems acting as storage and reproduction structures, and does not produce seeds or exist as a spontaneous plant.

Figure 1. Saffron (Crocus sativus L.)

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Origin And Distribution:

The word saffron probably comes from the Persian sahafaran that derives from asfar meaning yellow. Its center of origin is not entirely certain. Some information is given on saffron origin and domestication: Vavilov indicates the Middle East (1951), while other authors suggest Asia Minor or the south-west Greek islands as its probable area of origin (Tammaro, 1990). Results from research (Negbi, 1999) show that Crocus sativus was probably selected and domesticated in Crete during the Late Bronze Age. From here, it spread to India, China and the Middle Eastern countries. From these latter, the Arabs brought saffron to all Mediterranean Europe (Ingram, 1969). Anyway, according to recent archaeological studies on ancient coins and inscriptions (Manganaro, 2001), saffron was already cultivated in the Greek-Roman period in Sicily.

Even if many legends surround the origin of saffron, the first detailed historic information dates back to Papyrus Ebbers (1550 years B.C.) that documents the use of saffron for medical purposes and frescoes in the Minoic Palace of Knossos (about 1500 years B.C.), depicting young girls gathering crocus flowers in baskets. Many other historic references are reported in the Old Testament and in the texts of many Greek (such as Theophrastus, Aeschylus, Pindarus, Hesiod, Hippocrates and others) and Roman (such as Plinus, Largus and Celsus) writers, documenting its use for the preparation of perfume, food and as a dye.

Morphology:

Morphologically saffron, being a clone, has great uniformity over a wide cultivated area (Brighton, 1977; Mathew, 1977). The corms, a tuberous-bulb formation, are squashed, flattened at the base, to about 4.5–5.5 cm diameter, and covered by several reticulated fibrous tunics (Fig. 2). Corms have one or two main buds in the apex position and about (depending on the dimension) 4–5 or more secondary buds, arranged irregularly in spiral form. Corms derived from secondary buds are smaller than corms produced by apical buds. Each mother corm produces 1–3 medium-big daughter corms from apical buds and several small corms from lateral buds, depending on the size of the mother corm. Leaves (from 6 to 9) are erect, narrow, grass-like and dark green colored. The flower, usually one or several, but even as many as 12, is composed of a perianth of 6 violet tepals (perigon) connate at the base in a long and narrow tube. The pistil is composed of an inferior ovary from which a slender style, 9–10 cm long, arises. The style is divided into 3 dark red branches, each one up to 30–40 mm long, named stigmas, which droop over the perianth segments. Three stamens with two lobed anthers each are also present.

Figure 2. Main morphological characteristics of saffron.

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Biology And Physiology:

Saffron is an autumnal flowering geophytecharacterized by a long summer rest in which the plant survives periods of drought by means of corms (Fig. 3). Its biological cycle starts with its above-ground vegetative growth at the first autumn rains with the emission of leaves and flowers almost immediatelyand ends with the production of replacement corms in about 220 days. Unlike many other species of the Crocus genus that flower in the winter-spring period, in saffron flowering can occur from mid-October to the end of November, essentially depending on the climatic conditions. It generally starts from 60 to 90 days after planting, mainly depending on sowing time, but snowy and cold periods may retard flowering. Flower induction is a very complicated mechanism in saffron. Little information is available on flower induction in saffron; nevertheless, flowering seems to be mainly influenced by environmental factor such as Molina et al. (2004a) ascribe the ability to influence the beginning and duration of flowering to temperature, while an inferior or negligible role is ascribed to soil water content. Certainly, as in most geophyte plants, both seasonal and daily thermoperiodism are involved as the main environmental factors inducing flowering (Halevy, 1990). Saffron is considered a subhysteranthous plant (Mathew, 1977, 1982). Indeed, the phenological sequence of the different phases is not predetermined: flowers can appear before, at the same time or after leaf appearance. Hysteranthy is a strange phenomenon present in many geophytes such as *Scilla autumnalis, Urigineamaritima Amaryllis belladonna, Pancratiumsickenbergeri, Colchicum alpinum, Sternbergiacolchiciflora,rnithogalumpyrenaicum,* etc., that flower before leaf emergence, supporting flowers only with the storage nutrients concentrated in the corm (Dafni et al., 1981). In Mediterranean geophytes, this response can be explained as a strategic adaptation to the temporal unpredictability of the onset of rain after the summer drought (Debussche et al., 2004).

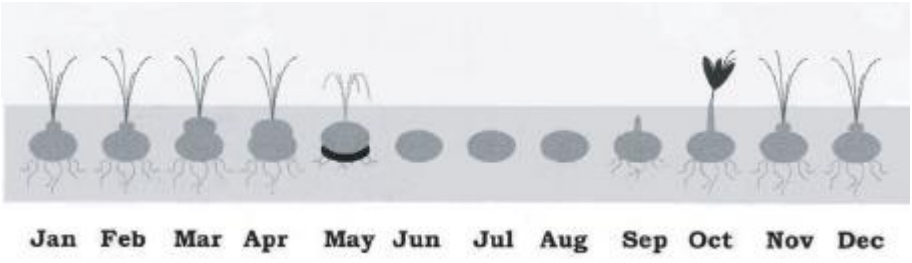

Figure 3. Biological cycle of saffron (from Alvarez-Orti et al., 2004).

Soil:

Saffron grows on a wide range of soils. Skrubis (1990) indicates that the best performances are achieved on well-drained clay-calcareous and deep soil. Fernandez (2004) suggests that clay is a good soil for saffron, while Sampathu et al. (1984) reports that saffron requires a well-ploughed sandy-loamy soil or a well-drained clay soil. Saffron is also cultivated on sandy soil in Azerbaijan (Azizbekova and Milyaeva, 1999). Tammaro (1999) suggests that the humus-clay soil of Navelli guarantees good water storage for saffron. Saffron grows well in salty soil, while a limiting factor could be calcium carbonate deficiency (Mollafilabi, 2004). Good soil pH ranges from neutral to slightly alkaline. Conflicting information is reported on nutrient needs among different authors (Goliaris, 1999; Tammaro, 1999; Skrubis, 1990).

Irrigation:

Irrigation is not a necessary practice. Water requirements of saffron are low and can be satisfied by the scarce rainfall when cultivated in semi-arid conditions. Even in the Mediterranean environment, saffron is not watered in many cultivated areas (Sardinia, Abruzzo, Greece, etc.) (Tammaro, 1999; Skubris, 1990). Some authors (Koocheki, 2004; Mosaferi, 2001) report up to 3000 m3 flood irrigation per year in Iran, Afghanistan and up to 500 m3/ha in Morocco (Ait-Oubahou and El-Otmani, 1999). Experiments carried out in Greece (Skrubis, 1990) demonstrate that irrigation at the beginning of September resulted in an earlier onset of flowering, while irrigation at the end of September and during October determined an increase in production. Late irrigation could result in a worsening of the quality traits of saffron, especially if watered

ISSN NO: 2770-0003
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just before flowering. Certainly, the most crucial moment for irrigation is after summer to awaken the corms, but this coincides with autumn rains so, excepting a severe drought season, this may be considered unnecessary.

Fertilizing:

The application of about 20–30 tons per ha of organic manureis the most common fertilization practice all over the world (Kooceki, 2004; Tammaro, 1990), while 40 units of N, 30 units of P2O5 and 40 Units of K2O are applied in Greece (Goliaris, 1999). Mature horse and cow manure of about 25–30 t/ha, without any chemical fertilization, determine good results in Navelli (Tammaro, 1999). On the contrary, incorporation of organic matter before planting did not improve saffron yields in New Zealand (McGimpsey et al., 1997). Behzad et al. (1992) found that 25 t/ha of cow manure significantly increased the dried stigma production in a soil with low organic content (0.3% in Organic Carbon), but had no effect in a soil with 1.0% O.C. They also observed that annual distribution of 50 kg/ha of nitrogen increased saffron yields, and that phosphorus and potassium seems unnecessary. Sadeghi (1980) reports promising results of applying chemical fertilizer, while, in a three-year experiment in two sites inran, Behnia et al. (1999) found contrasting results on nitrogen fertilizer, and no effect was shown by the application of phosphorus. Urea foliar fertilization applied on saffron in winter(from January to March) resulted in a significant increase in flower number in a two-year experiment carried out in Iran (Hosseini et al., 2004).

Weed Control:

Weeds are probably the main problem for saffron, since it is unable to compete, above all because of its very low height. Nevertheless, due to the short time between the corm planting and flowering, severe weed problems start the following spring in perennial cultivation. From flowering, weeds can be left to grow until May and then cut without damaging the crop when the saffron leaves wither. Weeds are managed by hand in annual crops in Italy, while in perennial crops a good chemical control is generally achieved with 10 kg/ha of Simazine (Gesatop 50%) or Atrazine (Gesaprim 50%) (Goliaris, 1999). In Iran and Afghanistan, broad leaves are controlled with pre-emergence and post-emergence treatments of Sencor (Metribuzin) and narrow leaves with Gallant (Haloxy fopetoxy-ethyl) treatments after flower harvest. Pre-emergence treatments with Sonalan (Ethyl fluralin) are also used (Mollafilabi, 2004). During the summer rest, general herbicides such as Roundup (Glyphosate) or Buster (2, 4-D, 2, 4-DP) are applied. Little research has been carried out on indirect weed control methods. Interesting results in reducing weeds with agronomic methods have been obtained with wood chips and sawdust mulch (Galigani and Garbati Pegna, 1999; McGimpsey et al., 1997; Zanzucchi, 1987) Experimental trials to control weeds with plastic films as dead mulch are on-going in southern Sicily (Sortino O., personal communication).

Harvesting And Separating:

Gathering saffron flowers requires care and intensive manual labour: the flowers only grow a few centimeters aboveground and, depending on vegetative activity, might be surrounded by several leaves which must not be damaged otherwise daughter corms will not be produced. The flowers are harvested manually, generally by family members, by cutting the base of the flower stem with the fingernail. About 350–450 man hours are needed to harvest 1 kg of the spice, corresponding to between 200 000 and 400 000 stigmas, depending on the unitary weight. The saffron flower is highly ephemeral; given its very short life, it should be picked the same day of flowering and placed in baskets. The best practice is to pick the flower early in the morning each day, when the corolla is still closed, thereby preventing the stigmas from losing color and quality, avoiding any sudden deterioration by wind or rain (Zanzucchi, 1987; Tammaro, 1990) and allowing a ready separation into their constituent parts. After harvest, stigmas must be separated from the tepals and stamen as soon as possible by opening the corolla and cutting the stigmas with the fingers below the branching where the style changes color (from red to yellow).

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Drying And Storage Of Stigmas:

Drying and storage methods are very important because a poor undertaking of this procedure can completely compromise qualitative features of saffron (Carmona et al., 2005). According to the ISO norm, the moisture content may range between 10 and 12% (ISO-3632, 2003). Many methods are used for the dehydration of saffron. Concerning Italian production, the stigmas are normally spread over a large area and dried at room temperature in the sunlight or with forced air. In Navelli, dehydration is traditionally carried out by placing the stigmas on a sieve 20 cm above a charcoal fire (Tammaro, 1999), while in Sardinia it is performed by drying stigmas in the sun or at room temperature (for several days) or in the oven at low temperature (35–40 ◦C) in less time until moisture is reduced to 5–15%. Saffron is sun-dried in India and Iran, and toasted over hot ashes in Spain, while it is dried slowly at 30– 35 ◦C in dark rooms in Greece; therefore, many procedures are applied and, as is usual in such cases, there are still substantial disagreements over the best drying conditions (Raina et al., 1996; Carmona et al., 2005; Gregory et al., 2005). Storage of saffron must be done in the dark and possibly in a modified atmosphere, since saffron pigments are light-, oxygen- and temperature-sensitive. The best way to store saffron spice is to keep it hermetically closed in darkened glass containers, and possibly at low temperature (5–10 ◦C). (Mannino and Amelotti, 1977; Alonzo et al., 1990)

Flower Yield:

Yield is quite a difficult parameter to forecast in saffron: saffron yield is in fact a function of many agronomic, biological and environmental factors able to exert a great influence on production. As far as is known, production is strictly influenced by dimension (De Mastro and Ruta, 1993; Lombardo et al., 2005; Gresta et al., in press) and storage conditions of corms (Molina et al., 2004b), climatic conditions (Tammaro, 1990, 1999), sowing time (Gresta et al., in press), cultural techniques (annual or perennial), crop management (irrigation, fertilization and weed control) and disease. Moreover, saffron production increases from the first to the third – fourth years of cultivation (McGimpsey et al., 1997). Generally, one hectare of saffron may produce 10–15 kg of dried stigmas, but it can range widely, depending on the abovementioned factors, from 2 to 30 kg.

Pests And Disease:

The worst enemies of saffron are rodents and fungi (Tammaro, 1999; Goliaris, 1999). Moles, rats and rabbits can easily damage corms or eat leaves. Fungal attacks are mostly promoted by humid conditions. High moisture percentage together with high temperatures create ideal conditions for the rapid development and spread of nematodes and fungi (Fusarium, Penicillium, Rhizoctonia, etc.) and consequently corm rot. These conditions generally occur in the hot and rainy spring. Tammaro (1999) indicates that temperatures above 10–12 ◦C with rainy weather are a favorable climatic combination for the establishment of fungal disease on saffron. On the contrary, the hot and dry Mediterranean summer inhibitsthe spread of parasites. To avoid fungal infection, the best practices are crop rotation, the removal and burning of infected plants and corm treatments with anti-fungal products before planting, such as benomil or copper-based solution.

Conclusions:

From an agronomic point of view, saffron is a very unusual plant for its agrological and Eco physiological characteristics. It is unable to produce seeds and multiplies by means of a subterranean stem. Saffron has a reverse biological cycle compared with the majority of cultivated and spontaneous plants: flowering first in October-November, then vegetative development until May, which means that the vegetative development is not directly important for production of stigmas, but for the production of new corms. The plant itself has an annual cycle, but the crop is perennial, precisely owing to its vegetative multiplication. Saffron has a low water use and a very low harvest index (Fernandez, 2004). Above all, the parts harvested for production are the stigmas, from which a very expensive spice is obtained, probably a unique case in an agronomic context. Last but not least, saffron cultivation has been neglected for many decades by farmers, who have relegated it to adverse soil and climate conditions, and by research, which has led to a lack of innovation. All these reasons should induce revision of the most common agronomic knowledge for an effective revaluation of the crop.

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