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Saffron (*Crocus sativus* Kashmirianus) Cultivation in Kashmir: Practices and Problems

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ABSTRACT

The Kashmir valley is well known for quality saffron and represents one of the major saffron-producing areas of the world, dating back to 750 AD. However, in the last decade production and productivity of this crop has shown a declining trend. This paper highlights the practices followed in saffron cultivation in Kashmir and discusses different factors responsible for the decline in saffron production. It also stresses the need for using quality planting materials, a sprinkler irrigation system, pest and disease control measures and an efficient marketing system for increased profitability. Pressure due to increased urbanization on land on which saffron grows and clandestine saffron smuggling are contributing towards the decline of the saffron industry, and these have also been discussed.

Keywords: corm, disease, phenology, planting cycle, post-harvest handling, urbanization

CONTENTS

INTRODUCTION

Jammu and Kashmir (J&K) state is located between 32°17′ to 36°58′ North (latitude) and 73°26′ to 80°30′ East (longitude), encompassing the Western Himalayas and the Karakorum mountains. One of the largest states of the Indian Union, J&K covers an area of 2,22,236 km^2 and includes, besides the famous Kashmir valley, the area of Jammu, Ladakh, Baltistan, Gligit, Hunza and Nagar (**Fig. 1A**). Amongst these, the Kashmir valley represents one of the major saffron (*Crocus sativus* Kashmirianus) (**Fig. 1B**)-growing areas of the world. The time at which saffron was introduced to Kashmir is not precisely known, although evidence from '*Rajatarangini*', written by a 12th century poet-historian (Kalhana), indicates its presence in Kashmir even before the reign of King *Lalitaditya* in 750 AD. This "golden" spice is known as '*Kum Kum*' and '*Kesar*' in Sanskrit, and '*Koung*' in Kashmiri language.

Even though successful attempts to grow saffron in other areas of India such as Uttar Pradesh and Himachal Pradesh have been reported (Dhar and Mir 1997) as well as in other parts of J&K state like Kargil (Munshi *et al.* 2002), almost all saffron production is actually limited to Kashmir. In Kashmir, saffron is grown on uplands (termed in the local dialect as 'Karewas'), which are lacustrine deposits located at an altitude of 1585 to 1677 m above mean sea level (amsl), under temperate climatic conditions (Kanth *et al.* 2008). The soils are heavy textured with silty clay loam

Received: 16 September, 2010. Accepted: 10 December, 2010.

Invited Review

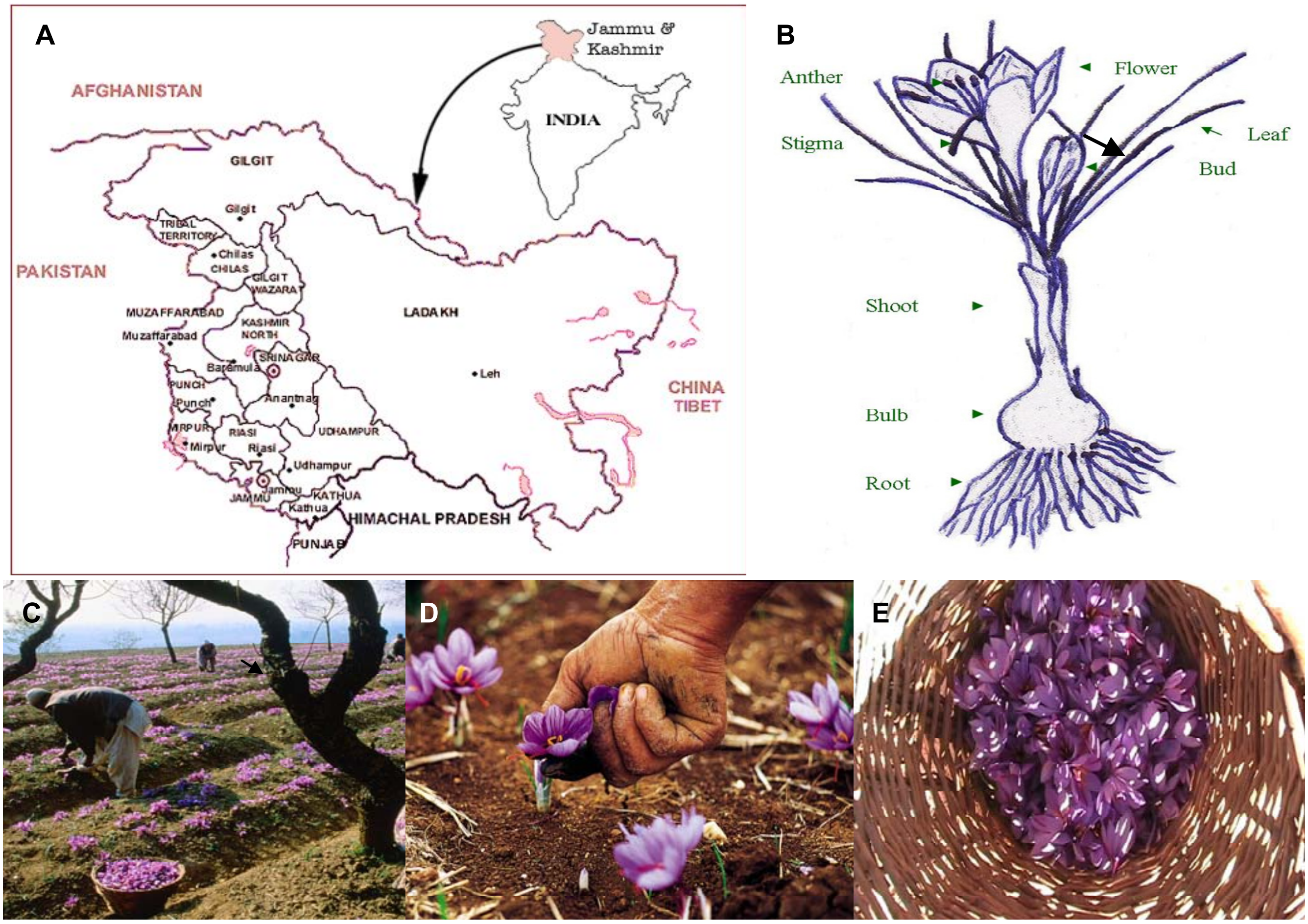

Fig. 1 Saffron in Kashmir. (**A**) The state of Jammu and Kashmir. (**B**) Sketch of *Crocus sativus* Kashmirianus plant. (**C**) Field laid into rectangular strips and alley cropping with almond. (**D**) Saffron flowers harvested by hand picking. (**E**) Flowers collected in a wicker basket or *Tokri*.

as the predominant texture in upper horizons and silty clay in lower horizons. These soils are alfisols and are well drained. The soils are calcareous in nature with average organic carbon and calcium carbonate contents of 0.35 and 4.61%, respectively. The soil is slightly alkaline with pH ranging from 6.3 to 8.3 and with electrical conductivity between 0.09 and 0.30 dsm^{-1} (Nazir *et al.* 1996; Ganai *et al.* 2000; Ganai 2002). Higher yields coincide with higher pH values (Shinde *et al.* 1984).

The total area under this crop in the State in 2007-08 was 3,110 ha with an annual production of 5.06 t and productivity of 1.62 kg ha^{-1} while almost a decade back in 1996-97 the area recorded was 5,707 ha with an annual production of 15.95 t and productivity of 2.79 kg ha^{-1} (Anonymous 2009). This shows a decrease of 83% in area, 215% in production and 72% in productivity of saffron in one decade in Kashmir. The lowest productivity of 1.57 kg ha^{-1} was recorded in 2003-04 due to an acute drought from 1999-2003 (Anonymous 2008, 2009) (**Table 1**). According to the data available for 1990-96 (not shown) the area of saffron cultivation in Kashmir varied in a narrow range of 4036 to 4496 ha, with more or less constant annual production (13.0-14.1 t) and productivity (2.90-3.21 kg ha^{-1}).

In the present paper we discuss cultivation practices of saffron followed in Kashmir, highlighting the major constraints that limit its production and productivity while also suggesting some ameliorative measures for its sustainable production.

Table 1 Year-wise trends in area, production, productivity of saffron in Kashmir.

Year	Area (ha)	Production (t)	No. of rainy days	Total rainfall (mm) $^{\$\$}$	Yield (kg ha^{-1}) $^{\$\$}$
*1996-1997	5707	15.95	49	583.7	2.79
#1997-1998	NA	NA	37	548.8	NA
*1998-1999	4116	12.88	50	387.4	3.12
*1999-2000	3997	7.65	52	399.7	1.91
*2000-2001	2831	3.59	49	518.5	1.26
$^{\$}$2001-2002	2880	6.52	NA	NA	2.26
$^{\$}$2002-2003	2742	5.15	72	884.0	1.87
$^{\$}$2003-2004	3075	4.83	63	635.2	1.57
$^{\$}$2004-2005	2989	8.85	72	680.8	2.96
$^{\$}$2005-2006	2928	4.85	89	887.6	1.65
$^{\$}$2006-2007	2436	9.13	3.74	501.8	3.74
$^{\$}$2007-2008	3110	5.06	NA	NA	1.62

Data not available (NA)
*Source: Planning Department, J&K Government, and Directorates of Agriculture, Kashmir and Jammu Divisions
$^{\$}$ Source: Economic Survey 2008-09, J&K Government
$^{\$\$}$ Source: Regional Metrological Centre, Srinagar, J&K; these are the figures for Srinagar district only and do not pertain to the whole area under saffron cultivation, as it is not available.

PHENOLOGY OF SAFFRON

Phenology, the study of development of a plant in relation to its environment, is important for understanding the basis for cultural operations in a crop. The phenology of saffron in Kashmir, as described by Kanth *et al.* (2008), occurs in three phases.

The first, generative phase starts with the onset of cold weather in fall and is an important stage for growers. Irrigation in late summer and early autumn is beneficial for this phase, as the physiological processes start well before apparent flower emergence. In Kashmir, this stage is recorded in mid-October to the first week of November and covers about 20-25 days.

The second, vegetative phase is the longest period in the life cycle of saffron and starts immediately after the flowering stage. At this stage leaves develop and provide necessary nutrients for corms. This stage can start early by an early rainfall or early irrigation, and leaves may emerge simultaneously with flowers. This phase lasts for at least 6 months (November to April) in Kashmir.

The third, dormant phase starts with leaf withering and senescence in the spring and ends with the first irrigation in late summer and early autumn. This period is considered by growers as the rest period. In Kashmir this stage is observed from April to September.

CULTURAL AND POST-HARVEST PRACTICES FOR SAFFRON PRODUCTION

In Kashmir, in spring (March-April), the field is ploughed either using a plough or tractor twice with an interval of about 20 days. In August, levelling and hoeing operations are carried out and fields are pulverized 3-4 times. Well-decomposed farm manure (15-20 t ha^{-1}) is applied by some progressive farmers and thoroughly mixed into the soil before the last tillage operation (Mir 1992; Munshi *et al.* 2002). However, in addition to the application of farm manure, chemical fertilizers supplying nitrogen (40 kg ha^{-1}), P_2O_5 (50 kg ha^{-1}) and K_2O (30 kg ha^{-1}) are recommended to restore and sustain soil fertility, although in actual practice the farmers do not apply these chemical fertilizers (Mir 1992; Munshi *et al.* 2002).

The field is laid out into rectangular strips (1.5-2 m wide and 2-3 m long) with drainage channels (30 cm wide and 20 cm deep) on both sides (**Fig. 1C**). The corms are sown at depth of 12-15 cm in these raised beds with 10×20 cm spacing (inter-corm and inter-row). The most suitable time for sowing the corms is from the last week of August till mid September (Mir 1992; Munshi *et al.* 2002).

The total rainfall during the saffron growing period is usually sufficient, but its distribution is not regular, and usually saffron faces some water stress. If rains are received at sprouting and pre-flowering stages, the flowering is optimum that year and saffron yields are good (Anonymous 1988). Any major drop in ambient temperature or un-seasonal rains during October causes serious damage to flowering, leading to heavy reduction in saffron yield. Flowering occurs between mid-October to mid-November every year, mostly in 3 flushes in a normal season.

In Kashmir flowers are picked by hand (**Fig. 1D**). This is done early in the morning mostly by female members of the family and to a limited extent by hired labor. The flowers are collected in wicker baskets, called in local language 'Tokri' (**Fig. 1E**). These are then taken to sheds or houses for separating the stigma and other flower parts. This is a tedious job and generally takes the whole night or more for each day's harvest. The separated flower parts are then dried in the shade for 2-3 days provided the days are sunny, otherwise drying is extended by a day or two.

The process of drying has a great effect on the quality and worth of the final product. In Kashmir, saffron is dried under shade or sometimes under direct sunlight. They are left there until the moisture evaporates, and only 10-11% water content remains in the stigma. The dried material (stigma alone called *'Mongra'* or stigmas attached with parts of the style, called *'Laccha'*) is packed mostly in poly bags and stored at room temperature until the farmer gets the desired price. The storage period varies from 25 days to 6 months (Mir 2002).

In some areas of Kashmir saffron is cultivated as an alley crop with almond trees (**Fig. 1B**). Rotation of saffron fields after a planting cycle of about 15 years is a common practice in Kashmir. Saffron fields are either kept fallow or rotated with linseed, maize, oats for a period of 2-3 years. This helps in control of pests and diseases, and restoration of soil fertility (Nehvi *et al*. 2008a).

MAJOR CONSTRAINTS FACING SAFFRON PRODUCTION IN KASHMIR

Non-availability of good quality corms

The saffron plant, being triploid, fails to set seeds, and thus is propagated vegetatively through corms. Well developed and large disease-free corms are an essential component for sustainable saffron production. As such, sorting of corms on the basis of weight and size is an important pre-requisite for higher productivity in saffron. A flowering corm contains 10-12 buds and each sprouting bud produces a cormel. Pandy *et al.* (1979) found that larger corms produced more leaves and flowers. This kind of positive relationship between corm size and number of flowers per corm and saffron yield is well established (Dhar 1991; DeMastro and Ruta 1993; McGimpsey *et al.* 1997; Omidbeigi *et al.* 2003). Small corms do not have the potential to produce flowers in the first year (Sadeghi 1983), while corms larger than 2.5 cm in diameter only flower (DeMastro and Ruta 1993). In addition, the weight of corms is also very variable and ranges between 1 and 20 g (Behnia *et al*. 1999). Corms weighing around 2 g do not flower and up to 8 g show very limited potential while corms weighing more than 10 g have the capacity to flower in the same year and are necessary for higher yield (Sadeghi 1993).

In Kashmir, corms with diameter greater than 2 cm and 10 g in weight are recommended for sowing, but due to non-availability of standard corms farmers generally plant substandard corms of smaller size and weight (Nehvi *et al.* 2004). In addition only one corm per hill is sown which leads to further low plant population and low productivity (Hassan and Shah 2002; Munshi *et al.* 2002). Due to the repeated use of the same substandard seed material year after year, the productivity of saffron in Kashmir is grossly compromised. Even when seed corms become available when some farmers dig out their fields for new planting the corms are sold at a high price (at Rs. 20000-40000 t^{-1}), which is unaffordable for small and marginal farmers.

Seed rate and planting cycle aberrations

In Kashmir, saffron is grown using corms of diverse sizes at a low seed rate of 1.5-2 t ha^{-1}, with the exception of a few progressive farmers who use about 4 t ha^{-1}. Due to the non-availability of seed corms for new planting in sufficient quantities small and marginal farmers use a seed rate which is about 3 times less than the recommended 5 t ha^{-1} (Nehvi *et al.* 2007a).

According to a comparative study by Kafi and Showket (2007) the number of corms sown $unit^{-1}$ of land in Kashmir is much lower than Khorasan (Iran). For instance, 40-50 corms are sown in 1 m^2 of saffron farm in Kashmir compared to 150-250 corms m^{-2} in Khorasan. In addition, only a single corm $hill^{-1}$ is sown in Kashmir (at a depth of 10-15 cm) in contrast to 3-15 corms $hill^{-1}$ (at 15-20 cm depth) in Khorasan. This could be the main reason why the farmers of Kashmir harvest negligible saffron flowers in the first year.

Studies have revealed that under a high plant population, 4-year-old fields give maximum saffron yield (14 kg ha^{-1}), whereas under low plant population maximum saffron yield is achieved at 6 years of age (13 kg ha^{-1}). There is a sharp decline in yield (< 3 kg ha^{-1}) when fields are 13 years old (Koul and Farooq 1984; Negbi 1999). In Kashmir, corms are planted under low population density (1.5-2 t ha^{-1}) and the average age of saffron fields is more than 15 years, therefore an important factor for low productivity. A well developed mother corm produces 15-20 cormels by the end of the 4th year. Studies on the planting cycle in Kashmir revealed maximum recovery of corm yield (16.1 t ha^{-1}) and saffron yield (4.8 kg ha^{-1}) after 4 years, which clearly suggests that saffron fields should be rejuvenated after every 4-5 years (Nehvi *et al.* 2004, 2008b). However, due to non-availability and high cost, the mother corms are retained in fields for many years even at the expense of declining productivity. Under larger planting cycles the overcrowded daughter cormels produce large numbers of contractile roots and later weaker cormels which die and decay due to lower availability of nutrients. A shorter planting cycle of 4-5 years, combined with appropriate planting depth of the mother corms, is most appropriate to harvest a higher proportion of large-sized corms.

Poor soil fertility

Growing saffron year after year without the supply of nutrients through organic manures and/or chemical fertilizers has drastically reduced the fertility of the soils in Kashmir saffron fields. These soils have become deficient in organic carbon as well as in micro-nutrients. Consequently, the size and vigor of the corms produced each season is reduced, directly affecting the crop stand and flowering potential of plants. The application of organic manures in recommended doses helps to enrich the soil with an adequate quantity of essential nutrients, improves soil health, water use efficiency and better growth of saffron shoots. Production of higher vegetative biomass (more leaves, longer leaf length and higher dry matter content of aerial shoots per corm) in turn results in the production of better daughter corms. The application of farm yard manure (FYM) (17.5 t ha^{-1}) in combination with inorganic fertilizers N: P_2O_5: K_2O (30: 20: 15 kg ha^{-1}) to quality saffron corms (>10 g) planted at a density of 0.5 million corms ha^{-1} resulted in corm yield of 16.5 t ha^{-1}, while in the control only 6.20 t ha^{-1} was recorded. The proportion of good quality corms with an average weight of above 10 g was 52.6% (Nehvi 2004). The application of FYM and chemical fertilizers also results in an increase in saffron yield. Nehvi (2004) reported an annual saffron yield of 1.66 kg ha^{-1} with the application of FYM (17.5 t ha^{-1}) + N: P_2O_5: K_2O (30: 20: 15 kg ha^{-1}), which is 62.7% higher than the control. Similarly, Kirmani (2010) recently reported saffron yield of 3.5-3.6 kg ha^{-1} when either FYM (60 t ha^{-1}) or nitrogen (90 kg ha^{-1}) was applied, which was 57% higher than the control; the crocin content was 12.35% while in the control it was 10.79%.

In a separate experiment three different doses of FYM (15, 20 and 25 t ha^{-1}) were tested in a saffron field in Kashmir, with three different corm sizes, viz. < 10 g, 10-15 g and > 15 g, planted at three different densities (0.5, 0.65 and 0.80 million ha^{-1}). The application of FYM at 25 t ha^{-1} using heavier corms (>15 g) at a density of 0.5 million ha^{-1} (10 × 20 cm, i.e., 10 cm inter-corm distance, and 20 cm inter-row distance) resulted in the production of quality planting material with a maximum proportion of flower-producing corms (Verma *et al.* 2008). The treatment resulted in maximum corm yield of 15.3 t ha^{-1} under a biannual planting cycle, with a yield advantage of 63.5% over the control. The proportion of flower-producing corms was 57.3%. Highest stigma length of 3.8 cm, style length of 3.5 cm, perianth size of 6.9 × 5.7 cm, highest number of leaves per mother corm (45.3) and maximum length of leaves (19.0 cm) were also recorded in this treatment. The results show that the application of FYM and corm weight are the most important variables for higher production of quality planting material whereas increased planting density (> 0.65 million ha^{-1}) showed a detrimental effect on corm multiplication and their further development.

Lack of assured irrigation

Saffron fields in Kashmir are entirely rain-fed. If rains fail, the crop also fails. Although water requirement is low for saffron, water stress affects yield, growth and development (Hassan and Shah 2002; Munshi *et al.* 2002). Srivastava (1963) reported that areas receiving 100-150 cm of well distributed rainfall with snow in winter are suitable for saffron cultivation, and rains in September are essential for meeting the water requirement of corms for good flower yields. Rainfall of 100-150 mm is considered essential during the pre-flowering stage (Kamili *et al.* 2007). However, due to climate change in the last several years the weather has become quite erratic and rains are either scanty or distribution is irregular, thus adversely affecting flowering in saffron. The State of Kashmir faced an acute drought in 1999-2003 (Alam 2007), and during this period productivity was reduced from about 3.12 kg ha^{-1} to 1.57 kg ha^{-1} (**Table 1**). However, favorable rainfall during 2004-05 improved saffron productivity to 2.96 kg ha^{-1}.

The campaign of improving productivity of saffron would not bear the desired fruit unless facilities for assured irrigation are created, at least at pre-sprouting and pre-flowering stages. Irrigation facilitates quick activation of buds leading to corm sprouting and flower initiation. According to Nehvi (2004) and Nehvi and Makhdoomi (2007b), the saffron crop requires 10 irrigations, and should be sprinkler irrigated at 70 m^3 ha^{-1} at an interval of 7 days at the sprouting stage (25th August to 15th September) followed by 3 irrigations at the post-flowering stage (8th November to 30th November) at weekly intervals. In a separate study, Aga *et al.* (2008) recommended 5 irrigations, each on the 20th August, 1st, 10th, 20th and 30th September. Despite all these recommendations not much effort is being made by Government agencies to incentivise farmers to use irrigation in saffron fields.

Poor pest and disease management

The intensive cultivation and monoculture of saffron in saffron-growing belts of the Kashmir valley, together with the continual use of diseased material has resulted in the frequent occurrence of corm rot diseases caused by pathogens such as *Rhizoctonia crocorum*, *Phoma crocophila* (Madan *et al.* 1967), *Fusarium moniliforme* var. *intermedium*, a non-sporulating basidiomycetous fungus (Dhar 1992), *Macrophomina phaseolina* (Thakur *et al.* 1992), *Fusarium oxysporum*, *F. solani*, *F. pallidoroseum*, *F. equiseti*, *Mucor* sp., *Penicillium* sp. (Wani 2004; Ahmad and Sagar 2006) and *Sclerotium rolfsii* (Kalha *et al.* 2007). Of these diseases, corm rot of saffron caused by *F. oxysporum* and *F. solani* is considered to be most destructive in Kashmir (Wani 2004; Ahmad and Sagar 2006). These infections generally take place through the injury of corms. Infected corms possess dark-brown sunken and irregular patches below the corm scales, mostly near root and bud regions. In severe cases the entire corm turns into a black powdery mass. The foliage of infected corms shows symptoms of 'die-back' (Ghani 2002). The disease is quite widespread and causes loss of a considerable proportion of the produce every year. Different groups have reported different figures for corm rot incidence in different parts of Kashmir. Rekhi *et al.* (1990) recorded that the disease incidence among farmers in the Kashmir valley was 98% and Dhar (1992) observed that although none of the saffron-growing areas in the Kashmir valley were free from the disease (100% disease incidence), its severity (disease severity) was more in 6.7-15.2% of areas. Nehvi (2003), however, reported the incidence of corm rot as 46% in traditional saffron-growing areas, while Ghani (2002) put the figures at 11.6-21.6% for Pampore (traditional saffron belt). All these studies point to the severity of the problem, which may be due to built-up of inoculum over longer planting cycles, common in Kashmir.

For controlling saffron corm rot, the corms to be planted should be put in a fungicidal solution containing Mancozeb 75WP (0.3%), Carbendazim 50WP (0.1%) for 5-10 min, and then spread on a cloth and allowed to dry in shade for another 10-15 min (Ghani 2002). In a separate study where six fungicides, viz. Blitox (copper-oxychloride), Indofil M-45 (mancozeb), Difolatoan (captafol), Folpat (captafol), Bavistin (carbendazim) and Tecto (thiobendazole) were evaluated, Bavistin and Tecto (0.2% each) as a dip or drench gave complete disease control (Sud *et al.* 1999). In a pot experiment, Ahmad and Sagar (2007) observed that corm treatment with Carbendazim 50WP (0.2%) or Myclobutanil (10WP) (0.2%) proved most effective in reducing the corm rot severity to 7.4 and 5.2%, respectively when corms were dipped overnight in fungicidal suspension, compared to 46.7% in untreated corms.

Besides the damage caused by corm rot, plant parasitic nematodes of many species infesting saffron-growing soil cause damage to corms by sucking the sap. Zaki and Mantoo (2008) reported the percentage infestation at the Konibal area of Pampore as *Helicotylenchus vulgaris* (16.6%), *Pratylenchus thrornei* (8.8%), *Tylenchus* sp. (13.0%), *Tylenchorynchus* sp. (10.7%), *Xiphinema* sp. (14.6%), *Aphelenchus avenae* (5.8%), and *Hemicriconemoides* sp. (3.2%). The sap sucking causes necrosis in roots and predisposes saffron corms to corm rot, causing heavy production losses. Despite this, no systematic control measures are presently being adopted by farmers (Ghani 2002). Application of Chlorpyriphos 10G (at 1000 g a.i. ha^{-1}) or Fenvalerate 0.4% (at 120 g a.i. ha^{-1}) as soil treatment effectively reduces the pest population (Zaki and Mantoo 2008). An ecologically sound solution would be to identify efficient biological control agents. For example, antibiotic-producing *Pseudomonas* strains relevant to biocontrol, such as superior root colonizing ability or higher antibiotic production need to be identified from Kashmir saffron fields.

Poor weed management

Saffron in Kashmir begins its vegetative growth around October-November, which then lasts until April. Thereafter, saffron fields remain vacant due to the dormant phase from April to September. According to Pir *et al.* (2008), the long period from April to September provides an open space for weeds in saffron fields, which gain a monopoly to spread over the entire fields without any resistance that would otherwise be encountered in the presence of the crop. In addition, the saffron plant, being short with narrow upright foliage with little lateral spread offers very little competition to the weeds. The major weeds found in saffron fields of Kashmir include *Euphorbia helioscopia*, *Papaver rhoae*, *Lepidium virginicum*, *Salvia moorcroftiana*, *Chonspora tanella*, *Galium tricorne*, *Tulipa stellata*, *Erodium cicutarium*, *Lithospermum arvense*, *Ranunculus arvensis*, *Medicago lupilina*, *Filago arvense*, *Poa bulbosa*, *Crepis saneta*, *Descurainea Sophia*, *Polygonum aviculare*, *Chenopodium album*, among others (Pir *et al.* 2008). Despite the presence of these weeds no weed management practices are followed by saffron growers except for harvesting of some weeds as fodder by farm women in May, and cattle grazing by some farmers in August. Herbicides have yet to find a place in weed management of saffron in Kashmir. Norouzzadeh and Delghadi (2006) in Iran reported that Ioxynil (750 g a.i. ha^{-1}) and Tribenoronmethyl (18.75 g a.i. ha^{-1}), when sprayed at the 6-8 leafy stage of weeds after saffron harvest, were highly efficient in controlling weeds. In autumn trials, weed control by Ethalfloralin (1320 g a.i. ha^{-1}) and Trifloralin (960 g a.i. ha^{-1}), when applied at pre-emergence and before saffron flowering, was also found to be promising but caused yield loss. The application of Metribuzin (560 g a.i. ha^{-1}) in spring or autumn controlled weeds to a large extent without any injury to saffron.

Weed-infested fields have become a breeding place for rodents, too. It is generally observed that bad hygiene of fields, particularly during the critical stage of crop growth (November–May), was responsible for loss of planting material due to rodent attack. Fresh as well as old burrows are distinctly visible in saffron fields. The extent of damage to saffron corms by rodents ranges from 10 to 50% (Manzar *et al.* 2008). Due to a traditional longer planting cycle, cultivation on raised beds, mixed cropping with almond and poor weed management, rodents have found saffron fields as a breeding ground due to availability of food material during fall months (October to March), when all other agricultural fields are fallow and thus devoid of any grain to be used as a food material by rodents. Manual weeding (pre- as well as post-winter) has been found to be effective in the control of rodents, enhancing growth of saffron plants with a significant effect on improving corm and saffron yield.

Smaller flowers

There are many genetic and environmental factors affecting flower size and ratio of different parts of the flower. Environmental factors such as physical and chemical properties of the soil, time of harvesting the flowers, age of the corms and cultural practices can influence the size of the flower and stigma inside it (Mir 1992; Kafi *et al.* 2006).

In Khorasan, 78.5 kg of fresh flowers (equal to 170,000 flowers) are required for producing 1 kg of dry stigma and style (standard saffron). This means 1 kg standard saffron of Khorasan is collected from 2165 fresh flowers (Mollafilabi 1994; Kafi *et al.* 2006). On the other hand, the number of flowers required per kg of standard saffron of Kashmir varies between 2680 and 3840, indicating that the saffron flowers of Kashmir are smaller than those of Khorasan (Kafi and Showket 2007). In other words, labour costs engaged per unit area per operation will be higher in Kashmir than in Iran.

Poor post-harvest handling

There are data available that point to the diverse quality of saffron with different major traders of Kashmir State, with very few conforming to the norms set by the Indian Standards Institute (ISI 5453) for Indian saffron (data not shown). One major reason for this diversity in quality is poor post-harvest handling and storage. Quality evaluation of Kashmir saffron has confirmed its intrinsic high quality with respect to colouring pigment, and traditional postharvest processing is responsible for its deteriorating quality (Nehvi *et al.* 2005). There is a high percentage of crocin (14-17%) in the fresh stigmas of Kashmiri saffron (Nehvi *et al.* 2007c). However, the practices followed by farmers for harvesting flowers, separating stigmas, drying, packing, storing and marketing bring down the crocin content to 9-11.5%. As such there is a need for awareness programmes for improving postharvest handling, educating farmers about the benefits of picking flowers at the right stage, separating stigmas and style in the shortest possible time, popularizing the use of solar dryers, quality evaluation and branding, etc.

1. Picking and sorting

In Kashmir, flower picking is not usually done daily. It is usually done once every four days, before 9 a.m. This should be done on a daily basis because flowers are short-lived and if they are left for a longer period, not only can they get damaged, but the quality of saffron also decreases (Mir 2002; Munshi *et al.* 2002). Flowers should be carried in clean baskets and should not be overloaded as that may prevent free air circulation.

A delay in flower picking from the date of flower opening and a delay in separation of the stigma from the flower contribute to the drop in crocin content. Flowers picked on the 4^{th} day of emergence give maximum recovery (weight) of stigmas and pistils, called *Laccha* (0.760 g per 100 flowers) and crocin content (12-13%). The sorting of stigmas from stamens and the remaining floral matter is a crucial stage of the processing. If the separation of stigmas is completed within 6-8 hrs after picking, more than 95% of the saffron is recovered, while 24 hrs after picking only 40-50% is recovered. After 72 hrs of picking, the entire saffron flower becomes a cake-like mass with no recovery (Nehvi *et al.* 2004). During all these operations the processors of their product should always keep in mind the need to keep all surfaces clean. In order to comply with ISO specifications it is a good idea to repeat sorting 2–3 times per batch.

2. Drying

Drying is a critical step in saffron processing. Drying brings about the physical, biochemical and chemical changes necessary for imparting the desired attributes to saffron. Washing saffron to remove foreign matter (dust, mud, parts of insects, etc.) is strictly prohibited because its principle constituents, the crocins, are water-soluble. In addition, like all carotenoids, these are also light sensitive and hence exposure to light throughout processing should be a minimum. Picrocrocin, the bitter constituent, decreases during drying and the subsequent treatment steps, whereas safranal, absent before drying and the period just after that, starts to develop in the first period of storage (Ordoudi and Tsimidou 2004).

Saffron drying depends heavily on temperature and relative humidity of the drying room. In Kashmir, the traditional drying practice followed by farmers takes about 27-53 hrs in shade leaving a moisture level of about 10%, which is higher than the recommended level (8%). Moreover, a longer drying period (27–53 hrs) adversely affects the quality, possibly due to both biodegradation and oxidative destruction of the principle components (Sampathu *et al.* 1984). Raina *et al.* (1996) elaborated some drying schemes at a laboratory scale for samples collected from Kashmir. The drying methods employed were (i) shade drying, 4-18°C; ii) sun drying, 11-h photoperiod per day, 12-21°C; iii) solar drying, highest interior temperature 49°C (29°C higher than ambient; iv) dehumidification drying over Si-gel (blue), 40°C; v) in a vacuum oven at 40, 50 and 65°C and at reduced pressure of 40 mm; vi) in a cross-flow oven at 20, 40 and 50°C and vii) in an electric oven at 40, 50, 65 and 80°C. The optimum tray-load was found to be 1 kg m^{-2}. The proposed ideal temperature for artificial drying was 40 ± 5°C. At lower temperatures, lengthy periods of processing were experienced that resulted in pigment loss whereas at 50 or 60°C thermal degradation of pigments was observed. For example, using electric oven and cross-flow drying methods the crocin content was 154 and 156 g kg^{-1}, respectively at 40°C, while it was much lower (124 and 129 g kg^{-1}) at 20°C and slightly lower (148-150 g kg^{-1}) at 50°C. Vacuum and cross-flow drying caused a significant reduction in safranal content (200-350 g kg^{-1}) but at the same time increased levels of 4-β-hydroxysafranal (500-700 g kg^{-1}), causing it to have unpleasant sensory characteristics. Samples dried in shade or under accelerated conditions had a better flavour profile that coincided with higher amounts of safranal (550-680 g kg^{-1}) and lower levels of 4-β-hydroxysafranal (140-200 g kg^{-1}).

3. Decontamination

Spices may be highly contaminated with moulds, yeasts and bacteria, either as vegetative cells or spores coming from plants, soil, or the faeces of birds, rodents, insects, etc. Contamination may occur during harvesting, handling, transportation or storage of the spices (Sjöberg *et al.* 1991). Considering their high microbial load (10^3–10^8 organisms per g), it is obvious that when they are used untreated they may well cause several food-borne diseases. Fortunately, for public health, herbs and spices are used in minor quantities and risks are, thus, reduced. In Kashmir, no decontamination practices are followed, as decontamination by chemical treatment (ethylene oxide, propylene oxide and methyl bromide) or irradiation leave toxic residues and adversely affect organoleptic properties (Sjöberg *et al.* 1991). The effect of γ-irradiation on the colour and flavour of saffron has indicated a perceptible deterioration in the oil obtained from the samples treated at doses higher than 5 kGy (Zareena *et al*. 2001). A substantial decrease (*ca*. 90%) was noticed in the crocins content of irradiated stigmas of saffron and a concomitant increase in the crocetin level. They suggested a cleavage in the glucosidic linkages that may occur during irradiation causing an about 2-fold increase in the crocetin content corresponding to a 83–89% loss in crocin content. These findings led to the conclusion that irradiation doses for this spice should not exceed 5 kGy and thus decontamination using γ-irradiation can be applied to saffron only when having a low microbial load.

4. Packaging

Dried saffron is vulnerable to moisture ingression, light and air (photo-oxidation). Once exposed to these conditions hydrolysis of crocin into crocetin occurs reducing the quality. Packaging of a dried product is normally done in poly bags by farmers and later (between 1-6 months) sold to wholesale traders. Saffron growers of Kashmir usually store saffron in earthen pots or polythene bags without taking care of moisture (Mir *et al.* 2008). Saffron packed in 10 gauge polythene bags and stored at ambient temperature in the dark over a period of one year loses 60-70% of its crocin content (Mir 2002). Additionally, due to high moisture content on account of traditional drying the saffron loses its colouring strength during storage and becomes inferior.

India should formulate suitable guidelines and methods of harvesting, separation, drying and storage of saffron for Kashmiri saffron farmers, on a similar pattern as in Iran. In Iran Institute of Standard and Industrial Research Organization (ISIROI) has released "Control Points of Harvesting and Processing of Saffron" with the aim to introduce suitable methods of harvesting, separation, transportation, drying and storage of saffron. In addition, in Iran, the Hazard Analysis Critical Control Points (HACCP) states the best way for analyzing hazardous risks and critical control points from the time of flower harvesting to stigma packaging, and is implemented by companies dealing with drying, packing and export of saffron.

Urbanization and pollution

The traditional saffron belt of Pampore is located on the national highway connecting Srinagar (capital city of J& K) to the rest of the country. It is barely 20 km away from the city centre and hence lucrative for development of satellite townships by real estate developers. Due to the high rise in price of the land in Srinagar, the land brokers have been trying hard to divert saffron fields towards construction business.

In addition to the air pollution caused by heavy vehicular traffic in the traditional saffron belt, recently mercury accumulation in saffron fields close to a cement factory has been reported by Jan and Bhat (2008). Increased mining and high rate of fossil fuel burning by the cement factory have been cited as the main sources of mercury pollution.

CONCLUSIONS

In Kashmir, the saffron crop is totally rainfed and if rains are received at the sprouting and pre-flowering stages, flowering is optimum and saffron yields are normal. Any major drop in precipitation at these stages or unseasonal rains during October cause serious damage to flowering and hence saffron yields. The major factors responsible for lower production and productivity in Kashmir can be summarized as: (i) Inadequate moisture management, a critical input to initiate timely growth of roots and floral/aerial vegetative shoots under rainfed conditions on uplands; (ii) Planting of small and defective corms of different grades as opposed to selected corms (> 2.5 cm diameter); (iii) Planting of untreated corms vs the recommended fungicidetreated corms; (iv) Longer planting cycles of 10-15 years vs annual planting in Italy and a 5-7 year cycle in Spain and Greece, and 6-15 years in Iran; (v) Non-application of organic manures in contrast to the recommended carpet dressing of well decomposed organic manure; (vi) Poor weed management; (vii) Poor post-harvest handling practices and storage; (viii) Inhibition of the adoption of improved production practices and lack of scientific aptitude among small and marginal farmers.

In the last decade Iran has shown a continuous expansion of the saffron-growing area with a mean annual growth rate of 11.5% compared to a 7.5% annual decline in Kashmir. The shorter age of saffron fields, high planting density, proper nutrient management system with adequate facilities of irrigation, non-incidence of corm rot and proper weed and insect management are the key factors for higher saffron production in Iran, all of which are lacking in Kashmir.

With a recent increase in world price of saffron, some farmers have shown interest in improved technologies and adoption of scientific techniques for commercial benefits. Furthermore, there is a need to evaluate the possibility of 'organic farming' of saffron in fields or indoors for improving farmers' income opportunities.

ACKNOWLEDGEMENTS

The first author acknowledges the ideas and inputs received from various saffron growers and traders in India, and highly appreciates the support given by officers of J&K Government.

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