

# Sustainable Saffron (*Crocus sativus* Kashmirianus) Production: Technological and Policy Interventions for Kashmir

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## ABSTRACT

The Kashmir valley is well known for quality saffron but since the last decade production and productivity of this crop has shown a declining trend in Kashmir. This paper emphasizes ample scope for maximizing profitability of this crop for Kashmir saffron growers, provided that sincere efforts are made. Initiatives are needed for reversing this declining trend by adopting strict quality control measures, preventing adulteration, mechanizing production and introducing marketing interventions. Adoption of novel scientific technologies, including biotechnology, can go a long way to reduce the costs of saffron production in the future.

**Keywords:** adulteration, biotechnology, government, mechanization, quality, tissue culture

**Abbreviations:** BA, 6-benzyl adenine; BAP, 6-benzyl amino purine; 2,4-D, 2,4 dichlorophenoxy acetic acid; GA<sub>3</sub>, gibberellic acid; IAA, indole-3-acetic acid; Kn, kinetin; MS, Murashige and Skoog; NAA,  $\alpha$ -naphthalene acetic acid; TDZ, thidiazuron

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## INTRODUCTION

Saffron (*Crocus sativus* Kashmirianus) covers about 4% of the total cultivated area of the Kashmir valley and provides about 16% of total agricultural income (Anonymous 2008). Saffron is chiefly grown in the following districts: Pulwama (74.64%) comprising Pampore, Balhuma, Wayun, Munpur, Mueej, Konibal, Dus, Zundhur, Letpur, Sombar, Baras, Ladu and Khrew; Badgam (16.13%) comprising Chadura,

Nagam, Lasjan, Ompora and Kralpura; Srinagar (6.68%) comprising Zewan, Zawreh and Ganderbal; Doda (2.50%) comprising Poochal, Namil, Cherrad, Huller, Blasia, Gatha, Bandakoota and Sangrambatta, and some areas of Anantnag district comprising Zeripur, Srechan, Kaimouh, Samthan and Buch. Saffron cultivation forms an important sector for the livelihood security of more than 16,000 farm families located in 226 villages. The limited size of land holdings makes cultivation less profitable, with over 61% of holdings

**Table 1** Test value range of Kashmir saffron as per the procedure of BIS (IS 5453 Part 2): 1996, ISO-3632-2: 1993.

Parameters	Total value range
Isolated stigmas (%m/m)	0.00-71.15
Un-isolated stigmas (%m/m)	15.75-96.76
Floral wastes (%m/m)	3.04-21.75
Extraneous matter (%m/m)	0.05-0.58
Moisture and volatile matter (%m/m)	9.78-13.69
Bitterness (as direct reading of absorbance at 257 nm)	42.00-75.00
Saffranal (as direct reading of absorbance at 330 nm)	27.00-41.00
Colouring strength (as direct reading of absorbance at 440 nm)	97.00-172.00
Total ash (%m/m)	4.60-4.95
Acid insoluble ash (%m/m)	0.86-1.61
Total nitrogen (%m/m)	2.06-2.68

below 0.5 ha, and only 26% of holdings between 0.5-1.0 ha and 13% of holdings > 1.0 ha (Anonymous 2009). The total area under this crop in the State of Jammu & Kashmir has shown a decrease of 83% in the last decade, a 215% decrease in production and a 72% decrease in productivity (Husaini *et al.* 2010).

In the present paper we highlight the major causes for diminished export potential, and also suggest some technological and policy measures for sustainability of saffron production and revival of the saffron industry.

### SAFFRON TRADE

Until the beginning of the 1980s, Spain almost monopolised the world saffron trade (>90%). Its production accounted for 52% of overall global saffron production while India (Kashmir), Greece, Italy and France produced 21.2, 13.2, 7.5 and 6.1%, respectively (Sampathu *et al.* 1984). At the end of the 1990s, significant changes in production trends were observed, with Iran taking a lead by annually producing 80 tons (t) of saffron, followed by Kashmir (10 t), Greece (6 t), Spain (3 t) and Morocco (1 t) (Saltron *et al.* 1999; Alonso *et al.* 2001). Minor quantities of saffron are produced in different countries throughout the globe, viz. China, Afghanistan, France, Switzerland, Turkey, Azerbaijan, Japan, Australia (Tasmania), New Zealand, Argentina, and the USA (de los Mozos Pascual *et al.* 2010).

Kashmir saffron is exported mainly to Spain, France, USA, UK, UAE, Israel, Japan, etc. The exports have declined by about 87% from 9.77 tonnes in 1998-99 to 1.30 tonnes in 2005-06, due to the declining trend in domestic and international prices during this period (Anonymous 2007). Recently, increasing costs of saffron producers in the EU can open avenues for Kashmir to offer saffron to the world market in larger quantities (Fernández 2007). However, aggressive exports from Iran, with 90% of produce being exported, have challenged saffron exports from India (primarily Kashmir).

### SAFFRON QUALITY

According to the definition given by the Food and Agricultural Organisation (FAO), saffron forms “a loosely matted mass of dark, reddish-brown flattened threads, amongst which a few narrower yellow ones can be distinguished. The upper, enlarged part of the flattened threads is the stigma of the flower, the lower narrower portion is the style” (FAO 1986).

The quality and consequently the commercial value of saffron are based on an estimation of colouring power, bitter taste and aroma. The quality of saffron is certified in the international trade market following the International Organisation for Standardisation (ISO) 3632 Normative since 1993. The ISO issued a specific standard for saffron ISO 3632 in 1975, revised it in 1980 and technically improved it in 1993. In ISO 3632 1&2 (1993) trade standard definitions as well as requirements for saffron quality and methods of analysis are given as follows: (i) Saffron in filaments are the stigmas of *Crocus sativus* Linnaeus, dried,

dark red in colour and trumpet shaped, serrated or indented at the distal end. The length is between 20 and 40 mm. The stigmas may be isolated or joined in pairs or threes at the end of the portion of the style, which is white/yellow in colour; (ii) Saffron in cut filaments are the stigmas of *C. sativus* with styles removed and completely detached from each other; (iii) Colouring strength is mainly due to its crocin content, as measured by its optical density at about 440 nm; (iv); Bitterness is mainly due to its picrocrocin content, as measured by its optical density at about 257 nm; (v) Flavour is mainly due to its safranal content, as measured by its optical density at about 330 nm.

In Iran the agency responsible for guarding the quality standards of products, including saffron, is the Institute of Standard and Industrial Research Organization (ISIROI). Its main aim is to specify the norms of packing, labeling and sampling, and methods of testing (for filament and powder form). In 1993, the organization introduced and published guidelines for saffron standards under the title "Saffron Specifications". There is another part of the standard (Saffron Test Method) that introduces methods for testing saffron and is applicable to filament and saffron powder. It explains general tests such as moisture and volatile matter, colour strength, bitterness, flavour, floral waste content, microscopic examination of saffron powder, determination of total ash and acid-insoluble ash together with measurement of crocin, picro-crocin and safranal by spectrophotometry. Besides, there is one more standard (Microbial Specification and its Tests) that examines microbial contamination during picking of flowers, flower transportation, stigma separation, drying and packing.

In India, the agency that sets up and guards the quality standards of saffron products is the Bureau of Indian Standards (BIS), and 'saffron specification' is defined in IS5453: Part 1 (1996), which is equivalent to ISO3632-1 of 1993, and 'saffron methods of test' are defined in IS5453: Part 1 (1996), which is identical to ISO3632-2 of 1993. Following the saffron test method as defined in IS5453: Part 1 (1996), various samples of saffron from Kashmir have been analyzed, which indicated a wide range of test values for various parameters (Table 1) (Anonymous 2008).

The chemical composition of dried saffron stigmas has been extensively studied since the end of the 19<sup>th</sup> century. Proximate composition of dried stigmas of saffron indicate that they contain water (10–12%), mineral matter (5–7%), fat (5–8%), protein (12–13%), reducing sugars (20%), free sugars (trace), starch (6–7%), pentosans (6–7%), gums and dextrins (9–10%), crude fibre (4–5%), crocin pigment (8–9%) and essential oil (0.3%) (Sampathu *et al.* 1984; Ríos *et al.* 1996).

### Crocin

Saffron colouring properties are mainly attributed to the water-soluble crocins. Pfander and Rychener (1982) found that crocin 1 represents 40–45% of the saffron aqueous extract, followed by the crocetin-( $\beta$ -D-gentiobiosyl)-( $\beta$ -D-glucosyl) ester (35%), the crocetin-di-( $\beta$ -D-glucosyl) ester (10%), as well as the crocetin-mono-( $\beta$ -D-gentiobiosyl) and

mono-( $\beta$ -D-glucosyl) esters (each 2%). Alonso *et al.* (2001) examined the content of Spanish, Indian and Iranian saffron in crocin derivatives and gave results for *trans*- and *cis*-crocin (*trans*-crocin: 0.46–12.12%; *cis*-crocin: 0.04–8.53%; *trans*-( $\beta$ -D-gentiobiosyl)-( $\beta$ -D-glucosyl) ester: 0.01–9.44%; *cis*-( $\beta$ -D-gentiobiosyl)-( $\beta$ -D-glucosyl) ester: 0.01–2.26%). Similarly, Caballero-Ortega *et al.* (2004) quantified the contents of *cis/trans*-crocin from saffron samples of Azerbaijan, Kashmir, Iran and Spain and found that the total carotenoid content in Azerbaijan and Iran was higher than other samples. This difference was attributed to the geographical location or the degree of purity of these samples.

### Picrocrocin

The colourless glycoside picrocrocin (C<sub>16</sub>H<sub>26</sub>O<sub>7</sub>, 4-( $\beta$ -D-glucopyranosyloxy)-2,6,6-trimethyl-1-cyclohexene-1-carboxaldehyde) is the major bitter compound of saffron. Alonso *et al.* (2001), who examined several samples of Spanish, Indian and Iranian saffron, found differences in picrocrocin content: 0.79–12.94% in Spanish saffron, 1.07–2.16% in Indian saffron and 2.18–6.15% in Iranian saffron. Caballero-Ortega *et al.* (2004) quantified the contents of picrocrocin from saffron samples of Azerbaijan (2.69%), Kashmir (0.39%), Iran (3.24%) and Spain (1.02%).

### Safranal

Safranal is the main compound responsible for the aroma of saffron, even though there are other more volatile constituents which provide saffron with its final odour (Zarghami and Heinz 1971; Sampathu *et al.* 1984; Curro *et al.* 1986; Tarantilis and Polissiou 1997; Straubinger *et al.* 1998). The levels of safranal and of the other aroma compounds of saffron vary depending mainly on the conditions of processing and storage, and on the methods of analysis. Safranal content of saffron samples from Azerbaijan (0.859%), Kashmir (0.552%), Iran (0.281%) and Spain (0.582%) showed significant differences between samples (Caballero-Ortega *et al.* 2004).

### Crocin, picrocrocin, safranal standardization

The above results clearly show that the levels of each of these important biomolecules (crocin, picrocrocin, safranal) vary depending on the origin and overall processing conditions and storage length. The above results point towards comparatively poor quality of Kashmir saffron. On the contrary, in a study different approaches, including colourimetry (Hunter Lab), UV-visible spectroscopy (ISO 3632-2003) and APCI-MS (atmospheric pressure chemical ionisation-mass spectroscopy), were employed for comparing saffron samples (in filament forms without adulteration) from the UK, Iran (Birjand) and India (Kashmir) in terms of three main components of saffron (colour, odour and taste) (Yadollahi *et al.* 2007). Colouring strength (crocin) and aromatic strength (safranal) values of saffron solutions from the three countries were ranked as India > Iran > UK, while the mean bitterness value of Iranian saffron was greater than that of Indian saffron followed by UK saffron. Yadollahi *et al.* (2007) characterised saffron samples uniformly based on the method specified in ISO/TS 3632-1 and 2, and later compared them with values obtained from ISO/TS 332-1 as chemical requirements for saffron samples. The methodology used in the study further points out that care must be taken when comparing samples, i.e., a comparison must be made between equivalent samples (of the same quality grade) and saffron samples must be bought directly from the producers. Nevertheless, the reasons for these differences need to be investigated in greater detail to determine if this is due to inherent poor saffron quality based on geographical origin or due to impurities/adulteration or poor post harvest handling and storage.

## ADULTERATION

Saffron is considered to be the highest priced spice in the world (on average, 500 \$/kg). Its high value makes saffron the object of frequent adulteration and fraud (Fernández 2007). Oberdieck (1991) and Alonso *et al.* (1998) summarised the most frequent adulteration practices: (i) Misbranding or origin falsification; (ii) Admixture with old saffron or with style material; (iii) Admixture with stamens previously cut and dyed; (iv) Impregnation with substances to increase weight (syrups, honey, glycerin, oils, potassium hydroxide, saltpetre, Glauber's salt, Seignette's salt, borax, lactose, starch or glucose); (v) Parts of other plants with or without colouring power; (vi) Animal substances (fibers of salted and dried meat); (vii) Threads of coloured gelatin; organic colourings and colouring materials derived from tar.

Adulteration in saffron is rampant and a serious malpractice in Kashmir. Imported Iranian saffron is mixed with local saffron and sold as 'Kashmir brand' at a higher price. The exact figures of saffron routed into Kashmir are not known as most of the imports are clandestine in nature. In addition, ray florets of African marigold, sugar-coated paper cuttings, dried and meshed flesh fibres, dyed saffron stamens, dyed stigma of maize (corn silk), etc. are also mixed by corrupt traders. Fats, oils and glycerine are sometimes used to increase the weight of saffron. This adulterated and spurious saffron is sold to ignorant tourists who visit the Kashmir valley in large numbers.

According to a study on saffron sold in Kashmir, only 52% is genuine, 30% is poor grade and 17% totally adulterated (Mir 2002). Saffron produced in the Kashmir valley is classified as 'Special' (also called Mongra) when it contains only dried stigmas with deep red colour,  $\leq$  5% floral waste and  $\leq$  0.5% foreign matter (Fig. 1A). It is classified as 'Standard' grade (also called Laccha) when it contains stigmas mixed with styles, is of light red colour,  $\leq$  10% floral waste and  $\leq$  1.0% foreign matter. The saffron produced in Doda district of Jammu Province is equivalent to Laccha of Kashmir valley and is locally known as 'Guchhi' (Dhar and Mir 1997).

Microscopic observation of typical anatomical elements is valuable to test the authenticity of powdered saffron. Among the diagnostic characters are the upper epidermis of the stigmas with small papillose protuberances and large pollen grains (Ordoudi and Tsimidou 2004). Determination of the major organoleptic characteristics of saffron (picrocrocin, safranal and crocin) is carried out in an oversimplified way by spectrometric evaluation of an aqueous extract at three characteristic maxima (257, 330 and 440 nm, respectively). Molecular tools may be ideal for checking purity of product, even after processing, acting as markers for adulteration (with other plant species) (Khan *et al.* 2008).

Lack of laboratories to evaluate quality coupled with ineffective law enforcement are the major constraints in enforcing adoption of quality standards and uniform price fixation as per the standards in Kashmir. The Food and Adulteration Act of India (1949) is the only major law which the State agencies use to catch adulterators to save the saffron industry from this menace, although how many have been prosecuted is unclear.

## DISORGANIZED MARKETS AND LACK OF PROPER FINANCING

An economic analysis of costs and returns, net present value, benefit cost ratio, pay back period, internal rate of return and the farm profit measures indicate that saffron is economically viable for cultivation under Kashmir conditions (Anonymous 2004; Wani *et al.* 2008). The economic analysis of saffron in Kashmir (District Pulwama) revealed that benefit cost ratios (BCR) were 2.31 and 2.21 at 10 and 12% rates of interest, respectively. This indicates that at the prevailing rate of interest, an investment of \$1 fetched a return of \$2.31 and \$2.21 at 10 and 12% discounting rates, respectively. The undiscounted average BCR was calculated

as 2.97. Since BCR was >1, it showed that the investment in saffron cultivation was economically viable (Wani *et al.* 2008). However, since saffron markets in Kashmir are highly disorganized, a large cut of the profits is taken by private brokers and a long chain of middlemen linking the growers with the consumers. The majority of growers (70.86%) sell their produce through saffron brokers (*dalals*), accounting for 59.67% of saffron production while 16% of saffron growers sell saffron through sub-firms, and only 13% sell it through wholesalers/firms, retailers, government agencies and directly to consumers (Wani *et al.* 2008). In an earlier survey Munshi (2002) reported that 70% of saffron growers sell their produce to *dalals* and 25.7% to sub-firms, while only 1.43% sell it directly to wholesalers in the rest of the country (Delhi, Amritsar, Mumbai, Kolkata) and 1% to cooperative societies.

Sometimes brokers spread misinformation through print media about the possibility of a bumper crop in the valley, which causes the market prices of saffron to crash and hence buy saffron at much lower prices from farmers (Nehvi *et al.* 2008). This has discouraged farmers, and hence a strategy needs to be evolved for ensuring maximum returns to the farmers so that it enables them to make additional investments in adopting improved technologies for enhancing saffron production and productivity. There is an urgent need for setting up an organized saffron market centre (locally called 'Mandi') in the traditional area of saffron production, i.e. Pampore.

Until recently, there were no formal channels of financing saffron growers in the state. While banking on an informal financing system, growers had to pay exorbitant rates of interest resulting in thin margins for them and hence small growers showed a lack of interest in saffron cultivation. While appreciating these financial hardships of saffron growers, the J&K Bank (a state nationalized bank) designed a special scheme namely "JK Bank Zafran Finance" exclusively for saffron growers in 2007-2008. All saffron growers, including small, marginal and large farmers including contract farmers engaged in cultivation of saffron or intending to commence cultivation are eligible to obtain a loan under the scheme. The loan covers the entire plantation and production costs, including plant material, agricultural machinery, labour, post-harvest handling and packaging.

## INITIATIVES FOR SUSTAINABLE SAFFRON PRODUCTION AND REVIVAL OF THE SAFFRON INDUSTRY IN KASHMIR

The major initiatives that are needed for sustainable saffron production and revival of the saffron industry are discussed broadly next.

### Breeding and biotechnology

Saffron is a triploid species with  $3n=24$ ,  $x=8$  chromosomes. Its triploid nature allows for vegetative multiplication, but not regular sexual reproduction. This is because meiosis and gamete development in triploids are irregular, resulting in many anomalies in sporogenesis and gametophyte development. Manipulating seed to produce better plants has not been successful in cultivated saffron as meiotic abnormalities result in abnormal chromosome assortment and formation of an abnormal number of genetically imbalanced spores which vary in shape and size, leading to complete sterility (Chichiricò 1990). Moreover, corm multiplication does not induce genome variations with the exception of some mutations, which are not easily detectable in a triploid saffron population.

#### 1. Collection and conservation of genetic resources

Recently a consortium, composed of 14 groups of 9 EU and non-EU countries has taken the responsibility of creating and maintaining the genetic variability of saffron. The European Commission has approved a project on "Genetic Re-

sources of Saffron and Allies (*Crocus* spp.): CROCUS-BANK" to create, characterise and exploit a germplasm collection (bank) in *Crocus* species (Fernández 2007).

There is a need to establish a germplasm bank of saffron in India (preferably in the state of J&K) for collection and reproduction of saffron bulbs from all the areas that cultivate saffron in India. This plant material can then be used in selection programmes all over the country and serve as sources of resistance and other agronomically interesting traits to be transferred between saffron clones through appropriate breeding programmes and technological tools. These objectives can be achieved by a four-pronged strategy: (i) The collection of *Crocus* material by means of requests to different regional centres growing the plants and visiting specific locations at appropriate dates to collect both cultivated saffron species and sub-species; (ii) Multiplication of collected plant material for conservation in the Plant Germplasm Bank using tissue culture techniques; (iii) Preparation of a list of descriptors for primary characterisation of the collected material; (iv) Providing material to potential users by distribution of corms, tissue culture and DNA samples.

#### 2. Primary and secondary characterization of genetic resources

Primary characterization of the collected material based on the phenotypic characters with good heritability i.e. morphological (floral features, corm size), cytological (chromosome numbers, genome size and ploidy level), phytochemical (saffron chemical composition) and molecular (DNA analysis) studies are necessary. In view of stresses due to climate change, there is an urgent need to identify genotypes from marginal areas characterised by soil salinity and water stress. The collection of *Crocus* species needs to be evaluated in different stress levels for the number of flowers harvested per plant, fresh and dry style weight and chemical compounds of each sample.

The intensive cultivation and mono-culture of saffron in saffron-growing belts of the Kashmir valley together with the continual use of diseased material results in the frequent occurrence of corm rot diseases caused by different pathogens (Madan *et al.* 1967; Dhar 1992; Thakur *et al.* 1992; Wani 2004; Ahmad and Sagar 2006; Kalha *et al.* 2007; Husaini *et al.* 2010).

Screening *Crocus* accessions against these saffron pathogens is required to find genetic resistance. The number of infected corms in each accession can be determined by the presence of brown to dark brown sunken and irregular patches below the corm scales (Ghani *et al.* 2002).

#### 3. Selection

The genetic base of natural saffron populations around the world is very narrow and no significant improvement in productivity is expected through recurrent selection (Brandizzi and Grilli-Caiola 1996). Still, it would be worthwhile to continuously select well developed corms from a population for improved economically important characteristics like long red stigmas (Grilli-Caiola 1999). This method offers an advantage in maintaining the genetic characteristics of the plant, but it does not allow for making any genetic improvement.

In Kashmir, the cultivated population of saffron is *Crocus sativus* 'Kashmirianus', which is recognized by its extremely dark maroon-purple hue, and is among the world's darkest, suggesting strong flavour and colourative effects. Surveys undertaken to study the extent of variation revealed a wide spectrum of variability in saffron flowers and corm samples collected from saffron-growing areas of Kashmir (Dhar *et al.* 1998). Stigma length varied from 1.75-3.72 cm and style length ranged from 1.70-4.25 cm. The average number of daughter corms per mother corm ranged from 2.37-7.05 and their average weight ranged from 1.59-8.49 g. Crocin content ranged from 8.55-17.10%. Latto and Dhar

(1999) studied temporal saffron populations of Kashmir for 6 floral characters viz., number of flowers per spathe, fresh flower weight, flower size (perianth area), stigma length, fresh stigma weight and dry stigma weight. Appreciable differences in coefficient of variation for all the characters were observed. Maximum coefficient of variation was recorded for flowers per spathe (59.15), whereas minimum (0.42) was recorded for stigma length. Similar results of a wide range of variability in Kashmir have also been reported by Zargar (2002). Stigma length ranged from 2.41-3.87 cm, and crocin content ranged from 9.92-14.35%. Based on the reports of the extent of variability in natural subpopulations of saffron in Kashmir, the identification of elite genotypes is imperative for the Kashmir saffron industry. Collection and evaluation of saffron germplasm in Kashmir has led to the identification of 10 elite clones with distinct yield superiority (SMD-3, SMD-11, SMD-31, SMD-45, SMD-52, SMD-68, SMD-79, SMD-81, SMD-21 and SMD-224). The saffron yield of elite genotypes ranged from 4.0-7.6 kg/ha with a corresponding crocin content ranging from 13.89-17.10% (Nehvi *et al.* 2007a). Identification of these 10 clones with distinct yield superiority of 50-170% above the average of a natural heterogenous population is a milestone for the Kashmir saffron industry. Presently the area cultivated with heterogenous populations is 3110 ha (2007-08) with average productivity of 1.62 kg ha<sup>-1</sup>. Replacing the heterogenous population with an elite saffron clone, e.g., SMD-45 with an average productivity of 7.6 kg ha<sup>-1</sup>, would increase saffron production to 23.63 tonnes, a 366% increase. The yield superiority of this clone is attributed to by Nehvi *et al.* (2007a) to its superior traits: more flowers/spathe, fresh pistil weight and increased stigma and style length.

Therefore, utilization of heterogeneity in the natural population and development of high-yielding genotypes using the existing gene pool offers opportunities for improving the productivity of this crop.

#### 4. Creation of genetic variability

Saffron mutagenesis is a useful method for increasing genetic variability, which can be later exploited through selection. Mutagenesis in saffron should be done when the floral shoot emerges from the corm, as meristem differentiation and maximum mitotic activity takes place during this stage and chimera formation is low (Laneri 1990). Akhund-Zade and Muzafarova (1975) irradiated saffron corms with gamma rays, which resulted in an increase in corm production, flower number and stigma weight. Contrastingly, Laneri *et al.* (1990) observed only morphological variants and no useful mutant could be recovered. There have been very limited efforts by Indian researchers to increase genetic variability in saffron using non-conventional breeding techniques, such as irradiation for inducing mutagenesis and colchicination for inducing polyploidy (Zaffer *et al.* 2004; Nehvi *et al.* 2007a). A comparison of morphological characteristics (number, shape, size and texture of organs) in triploid and probable colchiploid variants of saffron revealed that the variant plants exhibited a slower rate of growth than triploids in vegetative and flowering stages (Zaffer *et al.* 2004). Nehvi *et al.* (2007a) irradiated saffron corms with gamma rays from a Co<sup>60</sup> source at 0.25, 0.50, 0.75 and 1 Kr doses. M1 mutants with 0.25 Kr showed 53.44 and 84.28% enhanced corm yield and saffron yield, respectively, while at 1.0 Kr plant survival was reduced to 79% (Nehvi *et al.* 2007a).

Inter-specific hybridization of saffron is another area that needs attention as it can generate variability for breeding. Introgression of genetic traits from closely related wild species into the saffron genome can result in resistance to pathogenic fungi and viruses (Russo *et al.* 1979), and improvement of the productivity and quality of saffron drugs (Negbi *et al.* 1989).

The pistils of saffron are receptive to pollen from other *Crocus* spp. viz. *C. thomasi*, *C. hadriaticus* and *C. oreocre-*

*ticus* (Chichiriccò 1989). The hybrid seeds with *C. thomasi* as pollen parent germinate and produce plants, while inter-specific crosses with *C. sativus* as pollen parent fail to germinate (Chichiriccò and Grilli-Caiola 1984, 1986; Chichiriccò 1989). This failure can be overcome by *in vitro* culture of cross-fertilized saffron ovaries and successful seed set may be accomplished.

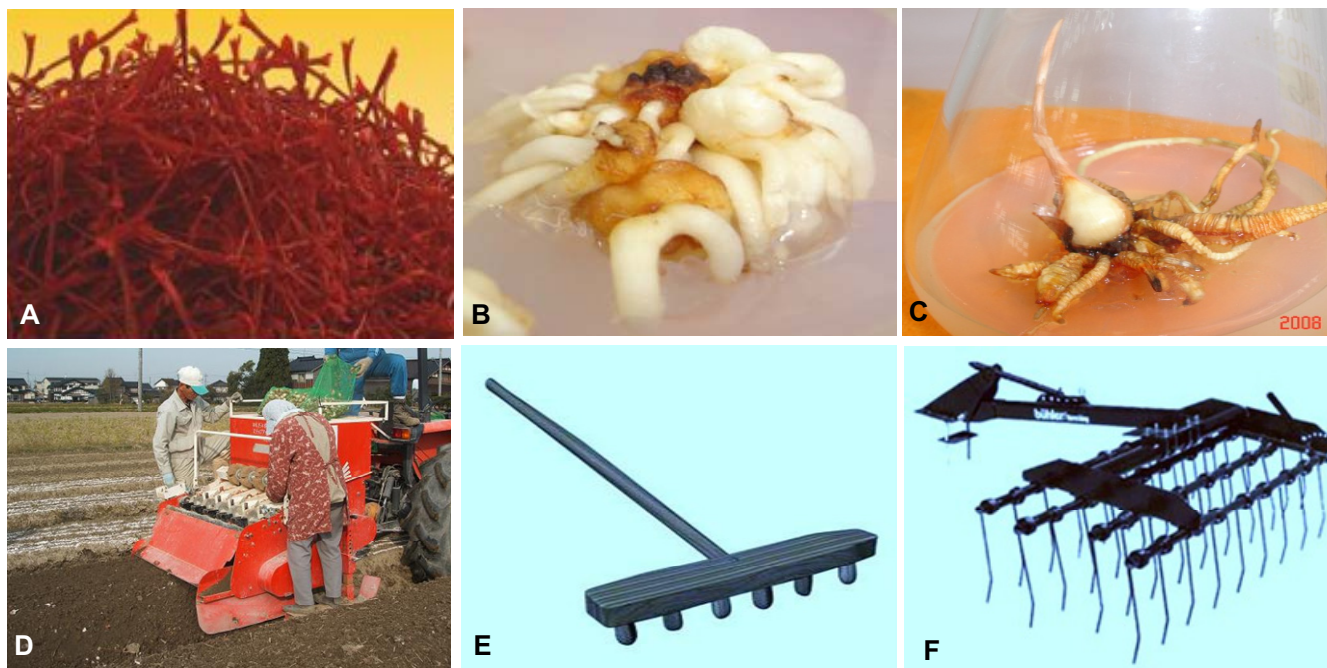
#### 5. Tissue culture

Reproduction in saffron is vegetative, dependent on humans and slow (Wani and Mohiddin 2009). Conventional methods are insufficient; therefore, saffron cultivation needs efficient mass production of pathogen-free corms. Micropropagation of saffron has therefore been advocated as the best alternative for its propagation (George *et al.* 1992; Ahuja *et al.* 1994). Tissue culture has been used for many genotypes, including saffron (Bagheri and Vassel 2006). During the past 30 years a number of attempts have been made by different workers across the globe having different objectives for *in vitro* studies in saffron, which are reviewed next.

***In vitro* corm production:** *In vitro* technology to increase the reproductive capacity of saffron will go a long way to overcome the low corm multiplication ratio (Dalal 2002). The earliest record of tissue culture of *C. sativus* is by Paradis (1957), who reported leaf and corm production from explants pretreated with ethylene. Later on, after a long gap, mini corm-like structures developed from corm callus which subsequently proliferated and even germinated (Homes *et al.* 1987). Corms can be generated from a variety of saffron explants producing regenerative calli even after a series of subcultures over several years (Homes *et al.* 1987). Cormlet and seedling formation has also been reported by Gui *et al.* (1988) in explants excised from dormant corms. Microsurgery of apical buds combined with ethylene pre-treatments (1000 mg l<sup>-1</sup>) can increase corm production (four corms developed at the base of each apical bud where other sprouting buds developed into mini corms) substantially (Plessner *et al.* 1990). Dhar and Sapru (1993) then also succeeded in *in vitro* production of corms and shoot-like structures from callus on MS medium augmented with kinetin (Kn) and  $\alpha$ -naphthalene acetic acid (NAA). Continued efforts in this direction lead Agüero and Tizio (1994) to obtain *in vitro* mass corm production from branches raised *in vitro* from culturing lateral buds of corms. On the other hand, corms were also induced on shoot explants and callus occurred optimally at 10°C (Milyaeva *et al.* 1995). A few years later microcorm production was again noted by Ebrahimzadeh and Rajabian (1998) and Piqueras *et al.* (1999). Organogenesis via callus formation from bulblets and its consistent production of corms/cormels has been standardized and rooting obtained in 50% of plantlets (Anonymous 1999, 2000). However, field trials in traditional areas of cultivation have not been conducted, which is a major constraint.

In recent years, more information regarding corm production has been published from diverse quarters. An important study on the comparative effect of 6-benzyl amino purine (BAP) and thidiazuron (TDZ) on multiplication and induction of independent micro-corms was carried out by Blazquez *et al.* (2001). The results of that study showed that 0.1 mg/l TDZ with 60% regenerated significantly more fully developed leaf primordia than 2 mg/l BAP, which resulted in only 20% regenerants. That study further revealed that TDZ could accelerate the recovery of complete development of plantlets for rooting and *ex-vitro* acclimatization. More recently, corm segments with buds were cultured on Murashige and Skoog (MS) media containing 2 mg/l BAP and 0.5 mg/l NAA, which favoured the production of 2-3 cormlets/explant. The developing corms were later transferred to pots for greenhouse growth (Karaoğlu *et al.* 2007). Concurrently, *in vitro* mini-corm production has also been obtained by culturing basal leaf segments of saffron on MS medium containing 4.0 mg/l BA (6-benzyl adenine, same as BAP) and 0.5 mg/l NAA (Raja *et al.* 2007). Sucrose plays a





**Fig. 1** *In vitro* regeneration of saffron and its mechanization. (A) Special 'Mongra' saffron of Kashmir. (B) Multiple cormlet production *in vitro*. (C) Increase in cormlet size and multiple thick root formation. (D) Tulip planter. (E) Locally made raker, used for hoeing. (F) Company-manufactured harrow.

vital role in cormlet production in saffron as an increase in sucrose concentration results in an increase in the osmotic pressure, inhibiting the vacuolation and shrinkage of cytoplasm in cells and thereby increasing the amount of biomass accumulation (Sharma *et al.* 2008). Similar observations have also been recorded where 15  $\mu\text{M}$  BAP with 30 g/l sucrose was not as effective as 15  $\mu\text{M}$  BAP with 70 g/l sucrose as far as cormlet number was concerned; among various trials carried out, 26.4  $\mu\text{M}$  BAP with 30 g/l sucrose favoured multiple mini-corm production most from sub-cultured callus raised from corm slices (Quadri *et al.* 2008). This shows that growth additives also have an important role to play in cormlet induction. In another experiment, Quadri *et al.* (2010) noted that 20  $\mu\text{M}$  BAP and 20  $\mu\text{M}$  NAA most effectively induced higher cormlet number (mean = 20) from corm slices indirectly through callus (Fig. 1B). The same group also studied the potential of *in vitro* raised mini-cormlets and vegetative buds (dormant and active) to increase the size/weight using different plant growth regulators and carbon source. The maximum increase in weight range (1-1.5 g) of mini cormlets was registered with 2  $\mu\text{M}$  BAP, 2  $\mu\text{M}$  NAA and 60 g/l sucrose. In vegetative buds only apical buds from active corms increased in size; this was significantly affected by the carbon source. The maximum increase in mass (1.5-2.0 g) occurred with 2  $\mu\text{M}$  BAP, 2  $\mu\text{M}$  NAA and 40 g/l sucrose; 8.8  $\mu\text{M}$  indole-3-butyric acid (IBA) and 40 g/l edible sugar; 2  $\mu\text{M}$  BAP, 2  $\mu\text{M}$  NAA, 2.5 g/l KCl, 30 g/l sucrose, 40 g/l edible sugar (Fig. 1C) (Quadri *et al.* 2010).

**Bud differentiation and shoot regeneration:** Ding *et al.* (1979) carried out tissue culture studies and reported shoot formation from corm buds. They could also successfully induce callus and subsequent shoot differentiation which lead to plantlet formation when the culture medium was enriched with IAA and 2,4-dichlorophenoxy acetic acid (2,4-D) at 1 mg/l each (Ding *et al.* 1981). Bud differentiation in saffron was reported on MS medium when augmented with 2  $\mu\text{M}$  BAP and 9  $\mu\text{M}$  2,4-D by Huang (1987) in callus cultures obtained from leaf bases. Using similar medium supplemented with 9  $\mu\text{M}$  2,4-D, Ilahi *et al.* (1987) reported callus formation from corm explants that showed the potential for bud differentiation. For the development of an efficient regeneration system in saffron, callus was induced on MS medium fortified with 0.5 mg/l 2,4-D and 0.3 mg/l Zeatin

(Zea) which was sub-cultured in the presence of 4  $\mu\text{M}$  NAA and 5  $\mu\text{M}$  BA for shoot regeneration (Isa and Ogasawara 1988). Separately, Isa *et al.* (1990) cultured protoplasts isolated indirectly from saffron bulbs via callusing immobilized in Ca-alginate beads on MS agar medium supplemented with 0.1 mg/l NAA and 1.0 mg/l BAP. After 2-3 months shoots and roots regenerated from the callus tissue. Shoot development from corm explants was also promoted by 14-56  $\mu\text{M}$  kinetin Kn or Zea or 4.5  $\mu\text{M}$  2,4-D (Plessner *et al.* 1990). Meristem tip culture and plant regeneration from cultured tissue has been reported to be the only way for the wide production of pathogen-free saffron (Hussey 1975; Debergh and Read 1991) but meristems have frequently been used by scientists for somatic embryogenesis rather than for direct plant regeneration. Aguero and Tizio (1994) noticed bud growth and branch proliferation exclusively from lateral buds of corms when used as explants using MS medium supplemented with 6  $\mu\text{M}$  Zea, 10  $\mu\text{M}$  BAP plus 40 g/l sucrose.

To examine the efficient cultural conditions for shoot regeneration, studies were conducted using calli induced from young ovaries;  $\text{NH}_4^+$  inhibited shoot regeneration. Moreover, maximum regeneration frequency was 50% on medium supplemented with 0.5  $\mu\text{M}$  NAA and 0.5  $\mu\text{M}$  BAP (Igarashi and Yuasa 1994). Ovary explants used in some other trials could induce shoots directly with 53.7  $\mu\text{M}$  NAA and 4.44  $\mu\text{M}$  BA and subsequently normal plantlet formation from corms was possible (Bhagyalakshmi 1999). Ovary explants are only competent to initiate organogenesis, particularly direct shoot regeneration, when at a specific stage of ovary development while 20°C seems ideal for caulogenesis from ovary explants (Bhagyalakshmi 1999).

Much akin to the work of Isa *et al.* (1990), shoot regeneration was also reported from saffron protoplasts immobilized in Ca-alginate beads but using a 0.5 mg/l 2,4-D and 0.5 mg/l BAP combination instead of 0.1 mg/l NAA and 1.0 mg/l BAP. Shoot regeneration was reported 6-7 months after protoplast isolation (Ebrahimzadeh *et al.* 2000a). More recently, Majourhat *et al.* (2007) reported enhanced plant regeneration from cultured meristems in sprouting buds of saffron corms using MS medium enriched with 5 mg/l BAP. By using this type of explant to initiate axillary shoot cultures, a new micropropagation procedure was developed suitable for clonal propagation or *ex situ* germplasm conservation of selected genotypes. Multiple

shoots were also induced from callus initiated from corm slices on 26.4  $\mu\text{M}$  BAP with a higher sucrose concentration i.e. 50 g/l (Quadri *et al.* 2008) while Sharma *et al.* (2008) found that 80 g/l sucrose was effective for cormlet production.

**Somatic embryogenesis:** Somatic embryogenesis in saffron has been reported as early as 1992 by George *et al.* (1992), who initiated callus from meristematic regions of corms on MS medium supplemented with 2 mg/l 2,4-D and 0.5 mg/l Kn then subcultured explants in the presence of 2 mg/l IAA, 2 mg/l Kn and 100 mg/l ascorbic acid, which resulted in globular embryo formation and subsequent plantlet formation. Ahuja *et al.* 1994 successfully induced multiple somatic embryos from shoot meristems on MS medium supplemented with 20  $\mu\text{M}$  NAA and 20  $\mu\text{M}$  BAP, which subsequently resulted in plantlet regeneration. Somatic embryogenesis was initiated from shoot meristems on Linsmeier and Skoog (Linsmeier and Skoog 1965) medium containing 5  $\mu\text{M}$  BAP and 5  $\mu\text{M}$  NAA where asynchronous development of somatic embryos occurred; these ultimately germinated and formed complete plantlets (Ebrahimzadeh *et al.* 2000b). Shoot meristems have also been used for inducing embryogenic callus with 4 mg/l Kn and 1 mg/l 2,4-D which was subsequently used for protoplast culture (Karamian and Ebrahimzadeh 2001). Embryogenic callus was frequently induced by Darvishi *et al.* (2007) when using 4.5  $\mu\text{M}$  2,4-D and 4.4  $\mu\text{M}$  BA. Somatic embryogenesis was initiated in four species of *Crocus*, including *C. sativus* on LS medium fortified with 21.5  $\mu\text{M}$  NAA, 17.8  $\mu\text{M}$  BA or 4.5  $\mu\text{M}$  2,4-D and 18.6  $\mu\text{M}$  Kn where matured embryos germinated later on; complete plantlets were obtained (Karamian 2004). Regeneration of somatic embryos from callus was improved by enriching the medium with 2.4  $\mu\text{M}$  of jasmonic acid (Blazquez *et al.* 2004b). In their study, Blazquez *et al.* (2004a) indicated an important correlation between the stage of somatic embryogenesis and the type of occurrence and expression of anti oxidant enzymes (superoxidase dismutases and catalase) which could act as markers of embryogenesis. Apart from shoot meristems used as explants for somatic embryogenesis, leaf segments have also been used for raising somatic embryos indirectly from embryogenic callus (Raja *et al.* 2007). Amongst various media tested, MS medium enriched with 10  $\mu\text{M}$  BA and 0.5  $\mu\text{M}$  2,4-D was quite responsive and embryos germinated after maturation and formed plantlets (Raja *et al.* 2007). Even TDZ, a compound having cytokinin-like activity, has been found to be significantly effective in the induction of somatic embryogenesis from 5 different types of corm explants (terminal or auxiliary buds, upper or lower parts of corm tissue and terminal buds from pre-treated corms at 40°C for 2 weeks) and different types of explants showed no significant effect; however, 0.5 mg/l TDZ was the most effective treatment (Sheibani *et al.* 2007); matured embryos thus recovered developed micro-corms from their basal part after 3 months. Rajabpoo *et al.* (2007) also successfully achieved somatic embryogenesis from upper and lower corm explants using 20 mg/l 2,4-D and 1.0 mg/l BAP were most effective; lower corm explants were much more responsive, indicated by the number and percentage of embryo response, about 33.3 and 93.3% for the upper and lower part of corm tissue, respectively. Even mature floral bases have also been used for inducing somatic embryogenesis on MS medium containing 2 mg/l BAP and 0.5 mg/l NAA, which ultimately germinated and resulted in cormlet formation (Karaoglu *et al.* 2007).

**Stigma proliferation and synthesis of major secondary metabolites:** In saffron, apart from micropropagation studies, attempts have also been made to artificially produce saffron and its active principles through *in vitro* multiplication of stigmas. To this end, Himeno and Sano (1987) cultured young half ovaries excised from young flower buds on LS and Nitsch (Nitsch and Nitsch 1969) media supplemented with 10 mg/l NAA + 1 mg/l Kn and 1 mg/l NAA

+ 1 mg/l BA, respectively. After 10 weeks, stigma-like structures (SLSs) were formed directly on the explants from which 7.57  $\mu\text{g}$  crocin and 1.19  $\mu\text{g}$  picrocrocin were detected on a dry weight basis. Safranal (0.78  $\mu\text{g}$ ) appeared only after heat treatment at 50°C for 120 min. Most importantly, the content of these major secondary metabolites in these SLSs were similar to those in intact young stigmas; they were also morphologically similar (Himeno and Sano 1987). In a separate study, young excised single stigmas or half ovaries were cultured to form SLSs to explore the possibility for industrial production of saffron spice (Sano and Himeno 1987). The maximum number of SLSs was 75/half ovary. Although morphologically these structures were similar and *in vivo* resembled grown intact stigmas, the total length was 80% shorter (1/5 of the size) than *in vivo* grown intact stigmas. Since the frequency of SLSs is still low for industrial production of saffron spice, the observations made can be useful as baseline data to conduct further studies (Sano and Himeno 1987). Apart from using ovaries, SLSs were also successfully produced from flower and petal explants (Namera *et al.* 1987), and from half ovaries (Himeno *et al.* 1988; Kohda *et al.* 1993). Young stigma explants favoured callus formation on LS medium enriched with 13  $\mu\text{M}$  BAP, 0.5  $\mu\text{M}$  NAA and 20 g/l coconut milk, which differentiated into SLSs. These grew and contained crocin and picrocrocin (Koyama *et al.* 1988). Hori *et al.* (1988) made attempts to induce calli (20-40% frequency) from pistils of saffron on MS, White (White 1963) and Nitsch media enriched with BA and NAA at 1.0 mg/l each. The HPLC analysis from calli revealed the presence of crocin, crocetin- di (monoglucosyl-diglucosyl) ester and crocetin- di (mono-glucosyl) ester. The content ratio of these three pigments in the callus was calculated from the chromatogram in an ODS column as 20: 10: 1 and was the same as in styles. The amount of these pigments in the callus, however was only one tenth of that in the pistils. They could even maintain such calli for more than 2 years in the dark. The authors also suggested that at least a higher level of auxin may be enough for callus induction; more importantly, it is useful to establish cultures having the tendency to differentiate organs for high production of pigments.

Sarma *et al.* (1990) successfully produced SLSs from stigma explants cultured on MS medium fortified with (3  $\mu\text{M}$  BAP) and (54  $\mu\text{M}$  NAA) which contained crocin and picrocrocin, responsible for colour and bitter taste, respectively. However, safranal could not be detected in fresh samples. Fakhrai and Evans (1990) also successfully obtained SLSs from different floral explants but did not observe intense pigmentation from these structures, which is very important. Sarma *et al.* (1991) achieved similar results as reported earlier from ovary explants on MS medium supplemented with (54  $\mu\text{M}$  NAA) and (44  $\mu\text{M}$  BA) but SLSs showed much lower levels of crocin (0.40%) and picrocrocin (0.37%) (6- and 11-fold lower, respectively) than in natural stigmas. Moreover, these authors were the first to publish a report on sensory analysis of spice produced in tissue cultures; this data indicates that saffron pigments produced in tissue cultures were one tenth that of natural stigmas. Further, a sensory profile test showed that tissue-cultured saffron was low in floral, spicy and fatty characteristics which are important characteristics of saffron spice, but was dominant in herbaceous notes-harsh/acrid and barky compared to saffron from natural flowers (Sarma *et al.* 1991). In that study, the % crocin, % picrocrocin and the crocin/picrocrocin ratio was 2.4%, 3.9% and 0.6, respectively for stigmas from flowers while the values from tissue-cultured derived stigmas were 0.4%, 0.37% and 1.08, respectively, all values on a dry weight basis. Explants such as shoots and young petals have also been used to regenerate SLSs using 50  $\mu\text{M}$  NAA, 30  $\mu\text{M}$  BAP and 20 g/l coconut milk (Lu *et al.* 1992). Otsuka *et al.* (1992) also induced SLSs from flower, petal or ovary explants on BAP (8, 9-22, 2  $\mu\text{M}$ )- and NAA (0, 5-5, 4  $\mu\text{M}$ )-enriched media with a high level (50-120 g/l) of sucrose in the media. Similarly, Han and Zhang (1993) could also achieve SLSs from other parts

of the flower and subsequently also identified the pigments in these structures.

To increase crocin, picrocrocin and safranal in *in vitro*-grown tissues raised from floral buds on MS medium supplied with 9  $\mu\text{M}$  2,4-D and 2,3  $\mu\text{M}$  Kn, Visvanath *et al.* (1990, 1994) successfully reported a higher quantity of picrocrocin from callus (obtained from floral buds on MS medium supplemented with 2 mg/l 2,4-D and 0.5 mg/l Kn and filamentous SLSs obtained therein, than in natural stigmas; safranal appeared only in callus but its content was at par with natural stigmas. Crocin content was lower in *in vitro* cultures. A very important observation is that full-strength MS medium supplemented with NAA and BA produced the best caulogenic response (28%) with highest shoot numbers/ovary. On the whole, the best response for shoot growth, both in terms of leaf length and number, was on medium with 0.54  $\mu\text{M}$  NAA and 2.22  $\mu\text{M}$  BA. Ovaries of different growth stages having stigmas of pale yellow, pale orange and bright orange regenerated a maximum mean number (3.8-4.2) of shoots/ovary (Bhagyalakshmi *et al.* 1997; Castellar and Iborra 1997).

An important study on optimization of *in vitro* conditions for frequency of proliferation of SLSs from half-ovary explants of *C. sativus* was carried out by Loskutov *et al.* (1999). The optimum proliferation of SLSs was observed on B5 basal medium (Gamborg *et al.* 1968) containing 5.4  $\mu\text{M}$  NAA, 44.4  $\mu\text{M}$  BA, MS organics, 0.05% casein hydrolysate and 11.2  $\mu\text{M}$  L-alanine. They reported that the amounts of crocin, crocetin, picrocrocin and safranal in SLSs, as determined by HPLC, were similar to those found in natural saffron stigmas. Guo *et al.* (1999, 2005) used a cell culture technique to produce crocin. Crocin production using *C. sativus* callus by a two-stage culture system was reported by Chen *et al.* (2003). Saffron callus was grown in a two-stage culture on B5 medium supplemented with 300 mg/l casein hydrolysate at 22°C in the dark with 2 mg/l NAA and 1 mg/l BA to give maximum biomass (16 g dry wt/l), and with 2 mg/L IAA (indole-3-acetic acid) and 0.5 mg/l BA for crocin formation. The maximum crocin production (0.43 g/l) was achieved by this two-stage culture method. This two-stage culture system significantly increased crocin production compared to the one-stage system used by others. The main reason for initiating such type of *in vitro* studies is from a commercial point of view so as to produce SLSs or callus with major secondary metabolites whose concentration will not be less than natural stigmas and will be less expensive on a larger scale. To date, there is no report which shows a technique for *in vitro* production of saffron on a commercial scale. Hence there is much scope for the refinement of the existing techniques of saffron production either through micropropagation or through the production of SLS and callus with major secondary metabolites on a larger scale for its use at the commercial level.

### Plant growth regulator treatment

A large, well developed corm produces flowers and the first bunch of aerial shoots from the apical bud. The apical bud also gives rise to 1-2 daughter corms, which are larger in size than those arising from lateral buds. Suppression of the growth of lateral buds helps in harvesting fewer corms of larger size (mostly flowering) from the mother corm than more smaller sized (non-flowering) corms (DeMastro and Ruta 1993). Corms treated with gibberellins before planting decreases the number of sprouting lateral buds, resulting in the formation of fewer daughter corms. The apical daughter corms grow larger and hence more flowers per corm are formed. Moreover, treatment of dry saffron corms with gibberellins plus other PGRs when dormant (June–July) promotes the formation of additional flower buds from undifferentiated meristems, leading to enhanced flower formation and saffron yield (Azizbekova *et al.* 1978; Kabdal and Joshi 1978; Azizbekova *et al.* 1982; Farooq and Kaul 1983; Chrungoo and Farooq 1984, 1989; Azizbekova and Milyeva 1999) and consequently of saffron itself. Application of

gibberallic acid (GA) (0.001-0.01%) or kinetin (Kn) (0.005-0.001%) to corms stimulated growth and formation of additional buds, leading to the formation of more flowers and increased yield of dry stigmas by 130-150% (Azizbekova *et al.* 1978). The best results were obtained by soaking corms in July by a single application of GA (100 or 500 mg/corm) to dormant corms as a concentrated microdrop in the apical notch (Azizbekova *et al.* 1982). The effect of gibberellic acid is reported to stimulate starch breakdown in favour of reducing sugars and pentoses (Chrungoo and Farooq 1989, 1991). An increase in plant height, number of leaves/corm and number of daughter corm/mother corm was reported after an overnight dip of mother corms in an aqueous solution (50 ppm) of 2,4-D (Kabdal and Joshi 1978).

### Mechanization

Modernisation of saffron cultivation depends on reducing labour costs through mechanisation efforts (Galigani and Pegna 1999). Cost benefit analysis of saffron cultivation in Kashmir ranges from 1:0.69 to 1:1.39, depending on productivity. According to Alam (2007), cost input in saffron cultivation is very high, the labour component accounting for 47% and other inputs 53%. This demands mechanisation for reducing labour costs as well as for removing drudgery, so that educated youth of saffron farmers may continue traditional farming (Alam 2007). Moreover, with increasing labour wages mechanisation has become imperative for profitability and sustainability of this cash crop. Highly sophisticated costly machines may not be affordable to saffron growers, as most of them are small and marginal farmers, but these machines can be made available on a custom hire basis.

Saffron is a difficult crop to mechanize since the plant is small and delicate, and presently no machines capable of totally mechanizing this crop are available (Alam 2007). Traditionally before planting saffron corms, deep ploughing (30 cm) is done using a bullock-drawn plough and planking. This operation can be mechanized using a tractor and matching ploughs and harrows or a power tiller with a ridger plough (Alam 2007). The field is laid out into strips (2 m wide and 10-20 m long) across the field slope with 30-cm wide and 15-cm deep drainage channels on both sides, to avoid water stagnation to which saffron is sensitive. After bed formation sowing is done by hand dropping saffron corms behind the plough. This operation too can be mechanized using a bed planter or semi-automatic vegetable transplanter (Alam 2007). In trials conducted in Italy with a ridger alone or in combination with a potato planter it was possible to make ridges about 15 cm high and 1 m wide separated by 30-cm furrows (Galigani 1987). Corm planting too can be mechanised using an onion or tulip planter (Fig. 1D). However, the major drawback in mechanical depositing of corms in the bed is the lack of consideration to their polarity, and corms planted deviant from their vertical axis or upside down show delayed sprouting and declined productivity (Galigani 1982). Another type of machine that can be adapted to saffron planting is the potato planter. Overall, this machine was found to give a lower yield than the onion planter but provided better control in terms of corm orientation (Galigani 1987; Galigani and Adamo 1987; Tammara 1990). It could also be combined with a ridger to prepare and plant in a single operation, reducing the working time (Amato *et al.* 1989). In Italy, trials were conducted in the 1980s by burying zinc-mesh cages with a U cross-section containing the corms, and the cages were expected to last for 3 years (Galigani 1987). Similarly, corms were planted in Spain in a mesh cage (45 cm wide) on raised beds (1.5 m wide) with the help of a tulip planter, in order to facilitate subsequent extraction of corms at the end of the planting cycle. Although this system provides ease to the operator, due to the tendency of the cage to wrap and corms to slide inside the cage, it causes unevenness in planting density (Alam 2007). Another machine for saffron corm planting has been developed (Mohammad 2006).



Weeding and hoeing accounts for the major labour cost component (35% of total labour cost). Several hoeing operations are carried out using locally made rakers with wooden or iron teeth (Fig. 1E) to aerate the saffron beds and destroy weeds. A wheel hoe specially designed for clay loam soils can be effectively used for light weeding and hoeing. Besides this, hoeing can also be effectively performed using a two-wheel tractor, taking care not to till at a depth greater than 2-3 cm because of the tendency of new corms to grow close to the surface (Alam 2007). Several companies have designed harrows with back teeth that can be quickly lever-adjusted to different positions to give the desired penetration and vibration action for superb weeding, seedbed preparation, residue incorporation and trash clearing (Fig. 1F).

Mechanization of the harvesting in saffron is extremely difficult owing to three main factors, viz. (i) flowers are delicate and grow close to the soil surface, (ii) flowers are usually accompanied by leaves, (iii) the quality of saffron becomes adversely affected if soil clods get picked together with flowers. Hence, mechanical harvesting of flowers would damage foliage and drastically reduce the production of replacement corms (Alam 2007). Garvi (1987) outlined a proposal for the automation of stigma separation in a Spanish patent named "saffron combine harvester" but the whole description was vague, and incomplete. Efforts have been made to separate the styles from the stamens and petals by means of a wind tunnel or a fan with certain modifications (Skrubis 1990). A new machine for automated cutting of saffron flowers to obtain their stigmas has recently been developed (Gracia *et al.* 2009). This new machine has been patented (Gracia *et al.* 2008) and a prototype has been constructed for experimentation and validation. The key point of the invention is the use of a vision system to obtain, using image analysis, the optimal cutting point. Importantly, the proposed automated cutting machine can cut 8,000 flowers h<sup>-1</sup> under the supervision of one operator, whereas one person only averages about 1000 flowers h<sup>-1</sup> using the traditional hand method. Therefore the production rate is increased eight times.

In Kashmir, drying is generally carried under shade which takes 27-53 hrs to dry the product to a moisture level of 8-10%, and causes deterioration in its quality. The design and development of equipment for the mechanisation of post-harvest treatment of saffron stigmas in India has been presented by Sama *et al.* (2000) and Anwar (2007). Low-cost solar heated dryers have been designed and fabricated in Kashmir, and these have reduced the drying time to 3-4 hrs and maintained quality (Kamili and Nehvi 2005). A hot air dryer and its modified version have also been designed, especially for inclement weather so that farmers can use it indoors. It is a tray dryer in which heated air (45 ± 5°C) with supplemental heating and operated on electricity and liquefied petroleum gas (Alam 2007).

At the end of the planting cycle saffron corms are dug out from the field. On average, 80-man days/ha are required for digging and gathering saffron corms. Several machines like a groundnut or potato digger can be used with slight adjustments (Alam 2007). A potato-picking machine drawn by a two-wheel drive tractor weighing 270 kg has been successfully used for such an operation (Galigani 1989, Amato *et al.* 1989).

## Government support

The saffron industry in Kashmir has been showing a steady decline, particularly during the last decade (Anonymous 2010). Analysis of factors responsible for this primarily includes reduction in production and productivity of this important commercial crop due to corm rot, cultivation under rainfed conditions and lack of adequate nutritional support. In addition, severe drought and scanty rainfall (prior to generative phase of saffron) from 1999-2003 has significantly contributed in the dismal performance of the saffron crop in the last decade.

## 1. Production and productivity

During the 1990's, a comprehensive research programme for addressing R&D in saffron was launched by Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K) with financial support by the Indian Council of Agricultural Research under National Agricultural Technology Project (NATP). Based on the researches technological up gradation and refinement resulted in a cost benefit ratio of 1:1.39 (Nehvi 2004). Research under NATP led to standardization of irrigation scheme, fertigation schedule, corm-planting population, disease control, and drying procedure for better saffron yield. The dissemination of these technologies together with support from the Government to promote their adoption by saffron growers should increase saffron production from the current level of 5 t to 20 t in the next few years. Keeping this objective in view, the Government of India launched a project in 2006 under the Technology Mission for Integrated Development of Horticulture, including saffron, under Mini Mission II so that improved technologies could be transferred to farmers' fields and adequate support be provided to facilitate their implementation. The assistance is meant for Integrated Development of Saffron in J&K by creation of an irrigation source at target sites, rejuvenation of old and unproductive saffron fields, creation of vermicompost units and provision of solar dryers to saffron growers. In addition, a National Mission for Kashmiri saffron with financial support of Rs. 37.5 million for irrigation, research, mechanization, processing and marketing support has been announced in 2010 by the Prime Minister of India. Initiatives have been taken for skill up-grading of saffron growers through hands-on training conducted through the Directorate of Extension Education (SKUAST-K) and State Agricultural Management & Extension Training Institute (SAMETI) with regard to improved technologies.

A separate scheme by the Government of India has been recently taken up in order to promote the cultivation of saffron crop in a non-traditional area (Kishtwar district) (Anonymous 2009). This scheme includes provision for providing special training to saffron cultivators, seed distribution, demonstration plots and subsidized tools and kits.

## 2. Marketing and quality control

Even though the suggestion of local saffron growers for imposition of import duties on saffron from Iran and other countries to ease the competition for Kashmiri saffron remains to be evaluated by the government, Kashmir's saffron sector is poised for serious trouble until smuggling of saffron into the country is effectively plugged. For this, legislations and their enforcement should be as stringent as for smuggling of drugs like heroine, etc. The other important area is the quality-based price evaluation and branding. There is a need for strict enforcement of quality standards by the concerned government agencies. A step in this direction is the recent decision by the government of J&K to set up a packaging unit in the traditional saffron growing area (Pampore) certifying quality under the brand name "Kung-posh" meaning 'saffron flower'.

One positive aspect of the saffron sector in Kashmir is that the farmers and their associations are now very keen in restoring the credibility of the trade. Their latest move of registering farmer groups as societies would go a long way in bringing in consistency in processing and marketing of Kashmir saffron. In France, for instance, associations of saffron farmers ("*Les safraniers du Gâtinais*" in 1987, and "*Les Safraniers du Quercy*" in 1999) were registered after decades of abandon of the crop for its revival (Fernández 2007).

In view of the rampant adulteration, the government of J&K has proposed some amendments in the Saffron Act for addressing the problems of adulteration and falsification of origin. Once these amendments are passed as law these will surely curb the malpractices to a large extent. However,

there is hardly a substitute to granting the status of Geographical Indication (GI) for Kashmiri saffron when it comes to ensuring its quality standards and market credibility. In Spain the designation of 'protected origin and protected geographical indications' was awarded to the "Azafrán de la Mancha" in the beginning of this decade (Commission Reg. 464/2001, OJ L66, 8.3.2001, p. 29), and two years earlier the Greek "red saffron" had also gained the same designation under the name 'Krokos Kozanis' (Commission Reg. 378/99 OJ L. 46, 20.2.1999, p. 13). Similarly the European Union has also awarded the designation to the Italian "Zafferano dell'Aquila" (Ordoudi and Tsimidou 2004; Fernández 2007).

## CONCLUSIONS

Kashmir has the potential of becoming a global leader in the saffron industry through the adoption of a scientific agro-technology, better post-harvest management and proper marketing strategy. Apart from factors related to agronomic production practices and lack of scientific aptitude among small and marginal farmers (discussed in Husaini *et al.* 2010), clandestine import of Iranian saffron and rampant adulteration practices have ruined the saffron market of Kashmir. Inadequate infrastructural facilities and poor quality control measures have shaken consumer confidence and therefore need to be addressed in earnest. Iran has set an example for Kashmir to follow. Replacement of marketing systems by a new intervention have made it possible for Iran to export about 120 t of saffron compared to 1.3 t exported from India (2005-06) where farmers are dependent on middlemen, traditional sun drying and family labour. Currently this golden spice is highly remunerative in the world market and therefore offers ample scope for employment generation in Kashmir.

Technological intervention and adoption of novel scientific methods based on breeding and biotechnology can help to address the problem of supplying disease-free cormlets in large numbers at reduced costs. However, these techniques are still not commercially viable and therefore, further research is needed in this direction. In addition, mechanization, though strongly advocated, has not been successful due to the delicacy of certain operations in saffron cultivation and processing. Moreover because of the marginal nature of this crop, investments by manufacturers are unlikely to be repaid as quickly as they would expect. In fact, this is a general limitation with the saffron crop and Kashmir is no exception. However, with a recent increase in the world price of saffron, farmers may be ready to pay for higher costs of machinery to the manufacturers, who may readily invest in designing better machines. A higher international price would also increase its potential of becoming an important source of foreign exchange for India, provided that adequate measures are taken by the political leadership of the country.

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