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Red Gold in Peril: A Multidimensional Analysis of Threat to Cultivation of Saffron in India

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Abstract: This paper highlights the threats to saffron cultivation in India. Based on a review of the literature combined with our experience in saffron research, climate change seems to be the primary threat followed by corm rot disease and rapid urbanization. Additional challenges include spice adulteration, limited availability of good quality corms, unsustainable aeroponic/hydroponic practices that deplete corms from traditional sites and manual cultivation practices. To ensure the sustainability of this heritage crop, this study emphasizes the need for geographic diversification, strategies to prevent injury to corms, post-harvest processing, protective policies and technological modernization for saffron cultivation.

Key words: Saffron, climate change, corm rot.

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Saffron (Crocus sativus L.) also known as "Red Gold" is one of the oldest and costliest spices in the world. Since ancient times, this crimson treasure holds significance in cultural rituals, traditional medicine and cuisine across diverse cultures (Bhagat et al., 2024). In India, saffron cultivation is a cultural heritage of Pampore region in the Kashmir valley and Kishtwar in Jammu, J&K. The purple flowers with crimson red stigma, that bloom across the fields each October/November, are the source of pride and symbol of identity for generations, in addition to being a source of revenue. Attempts are being made to spread its cultivations to Ladakh, which has similar climate conditions to saffron growing countries that is Iran and Afghanistan (Mehdi, 2023).

Crocus sativus L. is a perennial herb that propagates by multiplication of underground corms. The corm is a unit of storage as well as propagation. A typical saffron life cycle is completed in three years. The mature corm that produces flower is called the mother corm as it also gives rise to daughter corms. The flowering phase is followed by vegetative phase and the vegetative phase is followed by the dormant phase. The daughter corms that are produced during vegetative phase are small and underweight for flowering. Therefore, corms usually undergo an additional cycle of vegetative and dormant phase to mature into mother corm that can flower in next flowering season (Ali et al., 2025) (Fig. 1).

Despite its cultural and economic importance, saffron cultivation is facing a multifaceted crisis that threatens not only

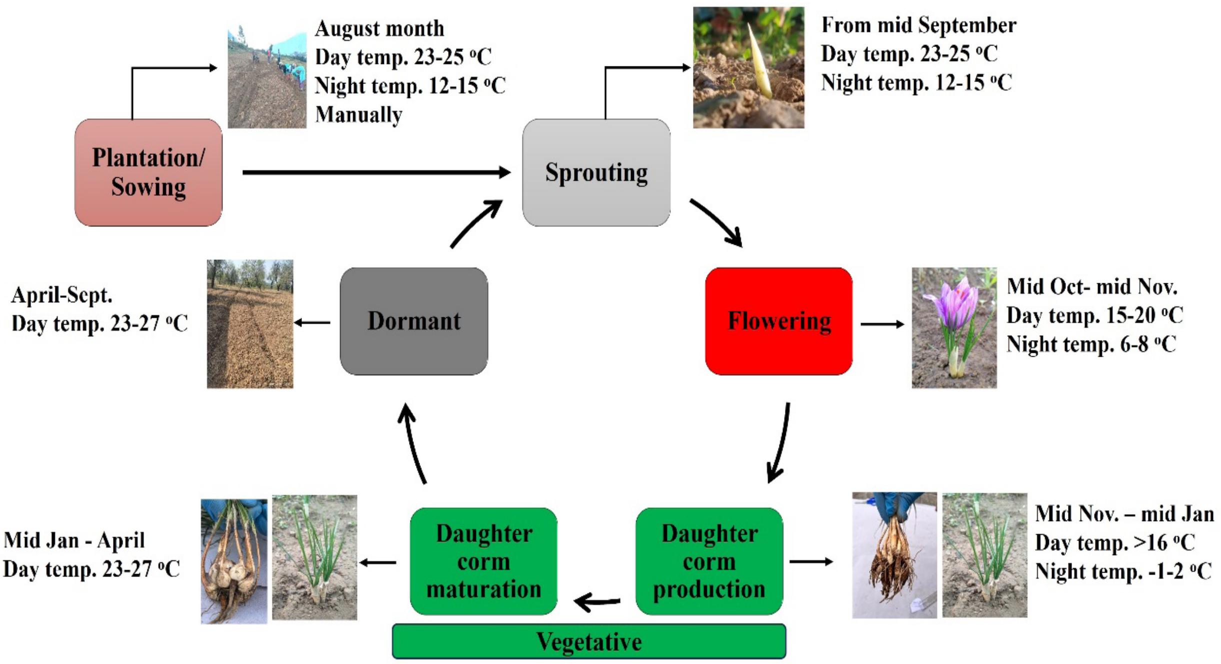

Fig. 1. Annual life cycle of saffron plant showing different phenological stages, optimal temperature ranges and seasonal timing. This cycle undergoes three years to produce mature daughter corms. Source (Ali, 2025).

its production, but even its survival. According to the department of agriculture Kashmir, J&K, there has been 68% decline in saffron production in the last two decades. Saffron production has decreased from 15.95 t in 1990 to 2.6 t in 2023-2024. This dramatic decline is not result of a single factor, but stems from the synergistic effect of several interconnected challenges that include climate change, come rot disease, poor soil quality, urbanization, unavailability of good quality saffron corms etc. This paper focuses on these challenges and explores possible solutions to mitigate them.

***Climate change*:** Among the various factors that are threatening saffron production and sustainability, climate change is the major factor. It is disrupting the delicate phenology of saffron, through shifting rainfall patterns, rising temperatures, and unpredictable snowfall, affecting both the production and quality of saffron corm and spice (Ayoub *et al.*, 2024). Though saffron is a rain fed crop but it demands specific temperature and rainfall at specific stages of its life cycle. Saffron corms are typically sown in August, and require an average day temperature of 23 to 25°C and 12 to 15°C night temperature (Cardone *et al.*, 2021). Flowering in October and November requires day temperature of 15 to 20°C and night temperature below 10°C. For the initiation of daughter corm production chilling temperature is required and for daughter corm maturation, day temperature of 27°C average and night temperature of 20°C average is required (Zahmati *et al.*, 2018; Nikolova, 2023) (Fig. 1). Additionally, the complete vegetative phase (January to April) requires about 418.90 mm of total rainfall ha^{-1} (Yasmin and Nehvi, 2018).

However, in recent years, erratic weather patterns including higher temperatures, low pre-flowering rainfall, and unseasonal rains have caused delays in sprouting and significant reduction in flowering. Unseasonal rains during the flowering phase can damage the stigmas, leading to a 50-65% drop in the yield (Ayoub *et al.*, 2024).

The year 2023 in Kashmir exemplifies above mentioned climate-related challenges on the cultivation of saffron. The rainfall in the month of September decreased to 40% of normal levels in the last two years, causing delayed sprouting due to hardened soil. Undesired rainfall in October damaged the corms rather than providing necessary nourishment (Kashmir Observer, 2024; Ayoub et al., 2024). Most critically, pre-flowering rainfall was decreased by approximately 79%, leaving fields cracked and dry, ultimately leading to 50% yield losses

(Kashmir Observer, 2024). It is important for the corms to have sufficient moisture content during winters provided by snow for growth and protection from infections. But nowadays, due to climate change, snow is completely absent in the plains that exposes corms to frost, which reduces cold-season nutrient uptake, resulting in low yield in the next season (Ayoub *et al*., 2024). The National Saffron Mission, initiated by the Government of India in 2010, aimed to address water-related problems by providing sprinklers for saffron cultivation; however, so far, no positive impact has been seen on the ground (The Tribune, 2015).

To mitigate the effects of climate change on saffron production, two adaptive strategies can be implemented;

(i) Extending saffron cultivation to suitable non-traditional areas with proper rainfall pattern and snowfall. For example, successful cultivation has been demonstrated by our group in Poonch district of Jammu, in JandK (Ali *et al*., 2025) and in Himachal Pradesh by a group led by Dr. Rakesh Kumar at IHBT (CSIR), Palampur, Himachal Pradesh (Kumar *et al*., 2022),

(ii) Another is shifting to two step saffron cultivation. In two step cultivation system, corms are cultivated in trays or crates and kept indoors under controlled optimal conditions for flowering phase and then are shifted to the open fields, at the areas conducive for the saffron cultivation for the corm multiplications. This practice is followed in China (**Dia** *et al*., 2021).

Corm rot disease and its management: Corm rot has been identified as the critical biotic factor responsible for yield loss. As saffron propagates vegetatively through corms, so it is inherently vulnerable to soil borne pathogens (Bhagat *et al*., 2022). Literature is replete with report of fungal and bacterial pathogens causing corm rot. Among pathogens *Fusarium oxysporum* (Fox) has been identified as most devastating pathogen but our studies state otherwise. We have found that corm rot infection typically occurs to injured corms rather than through direct pathogen invasion (Bhagat *et al*., 2022; Mansotra *et al*., 2023). Initially, we established this relationship with the most potent pathogen, *Fusarium oxysporum* in *in-planta* studies and found that it can only infect corms and roots when they injured (Bhagat *et al*., 2022). Subsequently, this finding was validated with 45 fungal isolates, confirming that all isolates become pathogenic only when corms and roots were injured (Mansotra *et al*., 2023). This hypothesis is further supported by our observation that *Trichoderma harzianum*, commonly used as a biocontrol agent against *Fusarium oxysporum* in saffron fields, exhibited severe pathogenicity when corms were injured, underscoring the critical role of injury in disease establishment (Mansotra *et al*., 2023). These injuries are commonly caused by rodents, nematodes in the fields, and mechanical damage during sowing, digging, and storage processes (Bashir *et al*., 2025).

Currently, management strategies are predominantly chemical-based. Chemical fungicides such as carbendazim, myclobutanil, mancozeb, bavistin, tecto, and dichloro diphenyltrichloro ethane are generally used to manage the corm rot disease. Though these chemicals are found effective in managing the disease initially, they have several limitations. Not only does pathogen develop resistance to them over the years but they impact environment, native soil microflora and human health negatively (Gupta *et al*., 2020). The effect on native microflora was observed by our group; we found that the cultivable fungal diversity was lower in Kashmir compared to Kishtwar and Ramban because farmers in Kashmir use chemicals frequently (Mansotra *et al*., 2023).

The current approach for the management of corm rot is fundamentally flawed, as it focuses on treating the symptoms rather than addressing the root cause. We recommend that instead of chemical management, corms should be sorted for injury and screened for any disease symptoms.

More critically, rodent and porcupines attacks in the fields should be stopped as these create the injury sites that predispose corms to fungal infections. In order to prevent the attack of rodents some of the approaches that can be used are crop rotation, field sanitization, reduction in the size of bunds up to 30 cm, burrow sanitization, poison bating, petting cats and trapping of rodents. For porcupines, placement of light lamps in the field, fencing of fields with 45 to 60 cm metallic sheets (Alie *et al.*, 2020). All these suggestions require one time investment but can be effective for years.

Effect of urbanization: Another serious threat to saffron cultivation in Pulwama, Kashmir, is that traditional saffron cultivation lands are being fragmented into residential and commercial developments, eroding both production capacity and cultural continuity. This has led to decline in area under cultivation, from 5,707 hectares in 1996-1997 to 2,387 hectares in 2018-2019 (Bashir et al., 2025). The location of saffron fields alongside main highway has made them primary target for the construction of residential complexes and establishing industries such as cement factory (Dar and Bijbehare, 2017; Mukhter et al., 2020). These developments not only reduced the available cultivation area but industrial activities have severely degraded the soil quality of nearby saffron fields as well.

In our opinion, government should make stringent policies that prevent the construction activities in the traditional saffron fields with restricted development rights. Economic incentives can be given to saffron growers such as premium pricing schemes, crop insurance and subsidies that make saffron cultivation financially attractive and sustainable.

Saffron adulteration: The adulteration in the saffron spice presents another serious threat that has affected its integrity and market credibility. The problem of adulteration is multifaceted: addition of cheap synthetic colorants and various adulterants such as red dyed corn silk thread, safflower petals, other parts of saffron plant such as stamens and petals, adding substances like glycerol, olive oil, honey to increase the weight, mislabeling the product for origin and presenting low-grade saffron as high quality (Raina *et al.*, 2024). Beyond compromising the quality of saffron, adulteration poses several health issues as many adulterants are not food grade material and may contain harmful chemicals. Economically, Kashmiri saffron, despite its superior quality and GI tag, for its origin, compete with low quality saffron in both domestic and international markets.

Traditionally, saffron authentication is done using physical methods but it also requires expertise, that most buyers lack and can be easily deceived by sophisticated adulteration techniques (Mehdizadeh et al., 2025). Presently, scientific methods based on spectroscopy, chromatography, molecular approached are

being employed to detect the adulteration in saffron spice (Johnson et al., 2025). Although these methods are specific and accurate, but they are expensive, time consuming and inaccessible to ordinary consumers and are not completely foolproof. For example, in Kashmir, the GI certification of saffron is based on spectrophotometric quantity of three important metabolites i.e. crocin, picrocrocin and safranal as per ISO 3632 standard. However, this method is crude and non-specific, as in spectrophotometer any impurity in this range can absorb. Therefore, for accurate quantification HPLC (High-Performance Liquid Chromatography), GC-MS (Gas Chromatography-Mass Spectrometry) LC-MS (Liquid Chromatography-Mass Spectrometry), should be adopted, as it enables precise separation and detection of target metabolites. Furthermore, once GI certification is granted, there is currently no robust mechanism to verify the authenticity of the product post-certification, particularly if adulteration occurs later in the supply chain.

In the recent years, artificial intelligence/ machine learning based methods have been developed for saffron authentication and adulteration detection. An electronic noise system has been developed based on principal component analysis (PCA), artificial neural network (ANN) and convolutional neural network (CNN) to detect the adulteration of style of saffron, safflower and other flower components (Heidarbeigi et al., 2015; Husaini et al., 2022). Future, research could advance this field by developing AI based systems that are capable of detecting common adulterants. These systems can be installed in the shops allowing customers to perform live testing and receive instant authentication results before purchasing.

Aeroponics and hydroponics and its impact on traditional cultivation: Aeroponics and hydroponics, both refers to soilless method of cultivation. In aeroponics, the roots of plants are suspended in air and misted with nutrient rich solutions, whereas in hydroponics, roots are submerged in nutrient rich solution. The emergence of aeroponics and hydroponics in saffron cultivation has introduced a new dimension to the challenges facing this crop. These methods are marketed as innovative farming techniques with low input and high profits (Kour *et al*., 2022). To our knowledge these techniques are still in research mode and not in technology transfer state.

However, in India, some YouTubers for earning quick bucks are uploading videos claiming that saffron can be grown through aeroponics methods while making significant profits, instigating other people to do the same. As mentioned earlier the corm weighing more than 8gm can flower anywhere as flower primordia are developed during corm development as shown in Fig. 2. Therefore, saffron corms of optimal size can indeed flower even under control conditions. However, in saffron cultivation, corm production is as important as flowering. On this aspect, YouTubers remain silent, despite our attempt to contact them on this issue. These practices require massive quantities of saffron corms, which are primarily, sourced from Kashmir or Kishtwar, the traditional growing regions. This fraud has added further to the scale of crisis; the reasons are outlined below.

Sufficient planting material is no longer available for cultivation in traditional land. We have a sanctioned project from DBT, BIRAC to extend saffron cultivation to non-traditional areas along with in-house developed biofertilizer, but getting corms for the project from traditional area for the research purpose is a huge struggle. The cost of the corms has increased 10 times in last 5 years after these YouTube videos but the cost of spices is more or less same. This further substantiates our claim. Recognizing the threat to indigenous saffron cultivation, Government has implemented restrictions and "bans" on corm exports from JandK (Rising Kashmir, August, 2024). At present corms are being smuggled out of Kashmir and this is reported in local newspaper during the time of sowing. If this continues unchecked, than in next decade saffron cultivation will be history in India.

Fig. 2. Mature saffron corm with visible floral primordia emergence. The floral primordia are pre-formed during corm development, allowing this reproductive structure to flower in any suitable environment.

Lack of technology for saffron cultivation: Saffron cultivation is still based on manual or indigenous techniques. Most of the processes, including sowing, de-weeding, plucking of flowers, stigma separation etc., are done manually that increases the labor cost and make spice expensive (Shokrpour, 2019). Therefore, the technology needs to be developed for the automation of the cultivation, harvesting and post-harvesting process in saffron, to make it attractive particularly to the younger generation. This will further reduce the cost of labor that in turn will reduce the cost of the spice. For example, for flower harvesting, grass cutters or mowers can be used without damaging the leaves, and corms harvesting machines can be used to reduce labor input, as in done in other countries (Saeidirad, 2020; Giupponi *et al*., 2023). Post- harvest processing significantly impacts the saffron quality by impacting the concentration of quality metabolites i.e. crocin, picrocrocin and safranal. Optimal stigma quality requires pre-sunrise collection, immediate separation, and shade drying for 2-3 days (Nehvi and Yasmin, 2021). Current manual processes cause substantial crocin loss. Research shows freeze-drying at-40°C and oven drying at 40°C retains highest quality saffron (Chen *et al*., 2020), but these technologies remain inaccessible to marginal farmers.

Conclusions

To preserve the legacy of saffron cultivation for future generations, a multifaceted approach needs to be adopted immediately. This approach should encompass technological interventions such as geographic diversification to mitigate the impact of climate change, AI governed drone-based irrigation, mechanical cultivation and harvesting of flowers and stigma, integrated pest management, protective land-use policies, robust authentication systems, and strict regulation of unsustainable cultivation practices. This is the critical time that requires immediate government action; otherwise, we risk losing this invaluable heritage crop forever.

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