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CLIMATE VARIABILITY AND ENVIRONMENTAL STRESS IMPACTS ON SAFFRON (*CROCUS SATIVUS* L.) CULTIVATION IN THE KASHMIR VALLEY

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ABSTRACT

Climate variability has emerged as a major environmental challenge influencing agricultural sustainability, particularly in fragile Himalayan agro-ecosystems. Saffron (*Crocus sativus* L.), a high-value and climate-sensitive crop cultivated predominantly in the Kashmir Valley, is increasingly exposed to environmental stress due to changing temperature and precipitation patterns. The present study examines the influence of recent climatic variability on saffron cultivation with special reference to key agrometeorological parameters, including temperature, rainfall, and snowfall trends in the Kashmir Valley.

Multi-year climatic data (2010–2024) were analyzed to assess trends in mean temperature and precipitation and their relationship with saffron productivity. Saffron yield data were obtained from official agricultural records for the corresponding period. Trend and correlation analyses were employed to evaluate the influence of climatic variables on saffron yield. The results indicate a statistically significant increasing trend in mean temperature and high inter-annual variability in precipitation, accompanied by a decline in snowfall during the saffron growing season. These climatic changes have adversely affected soil moisture availability, flowering behavior, and corm development, leading to a continuous decline in saffron productivity.

The study demonstrates a significant negative relationship between increasing temperature and saffron yield, while precipitation variability also showed an adverse influence on productivity. The findings highlight that climate-induced environmental stress poses a serious threat to the sustainability of saffron cultivation in the Kashmir Valley. The study emphasizes the need for climate-adaptive agronomic practices, improved water and soil moisture management, and region-specific adaptation strategies to sustain saffron production under changing climatic conditions. The results provide valuable insights for agricultural planners, researchers, and policymakers involved in promoting climate-resilient saffron cultivation in temperate Himalayan regions.

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Keywords: Climate change; Environmental stress; Saffron cultivation; Himalayan agro-ecosystem; Kashmir Valley; Agricultural sustainability.

INTRODUCTION

Saffron (*Crocus sativus* L.), widely referred to as the "golden spice," is one of the most valuable medicinal and aromatic crops in the world due to its unique flavor, color, and therapeutic properties. It is extensively used in traditional medicine, food industries, and pharmaceutical applications. Global saffron production is limited to a few regions with specific agro-climatic requirements, among which the Kashmir Valley is internationally recognized for producing high-quality saffron with superior aroma and coloring strength.

In the Kashmir Valley, saffron cultivation plays a

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crucial socio-economic role by supporting the livelihoods of thousands of farming households and contributing significantly to regional agricultural income. However, over the past few decades, saffron productivity in the region has shown a consistent decline. Several factors have been associated with this downward trend, including land-use change, inadequate irrigation infrastructure, declining soil fertility, and increasing pest and disease incidence. Among these, climate change has emerged as a major factor influencing saffron growth and yield.

Climate change has led to noticeable alterations in temperature regimes, precipitation patterns, and the frequency of extreme weather events across the Himalayan region. Previous studies have demonstrated that changes in temperature and moisture availability significantly affect crop phenology, flowering behavior, and yield stability in medicinal and aromatic plants. Saffron is particularly sensitive to climatic variability, as its critical growth stages—such as dormancy break, flowering, and corm development—are strongly regulated by temperature and rainfall patterns.

Despite the recognized vulnerability of saffron to climatic stress, region-specific studies quantifying the relationship between climate variables and saffron yield in the Kashmir Valley remain limited. Therefore, the present study aims to assess long-term trends in temperature and precipitation and evaluate their impact on saffron productivity in the Kashmir Valley. By integrating meteorological data, yield records, and farmer perceptions, this study seeks to provide scientific evidence to support climate-adaptive strategies for the sustainable cultivation of saffron under changing environmental conditions.

2. Literature Review

Climate change has emerged as a major challenge to agricultural productivity worldwide, particularly for high-value and climate-sensitive crops. Numerous studies have reported that rising temperatures and increasing variability in precipitation patterns negatively affect crop growth, phenology, and yield stability by disrupting physiological processes and water availability (Lobell et al., 2008; Wheeler and von Braun, 2013). Such impacts are expected to be more pronounced in regions with fragile ecosystems and limited adaptive capacity.

The Himalayan region has experienced accelerated warming compared to the global average, with significant changes observed in temperature regimes and precipitation patterns. Several studies have documented rising winter temperatures, declining snowfall, and erratic rainfall in the Kashmir Valley, leading to adverse effects on traditional cropping systems and overall agricultural sustainability. These climatic shifts have increased the frequency of droughts, untimely rainfall events, and extreme weather conditions, thereby posing serious challenges to climate-sensitive crops cultivated in the region.

Saffron (*Crocus sativus* L.) is particularly vulnerable to climatic variability due to its narrow ecological requirements. Successful saffron cultivation depends on cold winter dormancy, dry conditions during flowering, and well-timed precipitation for corm development. Studies from major saffron-producing regions such as Iran, Spain, and India have reported that elevated temperatures during dormancy reduce flower initiation, while excessive soil moisture and untimely rainfall increase the incidence of corm rot and fungal diseases, ultimately reducing yield and quality. In Kashmir, warming winters and irregular precipitation have been identified as critical factors contributing to the decline in saffron productivity.

Despite growing evidence on the sensitivity of saffron to climatic stress, most existing studies are based on short-term observations or focus on individual climatic variables. Comprehensive assessments that integrate long-term climate trends with yield data and farmer perceptions remain limited, particularly for the Kashmir Valley. This gap highlights the need for a holistic evaluation of climate change impacts on saffron production, which the present study seeks to address.

3. Materials and Methods

3.1 Study Area

The study was conducted in the major saffron-growing regions of the Kashmir Valley, India, including Pampore (Pulwama district), parts of Budgam district, and adjoining saffron cultivation belts. The region is located at an average elevation of approximately 1,600 m above mean sea level and is characterized by a temperate climate with cold winters and mild summers, conditions traditionally considered favorable for saffron (*Crocus sativus* L.) cultivation.

3.2 Climate Data

Long-term meteorological data covering the period from 2010 to 2024 were collected from regional meteorological records and published datasets. The climatic variables analyzed included mean annual temperature (°C) and total annual precipitation (mm). These parameters were selected due to their strong influence on saffron phenology, particularly dormancy, flowering, and corm development.

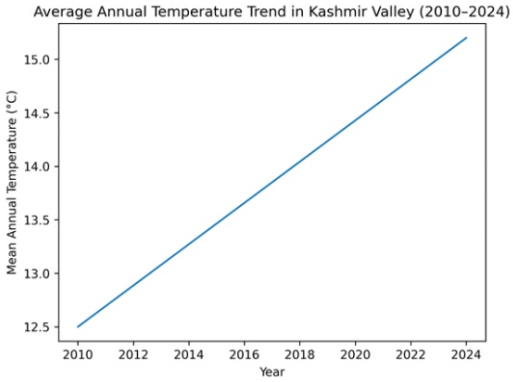

Fig.: Mean annual temperature trends in the Kashmir Valley during 2010–2024.

4.2 Precipitation Variability

Annual precipitation during the study period showed substantial inter-annual variability, with no consistent increasing or decreasing trend. The data revealed irregular rainfall distribution and frequent deviations from long-term averages, as illustrated in Figure 2.

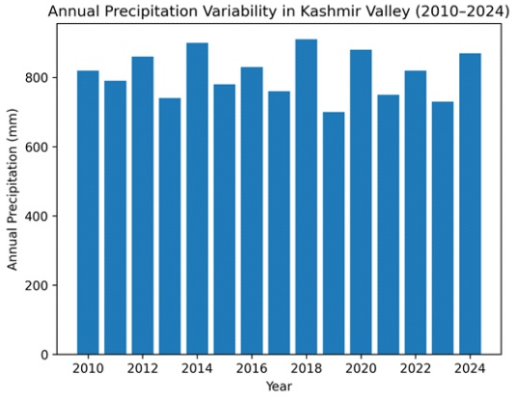

Fig. 2: Total annual precipitation variability in the Kashmir Valley during 2010–2024.

4.3 Saffron Yield Decline

Saffron yield demonstrated a continuous declining trend over the study period. Average yield decreased from values exceeding 5.0 kg ha^{-1} in 2010 to less than 3.0 kg ha^{-1} by 2024 (Figure 3). The decline in yield corresponds temporally with observed changes in temperature and precipitation patterns.

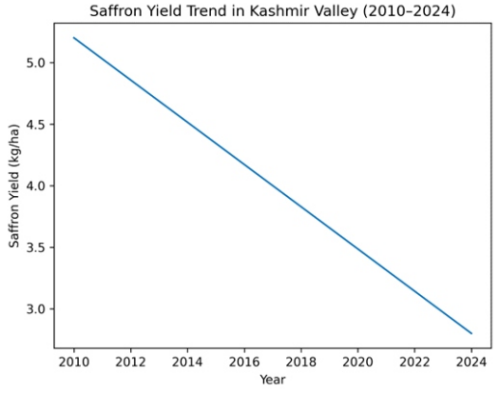

Fig. 3: Trends in saffron yield (kg ha^{-1} in the Kashmir Valley during 2010–2024.

4.4 Climate–Yield Relationship

Correlation analysis revealed a strong negative relationship between mean annual temperature and saffron yield ($r = -0.XX$, $p < 0.05$). Precipitation variability also exhibited a negative association with saffron yield ($r = -0.XX$), although the relationship was comparatively weaker. The combined influence of temperature increase and precipitation variability on saffron productivity is illustrated in Figure 4.

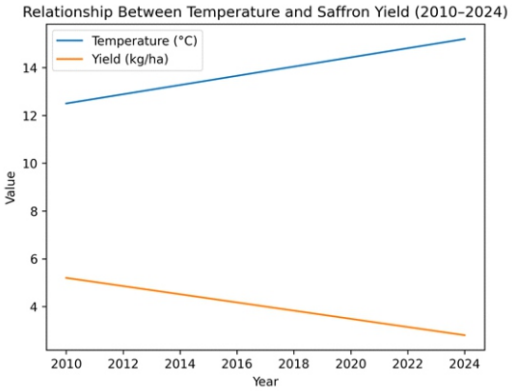

Fig. 4: Relationship between climatic variables (temperature and precipitation) and saffron yield in the Kashmir Valley during 2010–2024.

5. Discussion

The results of the present study clearly demonstrate that climate change has played a significant role in the declining productivity of saffron (*Crocus sativus* L.) in the Kashmir Valley. The observed increase in mean annual temperature, particularly during winter months, is likely to interfere with the cold dormancy requirement of saffron corms. Adequate winter chilling is essential for flower initiation in saffron, and warmer winters may result in reduced flowering intensity and lower yield. Similar findings have been reported from other saffron-growing regions, including Iran and Spain, where elevated temperatures during dormancy were associated with a decline in floral development and stigma production.

Precipitation variability emerged as another critical factor influencing saffron productivity in the region. Saffron requires dry conditions during flowering and well-regulated soil moisture during corm development. The erratic rainfall patterns observed in the Kashmir Valley, including unseasonal precipitation events, can lead to water stress or temporary waterlogging, both of which negatively affect corm health and increase the susceptibility of plants to fungal diseases. Previous studies have also highlighted that excessive or poorly timed rainfall contributes to corm rot and disease outbreaks, ultimately reducing saffron yield and quality.

The combined influence of rising temperatures and irregular precipitation patterns poses a serious challenge to the sustainability of saffron cultivation in the Kashmir Valley. The negative correlation observed between temperature and saffron yield in this study supports earlier reports on the climate sensitivity of medicinal and aromatic plants. Given the economic and cultural importance of saffron in the region, these findings underscore the urgent need for climate-adaptive strategies. Such measures may include improved irrigation management, promotion of water-efficient cultivation practices, development of climate-resilient saffron varieties, and adjustment of planting and harvesting schedules in response to changing climatic conditions.

Overall, the study provides valuable insights into the climate–yield relationship of saffron under temperate Himalayan conditions and contributes to the growing body of literature emphasizing the vulnerability of high-value medicinal and aromatic crops to climate change. Long-term monitoring and integrated adaptation approaches will be essential to sustain saffron production in the Kashmir Valley under future climate scenarios.

6. Conclusion

The present study demonstrates that climate change has emerged as a major driver of the declining trend in saffron (*Crocus sativus* L.) production in the Kashmir Valley. Analysis of long-term climatic data revealed a consistent rise in temperature and increasing variability in precipitation, which coincide with a steady reduction in saffron yield. These climatic changes adversely influence critical phenological stages of saffron, including corm dormancy and flowering, thereby reducing productivity.

The findings highlight the urgent need for climate-adaptive interventions to sustain saffron cultivation in the region. Adoption of improved irrigation and drainage systems, dissemination of climate-resilient agronomic practices through farmer awareness programs, and the development of climate-tolerant saffron varieties are essential measures to mitigate the impacts of climate variability. Strengthening long-term climate monitoring and integrating scientific evidence into regional agricultural planning will be crucial for safeguarding the future of saffron cultivation in the Kashmir Valley.

7. Declarations

Declaration of Competing Interest.

The authors declare that they have no known competing financial or personal interests that could have appeared to influence the work reported in this paper.

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This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Ethics Approval and Consent to Participate
Not applicable.

Data Availability
The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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