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Agro-climatic suitability assessment for saffron (*Crocus sativus* L.) cultivation in the serene hills of Idukki, Kerala, India

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Abstract
Saffron (*Crocus sativus* L.) is a high-value spice traditionally cultivated in temperate regions, with limited expansion beyond its conventional areas. The present study assessed the agro-climatic suitability of non-traditional hilly regions of Idukki district, Kerala, India, for saffron cultivation. Field experiments were conducted during two consecutive seasons (2022-2023 and 2023-2024) at three locations Kanthaloor, Vattavada, and Chinnakanal representing distinct altitudinal and climatic conditions. Site selection was guided by a MaxEnt suitability model, and standard agronomic practices were followed. Morphological traits, flower density, and stigma yield were recorded, along with soil and climatic parameters. Results revealed significant variation among locations, with Kanthaloor-Perumalai exhibiting the highest flower density, fresh flower yield, and dry stigma yield, attributed to favorable temperature, altitude, and soil characteristics. The findings demonstrate that select high-altitude regions of Idukki possess considerable potential for successful saffron cultivation, supporting diversification of high-value crops in Kerala's hill ecosystems.

Keywords: *Saffron*, *Crocus sativus* L., agro-climatic suitability, non-traditional cultivation, altitude, MaxEnt model, stigma yield, Idukki hills, Kerala

Introduction
Crocus sativus L. commonly known as saffron, "red gold," or "kesar," belongs to the Iridaceae family (Giorgi *et al*., 2017) [1]. And ranks among the world's most valuable spices (Winterhalter, P. & Straubinger, 2000) [2]. The prized crimson stigmas are harvested for use as a flavoring, dye, fragrance, and medicinal ingredient. Commercial production is concentrated in Iran, which supplies over 90 % of the global output predominantly from the Khorasan region-while Spain, India, Italy, Afghanistan, Azerbaijan, the United Arab Emirates, Turkey, France, Egypt, Switzerland, Israel, Greece, China, Japan, Iraq, and, more recently, Australia (Tasmania) also contribute smaller quantities. Global dried-saffron production is estimated at roughly 418 Mg per year (Cardone *et al*., 2020) [3]. In India, cultivation is largely confined to Jammu & Kashmir, with emerging trials in Himachal Pradesh and Uttarakhand. Propagation is carried out vegetatively through daughter corms produced by the mother corm. The distinctive color, taste, and aroma of saffron derive from three principal metabolites: crocin (intense color), picrocrocin (bitter flavor), and safranal (characteristic scent). Because of its high market value, saffron is frequently adulterated with substances such as corn stigmas or safflower stamens, which complicates trade and quality control (Babaei *et al*., 2014) [4]. Saffron imported into India originates primarily from Iran, with additional supplies coming from Spain and China. In 2018 India's saffron imports totalled US $18.3 million, ranking the country as the fourth-largest global importer (Srivastava *et al*. 2010) [5]. The saffron crocus produces violet flowers; the spice is derived from the dark-red to reddish-brown stigmas, which are trifid and about 25 mm long, while the accompanying yellowish-brown to orange style measures roughly 10 mm and is cylindrical in shape. The flowers are hysteranthous, blooming in October, and after flowering the original (mother) corm is replaced by newly formed daughter corms. Saffron is noted for its strong, characteristic aroma and a distinct bitter taste. Saffron possesses a range of medicinal attributes, including aphrodisiac, antispasmodic, antimicrobial, antibacterial,

Antifungal, antiseptic and anti-inflammatory effects (Schmidt *et al.*, 2007) [6], it also exhibits anticancer properties, which contributes to its high market value (Siddique *et al.*, 2020) [7]. The dried stigma is employed in food, pharmaceutical, cosmetic, perfumery and textile-dyeing industries, typically in powdered form. Cultivation is labor-intensive, requiring manual labor at every stage, especially the delicate hand-picking of stigmas from each flower (Abdullaev, 2002) [8]. This meticulous harvesting and processing demand skilled workers, making saffron expensive because of high labor costs, low yields, careful handling and its limited geographic distribution. The principal producing countries are Iran, India, Greece, Morocco, Spain, Italy, Turkey, France, Switzerland, Pakistan, China, Japan and Australia. Iran leads global production, supplying roughly 80% of worldwide demand, while India accounts for about 5% of total output, with the majority (≈ 90 %) of India's saffron being grown in the Pulwama and Budgam districts of Jammu & Kashmir (Melnyk *et al*., 2010) [9].

Considering the Foregoing Observations, a Research Initiative Was Launched With the Following Objectives

1. To assess morphological traits, yield attributes, and quality indices of saffron cultivated in three distinct, non-traditional zones of Idukki district, Kerala.
2. To determine the most suitable locations within the district for saffron production, based on the evaluated parameters.

The project aims to generate location-specific information that can guide future expansion of saffron cultivation in the region.

Materials and method

Experimental Site Description and Planting Material

The field trials were carried out over two consecutive growing seasons (2022-2023 and 2023-2024) at three sites in Idukki district, Kerala, each representing a distinct altitudinal zone and climatic regime. The locations-Kanthaloor, Vattavada and Chinakanal were selected using a maximum-entropy (MaxEnt) model to identify areas with the highest suitability for saffron. For each site, the latitude, longitude, elevation, and two-year averages of key meteorological variables (minimum and maximum temperature, relative humidity, and total precipitation) were obtained from the nearest weather stations. Saffron corms, averaging 8-10 g each, were supplied by the Saffron Research Station of Shere-Kashmir University of Agricultural Sciences and Technology (SKUAST) located at Dusso, Pulwama district, Kashmir.

Agronomic Management

At each location, the land was prepared by manual labor. Furrow system 30 to 60 cm in size were prepared. Farmyard manure (25 t/ha) was added before plantation at each site and corms were treated with a fungicide solution to reduce fungal diseases. During October, corms were planted at different geographical locations; the plots were managed, and crop yield data were collected for 2 years. Saffron corms were planted at 12 cm depth with the spacing of 20 cm 10 cm (row to row X plant to plant). Two factorial approaches were considered with 2 years and three planting sites in a factorial randomized block design (RBD). The experiment was executed in three replications, which were repeated for 2 years. The data on the number of flowers/m2, fresh flower yield (kg/ha), fresh stigma yield (kg/ha) and dry stigma yield (kg/ha) were recorded. Growth parameters, viz., the number of leaves and leaf lengths, were recorded from January to February at all locations during its life cycle. During the flowering season, flowers were plucked daily at early hours in the morning before perianth openings to minimize the loss of volatile compounds of economic importance. After plucking, fresh stigmas were removed from the remaining flower immediately and were shade dried at room temperature.

Climate and Soil Characteristics at Experimental Sites

Weather data of three different altitudinal locations is presented inTable1.The highest altitude was observed for location Chinakanal (1800MSL) followed by Vattavada (1659 MSL) and Kanthaloor (1525 MSL). This study identified and validated favorable environmental conditions under the Serene Hills of Idukki. For saffron cultivation through the MAXENT model. The altitude of selected locations varied from1525 to 1800 MSL. In Kerala, only the Kanthaloor represents one of the most significant saffron growing areas situated at an altitude of 1525-1650 MSL under temperate climatic conditions. The mean value of air temperature (maximum and minimum) was lowest in locations Kanthaloor (3-24.5C) and Vattavada (5-21.5). Reports of previous studies explain the significant influence of climatic factors, viz., rainfall, and temperature on soil Organic matter and other nutrients, ultimately affecting saffron cultivation. Relative humidity was observed maximum in location (77.7%) compared with other locations; however, it was lowest in location Chinakanal (74.5%). The soil pH was lowest in location Chinakanal (5.49) followed by Vattavada (5.56) and Kanthaloor (5.62). The soil textures of the selected study sites were sandy loam to clay loam. The percentage of soil organic carbon was significantly higher in location Chinakanal (1.2%) followed by Kanthaloor (1.0%) and Vattavada (0.55). This increase in soil organic matter at high altitudes might be due to the higher input of organic matter and limited decomposition rate by lesser temperature and higher water retention capacity. The available nitrogen was medium in locations Kanthaloor (591.3 kg/ha), Chinakanal (365.8 kg/ha), Vattavada (363.33 kg/ha).

Table 1: Location, Geographical and Climatic Characteristics of the Study Area of Saffron

Location	Geographical coordinates		Altitude (MSL)	Average temperature		Total Rainfall (mm)	Mean Relative humidity (%)
	Latitude	Longitude		Winter	Summer		
Kanthaloor	10°21'35''	77°19'72''	1525	3-24 °C	20-24 °C	650	77.2
Vattavada	10°17'77''	77°25'37''	1659	5-20 °C	12-25 °C	570	80.9
Chinnakanal	10°03'68''	77°17'73''	166-1800	7-25 °C	15-26 °C	685	74.5

Table 2: Variation in Soil Physio Chemical Properties at Different Altitudinal Locations

Location	pH	Organic carbon	Available N (Kg/ha)	Available P (Kg/ha)	Available K (Kg/ha)	Sand (%)	Silt (%)	Clay (%)
Kanthaloor	5.62	0.80	591.30	37.50	268.30	54.10	25.40	20.50
Vattavada	5.56	0.55	363.33	31.10	138.00	40.50	32.50	27.00
Chinnakanal	5.49	0.85	365.80	17.70	117.30	45.00	33.00	22.00

Morphological and Productive Traits

The trial recorded a markedly higher flower density (flowers m^{-2}) and fresh-flower yield (kg ha^{-1}) in the 2021-2022 season than in 2023-2024. Compared with the earlier season, the 2023-2024 crop showed a 7.2 % rise in flower count and an 18.3 % increase in fresh-flower yield. No other measured variables differed significantly between the two years. The improved corm quality observed in the second year likely contributed to the greater flower production. Variations in weather patterns between the years appeared to drive the differences in these traits, indicating a strong environment-by-year effect. When flower numbers were expressed per 25 cents, Kanthaloor-Perumalai produced the highest count (18210), while Chinakanal recorded the lowest (3825). The interaction of year and site revealed that the greatest flower production occurred at Kanthaloor-Perumalai in the second cropping year. Fresh-flower yield was also highest at Kanthaloor-Perumalai (140 kg ha^{-1}), followed by Kanthaloor (126 kg ha^{-1}) and Chinakanal (43 kg ha^{-1}). The greater number of flower blooms has been attributed by the better-quality corms that were generated the next year (Bayat *et al*., 2016, Mykhailenko *et al*., 2020) [10, 11]. Important direct correlation between the examined features and the environment and weather conditions during both years is ensured by variations in weather parameters between different years. Altitude, soil characteristics, temperature, photoperiod, and topographical locations are the critical environmental parameters that affect saffron production (Rahimi *et al*., 2017) [13]. According to Ganaie and Singh (2019) [12], slightly alkaline soil with pH in the range of 6.3 to 8.3 and electrical conductivity in the range of 0.09 to 0.30 ds/m is most suitable for increasing saffron productivity. The soil textures of the selected study sites were sandy loam to clay loam.

Table 3: Different altitudinal locations affect growth, yield and yield attributes of saffron

Location	Number of flowers (25 cents)	Fresh flower (Kg/ha)	Fresh stigma (Kg/ha)	Dry stigma (Kg/ha)	Fresh anther (Kg/ha)	Dry anther (Kg/ha)	Leaf Length
Kanthaloor	17425	126	9.5	1.9	5.10	1.56	24.15
Vattavada	18210	140	13.0	2.6	8.25	3.3	31.10
Chinnakanal	3825	43	6.4	1.2	2.5	0.40	34.15

A B

C D

Fig 1: Field and nursery activities undertaken for saffron (*Crocus sativus* L.) cultivation in the Idukki hills of Kerala, India.
(a) Visit to the Advanced Research Station for Saffron and Seed Spices, SKUAST-Kashmir, for procurement and technical guidance.
(b) Preparation of planting material and filling of pro-trays with growing media for corm sprouting.
(c) Nursery-raised saffron corms showing uniform sprouting under controlled conditions.
(d) Transplanting and field establishment of saffron corms at selected high-altitude locations, demonstrating early emergence and crop establishment under open field conditions.

Conclusion

The trial was concluded that saffron could successfully be cultivated in the hilly regions of Idukki (Kanthaloor-Perumalai). The studies suggest a need to have more research work on multiple sites in the same geographical locations with other factors that influence the quality of saffron production with altitude. Moreover, for each geographical location, there is a need to study the effect of saffron quality, bulb development with meteorological data.

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