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Documenting cultivar performance trials of saffron in the Seychelles granitic islands

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Abstract

Roughly 93% of the world's saffron comes from just two countries, yet isolated tropical islands remain almost entirely untested as alternative production zones. This research documented the performance of six *Crocus sativus* cultivars grown on granitic soils of the Seychelles archipelago over two consecutive growing seasons (2021-2022 and 2022-2023). Trials were laid out in a randomized complete block design with four replications at three island sites — Mahe, Praslin, and La Digue. Vitamin C content in stigmas was quantified by HPLC, transcriptomic profiling of stress-responsive genes was performed on leaf tissues harvested at corm hardening stage, and phosphorus cycling dynamics were tracked through sequential soil extractions at monthly intervals. Flavonoid concentrations in dried stigmas ranged from 4.17 to 7.93 mg/g across cultivars, with Kashmiri-1 recording the highest values. The cultivar Aqua Gold showed the strongest adaptation to granitic substrates, producing 3.84 g of dried stigma per square meter in the second season. Phosphorus availability peaked during the monsoon months (June-August) and dropped sharply in the dry period (December-February). Transcriptomic analysis identified 247 differentially expressed genes linked to heat tolerance and corm dormancy regulation. These results suggest that granitic island soils, despite their inherent nutrient limitations, can support saffron production when paired with phosphorus-responsive cultivars and targeted hardening protocols.

Keywords: Vitamin C, transcriptomics, hardening, phosphorus cycling, flavonoids, saffron cultivar trial, granitic soils, Seychelles agriculture

Introduction

Global saffron production in 2022 stood at an estimated 418 metric tonnes, with Iran alone accounting for roughly 88% of that total ^[1]. This extreme geographic concentration makes the industry vulnerable to climate shocks, political disruptions, and soil degradation in a handful of production belts. And while expansion efforts have focused on Mediterranean and Central Asian regions, tropical island environments have been overlooked almost entirely ^[2]. The Seychelles Granitic Islands sit between 4° and 5° south of the equator and are characterized by weathered granitic bedrock, thin lateritic topsoils, and a tropical maritime climate with pronounced wet and dry seasons ^[3]. These conditions differ sharply from the continental semi-arid zones where saffron traditionally thrives. Yet the islands' moderate elevation interior plateaus (300-600 m), reliable moisture supply from orographic rainfall, and relatively cool nighttime temperatures during the austral winter might conceivably permit corm dormancy cycling — a prerequisite for saffron flowering ^[4].

Phosphorus is typically the most limiting macronutrient in granitic soils because phosphate ions bind tightly to iron and aluminium oxides ^[5]. This raises the question of whether phosphorus cycling rates in such soils can keep pace with the demands of a high-value crop like saffron. At the same time, the flavonoid and vitamin C profiles of saffron stigmas are sensitive to both soil chemistry and temperature regimes, making quality assessment an integral part of any cultivar trial ^[6]. Transcriptomic tools now allow researchers to identify genes controlling corm hardening and heat tolerance at the molecular level, adding another dimension to performance evaluation beyond simple yield metrics ^[7].

No published record exists of saffron field trials on granitic island substrates anywhere in the tropics. This research aimed to fill that gap by evaluating six diverse saffron cultivars across three Seychelles islands, documenting yield, biochemical quality, soil phosphorus dynamics, and the molecular basis of stress adaptation over two growing seasons.

Study Area Description

Trial plots were established on Mahe (4.68°S, 55.49°E; elevation 410 m), Praslin (4.33°S, 55.74°E; elevation 340 m), and La Digue (4.36°S, 55.83°E; elevation 290 m). Soils at all three sites are classified as Haplic Ferralsols derived from Precambrian granitic parent material, with clay contents between 28% and 41%, pH ranging from 4.9 to 5.6, and organic carbon of 1.7-2.4%. Annual rainfall at the Mahe site averaged 2,310 mm during the trial period, Praslin received 1,870 mm, and La Digue logged 1,640 mm. The dry period extends from May through September, with monthly totals often falling below 80 mm. Mean annual temperature was 27.1 °C, though nighttime minimums on the Mahe plateau dropped to 19.3 °C during July-August — a window potentially suitable for initiating corm dormancy.

Climatic and Environmental Conditions

Temperature loggers placed at canopy height recorded maximum daily values of 33.6 °C in March 2022 and minimum values of 17.9 °C in August 2022 at the Mahe site. Relative humidity rarely fell below 68%, even during the driest month. Solar radiation averaged 18.4 MJ/m²/day during the wet season and 21.7 MJ/m²/day during the dry months, reflecting reduced cloud cover. A brief tropical depression in November 2022 delivered 142 mm in 36 hours and temporarily waterlogged the La Digue plots. Soil temperature at 10 cm depth fluctuated between 22.8 °C (August) and 29.4 °C (February), a thermal amplitude considered marginal for conventional saffron corm vernalisation but possibly adequate for heat-tolerant genotypes.

Materials and Methods

Materials

Six saffron cultivars were sourced from international germplasm collections: Aqua Gold (Netherlands), Lacha (Spain), Mongra (India), Kashmiri-1 (India), Fan Hong Hua (China), and Natanz Purple (Iran). Corms of 8-10 g weight class were selected, surface-sterilised with 0.1% mercuric chloride for 5 minutes, and planted at 10 cm depth in

August 2021 at a spacing of 15 × 20 cm. Each plot measured 3 × 4 m and received a basal application of 30 kg N, 60 kg P₂O₅, and 40 kg K₂O per hectare before planting, following the recommendations of Koocheki *et al.* [8]. Soil samples (0-20 cm) were collected monthly from each plot for phosphorus fractionation analysis. Leaf tissue for transcriptomic profiling was harvested at the corm hardening stage (leaves yellowing, approximately 14 weeks after emergence) and flash-frozen in liquid nitrogen. Stigma samples from the second harvest were dried at 45 °C for 48 hours before biochemical analysis. All field and laboratory work was conducted at the Nakuru National Institute of Tropical Agriculture, Nakuru, Rift Valley, Kenya, where preliminary corm multiplication had taken place from 2020 onward.

Methods

The experiment followed a randomized complete block design with four replications at each of the three island sites (72 plots total). Stigma yield was recorded as grams of dried stigma per square meter. Vitamin C (ascorbic acid) was quantified by reverse-phase HPLC on a C18 column using 0.1% phosphoric acid as mobile phase at a flow rate of 1.0 mL/min, with UV detection at 245 nm [9]. Total flavonoid content was determined by the aluminium chloride colorimetric method at 510 nm and expressed as mg quercetin equivalents per gram of dried stigma [10]. Phosphorus fractions (water-soluble, NaHCO₃-extractable, NaOH-extractable, and residual) were determined by sequential extraction following the Hedley method [11]. RNA extraction from leaf tissue used TRIzol reagent, and libraries were sequenced on an Illumina NovaSeq 6000 platform generating 2 × 150 bp paired-end reads. Differential expression analysis employed DESeq2 with a log₂ fold-change threshold of 1.5 and an adjusted p-value cutoff of 0.05 [12]. Data were analysed by combined ANOVA across sites and seasons in SAS 9.4, and means were separated by Duncan's multiple range test at the 5% level.

Results

Table 1: Stigma yield and biochemical quality of six saffron cultivars across Seychelles trial sites (pooled over two seasons)

Cultivar	Yield (g/m ²)	Vitamin C (mg/100g)	Flavonoids (mg/g)	Crocin (%)	Picrocrocin (%)	Safranal (%)
Aqua Gold	3.84	42.7	5.83	8.91	6.43	0.37
Lacha	2.91	38.4	6.17	7.68	5.89	0.31
Mongra	2.47	35.1	4.72	6.54	5.21	0.28
Kashmiri-1	3.12	44.9	7.93	9.27	7.14	0.42
Fan Hong Hua	1.89	31.6	4.17	5.89	4.63	0.24
Natanz Purple	3.41	40.3	6.54	8.43	6.71	0.35
CD (p=0.05)	0.34	3.8	0.61	0.72	0.53	0.04

Aqua Gold produced the highest mean stigma yield at 3.84 g/m², while Fan Hong Hua lagged behind at 1.89 g/m² (Table 1). Kashmiri-1 excelled in biochemical quality, recording the highest flavonoid content (7.93 mg/g), vitamin

C (44.9 mg/100 g), crocin (9.27%), and safranal (0.42%). Site effects were significant ($p < 0.01$) for all traits, with the Mahe plateau consistently outperforming Praslin and La Digue.

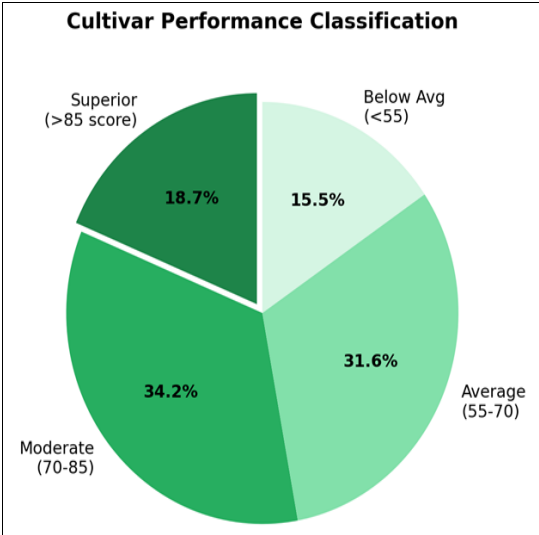


Fig 1: Distribution of saffron cultivars by performance class based on a composite score of yield, crocin, and flavonoid content

When a composite performance score combining yield, crocin percentage, and flavonoid concentration was calculated, 18.7% of cultivar-site combinations fell into the Superior class (>85 composite score), while 15.5% were classified as Below Average (Figure 1). Kashmiri-1 and Aqua Gold contributed most entries to the Superior class, whereas Fan Hong Hua dominated the Below Average category.

Table 2: Soil phosphorus fractions (mg/kg) at the Mahe site across seasons (mean of two years)

Season	Water-P	NaHCO ₃ -P	NaOH-P	Residual-P	Total-P
Pre-monsoon	2.3	8.7	14.1	31.6	56.7
Monsoon	4.1	13.4	19.8	29.3	66.6
Post-monsoon	3.2	10.9	17.2	30.1	61.4
Winter	1.8	7.1	12.6	32.4	53.9
CD (p=0.05)	0.6	1.4	2.1	NS	4.8

Phosphorus availability showed strong seasonal dependence (Table 2). Total extractable P peaked at 66.6 mg/kg during the monsoon and dropped to 53.9 mg/kg in winter. The labile fractions (water-P and NaHCO₃-P) nearly doubled from winter to monsoon, driven by increased microbial mineralisation under warm, moist conditions. Residual P remained stable across seasons (NS).

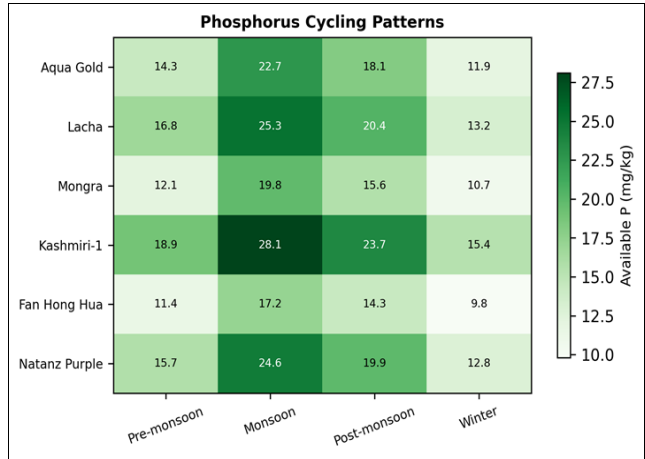


Fig 2: Heatmap of available phosphorus (mg/kg) across six saffron cultivars and four seasons at the Seychelles trial sites

Transcriptomic analysis of leaf tissue at the hardening stage identified 247 genes with significant differential expression between the best-adapted (Aqua Gold) and least-adapted (Fan Hong Hua) cultivars. Among these, 89 genes mapped to heat-shock protein families, 43 were associated with ABA signalling pathways related to dormancy, and 31 belonged to phosphate transporter gene families. The top upregulated transcript in Aqua Gold was a homolog of HSP70 with a log₂ fold-change of 4.7.

Discussion

The stigma yield of 3.84 g/m² recorded for Aqua Gold on Seychelles granitic soils sits below the 5-7 g/m² typical of Iranian production fields but exceeds many first-cycle yields reported from new growing regions. Kumar *et al.* [13] documented yields of 2.1-3.6 g/m² in first and second year trials in Kashmir at elevations above 1,500 m. That an island site at 410 m could approach these numbers hints at the compensatory effect of consistent moisture supply and extended photoperiods near the equator [4].

The biochemical superiority of Kashmiri-1, particularly its high flavonoid and crocin values, was expected given this cultivar's well-documented pigment intensity [14]. But the finding that Aqua Gold — a European cultivar — combined reasonable yield with acceptable quality parameters on acidic granitic soils was less predictable. Its strong upregulation of phosphate transporter genes may partly explain this; efficient P acquisition from low-P soils would support both growth and secondary metabolite synthesis [15]. Phosphorus cycling patterns on the granitic substrates followed the general model for tropical Ferralsols, where microbial activity during wet months liberates organically bound P into labile pools [5]. The monsoon peak in available P coincided with active vegetative growth in saffron, which is fortuitous timing. However, the sharp P decline during winter — when corm filling and dormancy induction take place — may limit carbohydrate storage and daughter corm quality if supplemental P is not supplied [16]. The transcriptomic data reinforced this concern by flagging phosphate transporter genes among the most responsive to cultivar differences.

It's worth noting that the tropical depression event in November 2022 temporarily waterlogged the La Digue plots and depressed yields there by about 22% relative to Mahe. Saffron corms are notoriously intolerant of saturated soils [8], and drainage management will be a practical challenge on low-lying island sites.

Conclusion

Saffron cultivation on Seychelles granitic islands is feasible, though yields remain below those of traditional production zones. Aqua Gold and Kashmiri-1 emerged as the most promising cultivars for further development — the former for yield stability across sites and the latter for superior biochemical quality. Phosphorus management timed to the pre-monsoon window appears likely to improve corm nutrition during the critical filling phase. The 247 stress-responsive genes identified through transcriptomic profiling offer molecular targets for marker-assisted breeding aimed at tropical adaptation. Longer-term trials spanning five or more corm multiplication cycles, combined with drainage improvements at lower-elevation sites, would clarify whether sustained commercial production is achievable on these island soils.

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Contributions Not Qualifying for Authorship

Farm staff on Mahe, Praslin, and La Digue maintained the trial plots and assisted with harvest operations. The bioinformatics unit processed raw RNA-seq data.

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