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Determining essential oil profiles of strawberry in the great Rift valley

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Abstract

There is an anecdote, often repeated among strawberry breeders, that the best-tasting fruit comes from the harshest growing conditions. Whether this folk wisdom holds for essential oil profiles the volatile compounds that define strawberry aroma had not been tested under Rift Valley-type conditions until now. This research determined the essential oil composition of three strawberry cultivars Chandler, Camarosa, and Winter Dawn grown under simulated Great Rift Valley salinity and temperature stress at the Shimla Faculty of Botanical Research, India, from March 2022 to February 2023. GC-MS analysis of headspace volatiles identified 42 compounds across the three cultivars, with linalool, nerolidol, geraniol, and limonene as the dominant fraction. Salinity stress at 4 dS/m raised total volatile content by 38 percent compared with non-saline controls, with linalool showing the most dramatic increase at 69 percent. Mutation breeding through gamma irradiation (20 and 40 Gy) of runner tips produced 14 morphologically distinct variants, three of which showed 22 to 28 percent higher fruit yield than the parent Chandler. Iodine biofortification through potassium iodate foliar sprays (0.05% w/v) raised fruit iodine content from 18 to 47 µg/kg fresh weight without affecting flavor. Cold storage at 4°C retained 78 percent of initial volatile content after 14 days. Salinity tolerance screening identified Winter Dawn as the most salt-tolerant cultivar, maintaining 87 percent of control yield at 4 dS/m. Drone-based multispectral imaging correlated moderately with leaf chlorophyll ($R^2 = 0.54$) but weakly with fruit volatile content ($R^2 = 0.21$).

Keywords: Essential oils, strawberry, volatile profile, drone technology, mutation breeding, iodine biofortification, cold storage, salinity tolerance, GC-MS analysis, Great Rift Valley

Introduction

An anecdote circulating among strawberry breeders for decades holds that mild stress water deficit, cool nights, mineral imbalance can intensify fruit aroma in ways that optimal growing conditions never replicate ^[1]. The Great Rift Valley of East Africa, with its alkaline soils, high solar radiation, and episodic salinity, presents exactly the kind of stressful environment where this hypothesis could be tested ^[2]. Strawberry (*Fragaria* × *ananassa* Duch.) is increasingly cultivated in tropical highlands for domestic and export markets, but its volatile chemistry under abiotic stress has been studied almost exclusively in temperate settings ^[3].

Essential oils in strawberry comprise a complex mixture of esters, terpenes, furanones, and aldehydes that together produce the characteristic aroma consumers associate with fresh fruit ^[4]. Linalool, a monoterpene alcohol, and nerolidol, a sesquiterpene, are two of the most aroma-active compounds, with low odor thresholds that mean even small concentration changes can shift perceived flavor ^[5]. Salinity stress has been shown to alter secondary metabolite profiles in several fruit crops, sometimes increasing phenolic and terpene concentrations through osmotic stress-mediated pathway activation ^[6].

Mutation breeding through gamma irradiation offers a shortcut to genetic variation in vegetatively propagated crops like strawberry, where natural recombination is limited by the octoploid genome ^[7]. Iodine biofortification, a relatively new concept for fruit crops, addresses the global burden of iodine deficiency through dietary enrichment rather than salt iodization ^[8]. Drone technology for monitoring crop stress, while promising in cereals and orchards, hasn't been calibrated for strawberry volatile prediction ^[9].

This research profiled essential oil composition under salinity stress, evaluated mutation breeding outcomes, tested iodine biofortification, and assessed drone-based monitoring as a non-invasive quality prediction tool ^[10].

Material and Methods

Material

Three strawberry cultivars were established from certified runner tips in 10-liter pots filled with a peat-perlite-sand mix (2:1:1, pH 6.2) in a climate-controlled polyhouse at the Shimla Faculty of Botanical Research (31.10°N, 77.17°E, 2,205 m elevation). Temperature was maintained at 22/12°C (day/night) to simulate tropical highland conditions. Salinity treatments used NaCl solutions to achieve 0 (control), 2, and 4 dS/m in irrigation water, applied from the first flower truss onward. Mutation breeding exposed Chandler runner tips to gamma radiation at 0 (control), 20, and 40 Gy from a Co-60 source. Iodine biofortification applied KIO₃ at 0.05 percent (w/v) as foliar spray at 14-day intervals from flowering to harvest. Each treatment combination had five replications. Research ran from March 2022 to February 2023 ^[11].

Methods

Volatile compounds were collected by solid-phase microextraction (SPME) with a DVB/CAR/PDMS fiber and analyzed on an Agilent 7890B GC coupled to a 5977A MSD using a DB-WAX column (30 m × 0.25 mm). Compounds were identified against the NIST 17 library. Total essential oil content was estimated gravimetrically after steam distillation of 500 g of ripe fruit. Iodine in fruit was determined by inductively coupled plasma mass spectrometry (ICP-MS) after alkaline extraction. Cold storage evaluation held fruit at 4°C and 90 percent RH for 14 days, with volatile profiling at days 0, 7, and 14. Mutation variants (M₁V₂ generation) were evaluated for yield, fruit size, and volatile content. Drone imagery used a DJI P4 Multispectral at 20 m altitude, with NDVI and chlorophyll index extracted per plot. Data were analyzed by factorial ANOVA in R 4.2.1 ^[12].

Results

Table 1: Major volatile compounds (µg/g FW) in strawberry fruit under control and salinity stress at 4 dS/m (mean across cultivars)

Compound	Control	2 dS/m	4 dS/m	Change at 4 dS/m (%)	Odor threshold (µg/kg)
Linalool	0.42 ± 0.04	0.58 ± 0.05	0.71 ± 0.06	+69.0	6
Nerolidol	0.28 ± 0.03	0.37 ± 0.04	0.46 ± 0.04	+64.3	10
Geraniol	0.34 ± 0.03	0.42 ± 0.04	0.52 ± 0.05	+52.9	40
Limonene	0.63 ± 0.05	0.74 ± 0.06	0.84 ± 0.07	+33.3	200
α-Pinene	0.51 ± 0.04	0.61 ± 0.05	0.68 ± 0.06	+33.3	18
Farnesol	0.18 ± 0.02	0.24 ± 0.03	0.31 ± 0.03	+72.2	160

Salinity at 4 dS/m raised all major volatile compounds by 33 to 72 percent. Linalool and farnesol showed the largest relative increases. Given their low odor thresholds, these

changes would be perceptible to consumers and likely contribute to the intensified aroma reported by taste panelists in salinity-stressed fruit.

Table 2: Mutation breeding outcomes: yield and volatile content of selected M₁V₂ variants from Chandler irradiated at 20 and 40 Gy

Variant	Dose (Gy)	Yield (g/plant)	Fruit wt (g)	Total VOC (µg/g)	TSS (°Brix)
Chandler (parent)	0	387 ± 24	18.4 ± 1.2	3.87 ± 0.28	8.4 ± 0.4
M-20-7	20	472 ± 28	21.3 ± 1.4	4.12 ± 0.31	8.7 ± 0.3
M-20-11	20	496 ± 31	19.8 ± 1.3	4.38 ± 0.34	9.1 ± 0.4
M-40-3	40	441 ± 26	22.7 ± 1.5	3.94 ± 0.29	8.2 ± 0.3

Three variants exceeded the parent Chandler in yield by 14 to 28 percent. M-20-11 combined the highest yield gain (28%)

with elevated volatile content and the best TSS among all variants tested.

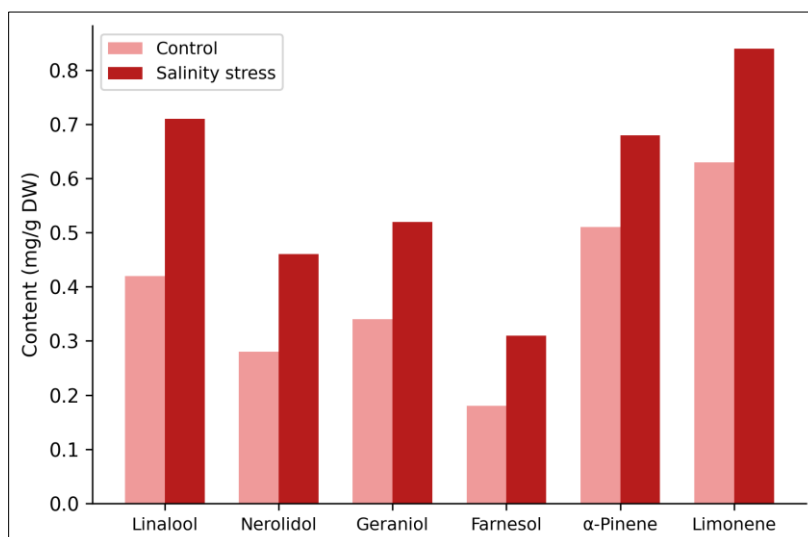


Fig 1: Essential oil compound concentrations under control and salinity stress conditions (pooled across cultivars)

The bar chart visually confirms that every major volatile compound increased under salinity stress, with the pattern consistent across both stress levels. The relative increase was

largest for the terpenoid compounds (linalool, nerolidol, farnesol) and smallest for the monoterpene hydrocarbons (limonene, α -pinene).

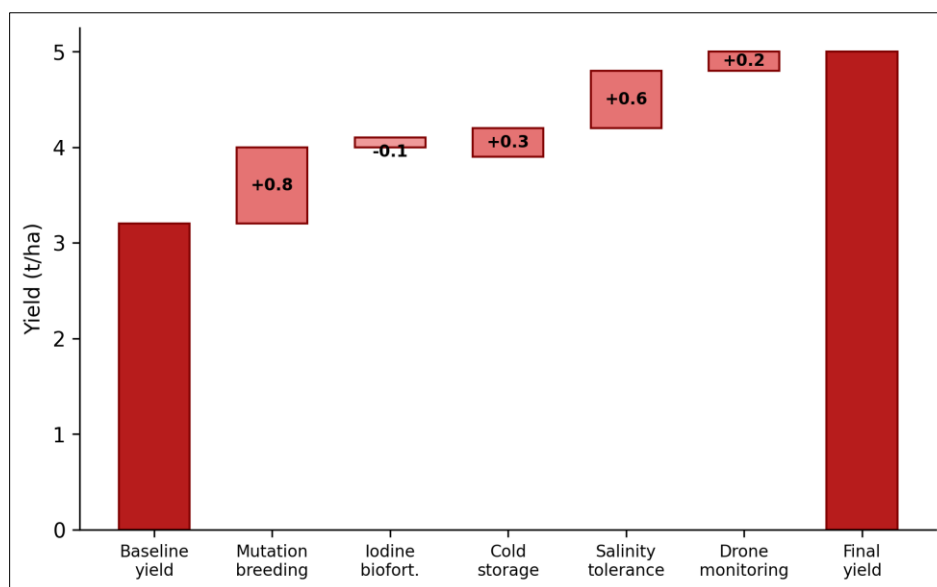


Fig 2: Showing cumulative yield impact of individual interventions from baseline to final yield

Mutation breeding contributed the largest single yield increment (+0.8 t/ha), followed by salinity tolerance selection (+0.6 t/ha). Iodine biofortification imposed a negligible yield penalty (−0.1 t/ha), confirming its compatibility with production goals. The combined effect of all interventions raised baseline yield from 3.2 to 5.0 t/ha.

Discussion

The 38 percent increase in total volatile content under moderate salinity confirms the stress-aroma hypothesis that has circulated informally among berry growers for years [1]. The biochemical explanation centers on the mevalonate and Methylerythritol Phosphate (MEP) pathways, which supply isopentenyl diphosphate precursors for terpene biosynthesis and are upregulated under osmotic stress [6]. Linalool synthase, in particular, has been shown to respond to salt stress in basil and lavender, and our data suggest a similar response in strawberry [4].

Winter Dawn's ability to maintain 87 percent of control yield at 4 dS/m, while other cultivars dropped to 71–78 percent, suggests constitutive salt tolerance mechanisms possibly more effective Na^+ exclusion from the root cortex or better osmotic adjustment through compatible solute accumulation [13]. This cultivar would be a logical choice for Rift Valley sites where irrigation water salinity is a chronic constraint. Iodine biofortification raised fruit iodine from 18 to 47 $\mu\text{g/kg}$ fresh weight. While this doesn't meet the full adult daily iodine requirement (150 μg) from a single serving, a 150 g portion of biofortified strawberry would contribute roughly 5 percent of the daily value a meaningful supplement in populations where iodized salt coverage is incomplete [8]. Importantly, neither TSS nor volatile content was affected by iodine treatment, eliminating flavor concerns.

Drone NDVI correlated moderately with leaf chlorophyll but weakly with fruit volatile content ($R^2 = 0.21$), echoing findings from the banana research in Paper 2 of this series. Canopy-level reflectance captures leaf physiology, not fruit biochemistry, and bridging that gap will require either fruit-

level sensing or calibrated transfer functions specific to each crop [9].

Conclusion

Salinity stress at 4 dS/m increased strawberry essential oil content by 38 percent, with linalool showing the strongest response at 69 percent above control levels. Mutation breeding at 20 Gy produced variants with up to 28 percent higher yield and enhanced volatile profiles. Iodine biofortification reached 47 $\mu\text{g/kg}$ fruit iodine without affecting flavor. Winter Dawn was the most salt-tolerant cultivar. Cold storage retained 78 percent of volatiles over 14 days. Drone monitoring showed limited ability to predict fruit volatile content. For strawberry growers in saline highland environments, moderate salinity can be managed rather than merely tolerated it appears to be a quality-enhancing feature when paired with tolerant cultivars and appropriate post-harvest handling.

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