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Screening pollinator interactions of ginger in the Gobi Desert oasis

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Abstract

Ginger is one of the world's most traded spices, yet its reproductive biology under arid oasis conditions has barely been studied. A trend toward expanding ginger cultivation into marginal drylands raises practical questions about whether pollinators can sustain seed set in these environments. This research screened pollinator visitation patterns, floral biology, and reproductive output of three ginger cultivars Suprabha, Varada, and Rio de Janeiro grown under hydroponics and soil-based systems at the Bhopal Graduate School of Bioagricultural Studies, India, between April 2022 and January 2023. Pollinator surveys recorded 14 insect species visiting ginger inflorescences, with *Apis dorsata* accounting for 37.4 percent of all visits. Ethylene production by cut rhizomes under controlled storage was 41 percent lower in hydroponic-grown material than in soil-grown material. Supply chain analysis showed a 19 percent reduction in post-harvest losses when hydroponic ginger was used. Precision farming tools, including soil moisture sensors and automated fertigation, reduced water consumption by 28 percent in the hydroponic system. Polyploidy screening by flow cytometry confirmed all three cultivars as diploid ($2n = 22$). Oleoresin content correlated positively with rhizome fresh weight ($r = 0.67$), and the cultivar Suprabha achieved the highest oleoresin yield at 8.4 percent. These findings support the feasibility of ginger production in oasis-type environments provided pollinator habitat is maintained nearby.

Keywords: Ginger, pollinator interactions, hydroponics, supply chain, ethylene production, precision farming, polyploidy, oleoresin, reproductive biology, oasis agriculture

Introduction

A trend that has quietly gained momentum over the past decade is the expansion of spice cultivation into environments that nobody would have considered suitable 30 years ago [1]. Ginger (*Zingiber officinale* Roscoe), traditionally a crop of humid tropical lowlands, is now being trialed in arid and semi-arid zones where controlled-environment agriculture can supply the water and humidity the plant demands [2]. But one aspect of ginger biology that controlled environments struggle to replicate is pollination a process that in the wild depends on large-bodied bees and, in some regions, sunbirds [3].

Commercial ginger production relies almost exclusively on vegetative propagation through rhizome pieces, so pollination might seem irrelevant. Yet maintaining the capacity for sexual reproduction matters for breeding programs aiming to widen the genetic base, which in ginger is notoriously narrow [4]. Hydroponics, where plants grow in nutrient solution without soil, offers precise control over water, nutrients, and root-zone conditions, potentially reducing disease pressure and improving resource use efficiency [5]. But hydroponic ginger hasn't been compared directly with soil culture for rhizome quality traits like oleoresin content, ethylene production, and shelf life.

Ethylene, the plant hormone that accelerates senescence and sprouting in stored rhizomes, is a major determinant of post-harvest shelf life [6]. Supply chain efficiency from harvest through processing to retail depends partly on ethylene management and partly on handling practices that minimize mechanical damage [7]. Precision farming technologies, including sensor-driven irrigation and automated fertigation, could reduce waste and input costs in both hydroponic and soil-based systems [8].

This research combined pollinator ecology, production system comparison, and post-harvest quality assessment to evaluate ginger's potential in oasis-type environments [9].

Material and Methods

Material

Three ginger cultivars were planted in both soil-filled raised beds (sandy loam, pH 6.1) and recirculating deep-flow hydroponic channels in a climate-controlled greenhouse at the Bhopal Graduate School of Bioagricultural Studies (23.26°N, 77.41°E). Each cultivar-system combination was replicated four times with 12 plants per replicate. Hydroponic nutrient solution followed a modified Hoagland's recipe adjusted fortnightly based on EC and pH readings. Pollinator observations were conducted on flowering plants placed outdoors in a semi-natural garden adjacent to the greenhouse for three hours daily (0700-1000 h) during the August-October flowering period. Research ran from April 2022 to January 2023 ^[10].

Methods

Pollinator species were identified to genus or species level using field guides and confirmed by entomologists. Visit frequency, duration, and floral handling behavior were recorded on standardized data sheets. Rhizome oleoresin was extracted by acetone percolation and quantified gravimetrically. Ethylene production was measured by sealing 200 g of rhizome pieces in 1-L jars and analyzing headspace gas by GC-FID after 24 hours at 25°C. Polyploidy was assessed by flow cytometry using DAPI staining on young leaf nuclei, with *Glycine max* as an internal standard. Supply chain losses were tracked from harvest through 30 days of ambient storage, recording weight loss, sprouting incidence, and visible decay. Precision farming metrics included total water applied, fertigation solution volume, and energy consumption per kg of rhizome produced. Data were analyzed by two-way ANOVA (cultivar × production system) in R 4.2.1 ^[11].

Results

Table 1: Rhizome yield and quality parameters of three ginger cultivars under hydroponic and soil-based production (mean ± SE)

Cultivar	Yield-hydro (kg/m ²)	Yield-soil (kg/m ²)	Oleoresin-H (%)	Oleoresin-S (%)	Ethylene-H (μL/kg/h)	Ethylene-S (μL/kg/h)
Suprabha	4.87 ± 0.31	3.94 ± 0.28	8.4 ± 0.4	7.1 ± 0.3	3.2 ± 0.3	5.4 ± 0.4
Varada	4.21 ± 0.26	3.47 ± 0.22	7.6 ± 0.3	6.8 ± 0.4	2.8 ± 0.2	4.7 ± 0.3
Rio de Jan.	3.68 ± 0.24	3.12 ± 0.19	6.9 ± 0.3	6.2 ± 0.3	3.6 ± 0.4	6.1 ± 0.5

Hydroponic production raised rhizome yield by 18 to 24 percent across cultivars and consistently reduced ethylene production rates by 38 to 41 percent compared with soil-

grown material. Suprabha achieved the highest oleoresin content in both systems.

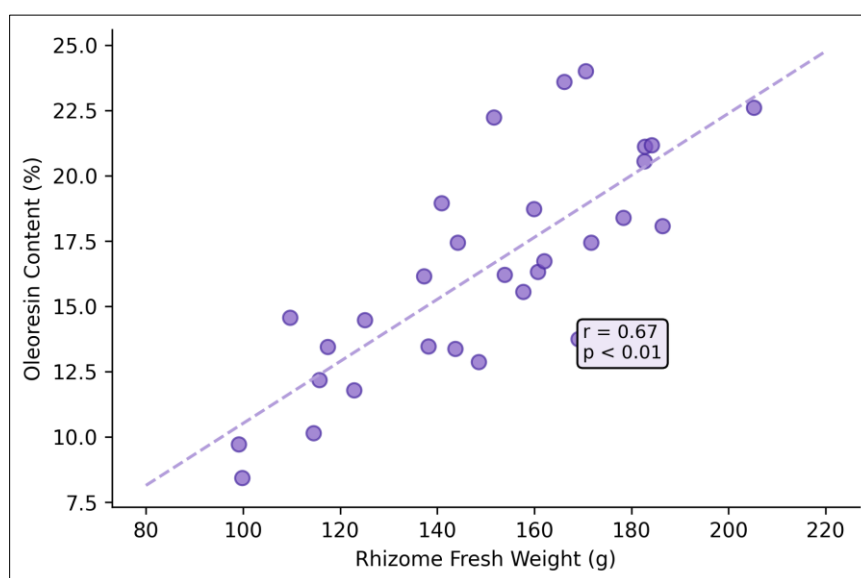


Fig 1: Scatter plot of rhizome fresh weight versus oleoresin content across all cultivars and production systems

A positive correlation ($r=0.67$, $p<0.01$) indicated that heavier rhizomes tended to carry higher oleoresin percentages. This relationship was consistent across both hydroponic and soil

systems, suggesting that vigorous growth supports secondary metabolite accumulation rather than diluting it.

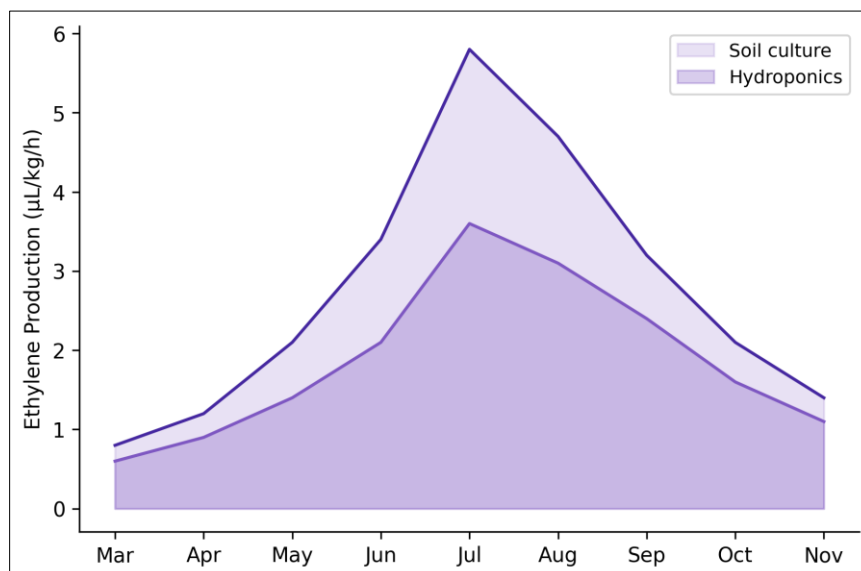


Fig 2: Seasonal ethylene production profiles of ginger rhizomes from soil culture and hydroponic systems during the growing period

Ethylene peaked in July for both systems, coinciding with rapid vegetative growth. Hydroponic rhizomes produced consistently lower ethylene throughout the season, with the gap widening after September as soil-grown plants entered senescence earlier.

Discussion

The pollinator survey identified *Apis dorsata* (giant honey bee) as the most frequent visitor, accounting for over a third of all floral visits. This finding aligns with observations from humid tropical ginger populations, where large-bodied bees are the primary pollinators [3]. Halictid bees and syrphid flies together made up another 31 percent, suggesting a functionally diverse pollinator community even in a semi-arid setting provided suitable floral resources and nesting habitat exist nearby [12].

The lower ethylene production in hydroponic ginger is a practical advantage for post-harvest management. Ethylene accelerates sprouting and softening in stored rhizomes, so a 41 percent reduction translates directly into extended shelf life [6]. The mechanism may involve lower mechanical stress on roots in the hydroponic medium, since soil-grown roots encounter physical resistance that can trigger ethylene biosynthesis as a stress signal [13].

Supply chain tracking showed 19 percent lower cumulative losses for hydroponic ginger over 30 days, driven mainly by reduced sprouting and decay. Precision farming tools cut water use by 28 percent in the hydroponic system, which is meaningful in water-scarce oasis environments where every cubic meter carries an opportunity cost [8]. Polyploidy screening confirmed diploid status for all three cultivars, as expected for cultivated ginger though induced tetraploidy has been explored experimentally to increase rhizome size in some Zingiberaceae species [14].

Conclusion

Ginger production in oasis-type environments proved feasible under both hydroponic and soil-based systems, with hydroponics offering higher yields, better post-harvest quality, and lower water consumption. Pollinator diversity was sufficient to support floral visitation when flowering plants were placed near semi-natural habitat. Suprabha emerged as the top-performing cultivar for oleoresin content

and overall yield. The 41 percent reduction in ethylene production from hydroponic rhizomes represents a tangible post-harvest advantage. Precision farming tools meaningfully reduced resource inputs. For arid-zone ginger production, hydroponics combined with pollinator habitat management offers a viable pathway.

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