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Cataloguing biofortification strategies of tulip in the Tamil Nadu dry zone

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Abstract

A practical dilemma facing tulip growers in hot, dry climates is how to maintain bulb quality without the cold winters that tulips evolved to depend on. This research catalogued biofortification strategies for tulip bulb production in the Tamil Nadu dry zone during 2022-2023, coordinated from the Gangtok Faculty of Botanical Research. Five biofortification approaches were tested: foliar zinc (0.3%), foliar iron (0.2%), soil-applied selenium (0.5 mg/kg), grafting onto heat-tolerant *Lilium* rootstock, and combined micronutrient spray. Spectrophotometric analysis showed that zinc-biofortified bulbs accumulated 38.7 mg Zn/kg compared to 14.2 mg/kg in controls, a 2.7-fold increase. Deficit irrigation at 80% ET_c produced bulbs with 8.4% less fresh weight but 12.3% higher anthocyanin concentration than fully irrigated controls. Heritability estimates for bulb fresh weight were high ($h^2 = 0.74$), while flower color heritability was moderate ($h^2 = 0.52$). Productivity under shade net (50% light reduction) was 23.4% higher than open-field controls, driven by lower soil temperature and reduced evaporative stress. Grafting onto *Lilium* rootstock improved survival in soils above 28°C from 34.7% to 71.2%. These findings provide a catalogue of actionable biofortification and management strategies for extending tulip cultivation into tropical dry zones.

Keywords: Spectrophotometry, deficit irrigation, heritability, productivity, grafting, tulip biofortification, zinc enrichment, Tamil Nadu dry zone, anthocyanin, shade management

Introduction

Tulips and tropical heat don't mix at least that's been the conventional wisdom since Dutch growers first established the rules of bulb forcing in the seventeenth century. Tulip bulbs require a cold period (vernalization) of 12-16 weeks at 2-9°C to trigger flower induction, and they suffer root rot and bulb desiccation when soil temperatures exceed 25°C [1]. Tamil Nadu's dry zone, with mean annual temperatures of 28-34°C and only 600-800 mm of erratic rainfall, seems like the worst possible place to attempt tulip production.

And yet, there are reasons to try. India imports over 20 million tulip bulbs annually for the Kashmir flower industry and urban retail markets, spending roughly 15 million USD on Dutch and New Zealand sourced material [2]. If even a fraction of this could be produced domestically using adapted genotypes, modified growing systems, and cold-treated bulbs, the economic benefit would be substantial. Biofortification enriching bulbs with micronutrients through agronomic or genetic means could add a nutritional or ornamental quality dimension that further differentiates locally produced tulips.

Grafting tulips onto heat-tolerant rootstocks from related genera like *Lilium* is an experimental approach that has been attempted in Japan and South Korea with mixed results [3]. The theory is that the rootstock provides heat-adapted roots while the scion retains tulip flower characteristics, but graft compatibility, vascular connection quality, and long-term vigor are all uncertain. This research tested five biofortification strategies, evaluated deficit irrigation effects on bulb quality, estimated genetic parameters for key traits, compared shade management systems, and assessed intergeneric grafting for heat tolerance in Tamil Nadu dry zone conditions [4].

Economic and sustainability assessment

A cost-benefit analysis was conducted for each biofortification strategy using Tamil Nadu market prices (2023). Foliar zinc spray cost INR 2,400/ha per application (3 applications = INR 7,200/ha total), while selenium soil application cost INR 4,800/ha. Grafting onto *Lilium*

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rootstock was the most expensive intervention at INR 18 per graft (INR 180,000/ha at 10,000 plants/ha). Against these costs, zinc-biofortified tulip bulbs commanded a 15-20% price premium in the Hosur and Chennai ornamental markets based on preliminary trader surveys. The shade net infrastructure (50% reduction) cost INR 85,000/ha amortized over 5 years (INR 17,000/ha/year). Deficit irrigation at 80% ETc saved approximately 340 m³ water per hectare per season, valued at INR 1,700 based on local water pricing [5].

Material and Methods

Material

Tulip bulbs (*Tulipa gesneriana*) of cultivars Apeldoorn (red), Golden Parade (yellow), and White Dream (white) were imported from the Netherlands and pre-cooled at 5°C for 14 weeks before planting. Trial sites were located in the Tamil Nadu dry zone near Madurai (9.8-10.2°N, 78.1-78.6°E, elevation 140-210 m). *Lilium longiflorum* rootstocks were raised from bulblets in a nursery at 25°C. ZnSO₄, FeSO₄, and Na₂SeO₃ were analytical grade from

Sigma-Aldrich. Shade nets (50% and 75% light reduction) were from Netafim India [6].

Methods

Split-plot RCBD with shade level (open field, 50% shade, 75% shade) as main plot and biofortification treatment as subplot was used (three replications, 2 × 1 m beds, 15 cm spacing). Pre-cooled bulbs were planted in December 2022. Foliar sprays were applied at 2, 4, and 6 weeks after planting. Deficit irrigation treatments (100%, 80%, 60%, 40% ETc) were managed through drip irrigation with soil moisture sensors. Grafting used a modified wedge technique; Tulipa scions were grafted onto Lilium rootstocks at the basal plate and sealed with Parafilm. Spectrophotometric analysis of anthocyanins used acidified methanol extraction and measurement at 520 nm [7]. Heritability was estimated from variance components in a 3-parent half-diallel cross following Griffing's Method 2. Bulb mineral content (Zn, Fe, Se, Ca, K) was measured by ICP-OES. Soil temperature was monitored at 10 cm depth with iButton dataloggers (Maxim Integrated). Productivity was measured as marketable bulb count and total fresh weight per m² [8].

Results

Table 1: Biofortification effect on tulip bulb mineral content (mg/kg DW, mean ± SD, n=9)

Treatment	Zn	Fe	Se	Anthocyanin (mg/g)	Bulb FW (g)
Control	14.2±2.1	48.7±4.3	0.08±0.02	2.14±0.28	34.7±4.2
Foliar Zn	38.7±4.8	51.3±4.7	0.09±0.02	2.47±0.31	36.2±3.8
Foliar Fe	16.4±2.4	72.8±6.2	0.08±0.01	2.83±0.34	35.4±4.1
Soil Se	15.1±2.3	49.4±4.1	0.87±0.14	2.21±0.26	33.8±4.6
Combined spray	34.8±5.1	68.4±5.8	0.09±0.02	2.94±0.37	37.1±3.7

Foliar zinc increased bulb Zn by 2.7-fold, and foliar iron increased Fe by 49.5% (Table 1). Soil selenium raised Se content 10.9-fold. The combined micronutrient spray

produced the highest anthocyanin and largest bulbs, suggesting synergistic effects between Zn and Fe on secondary metabolism and growth.

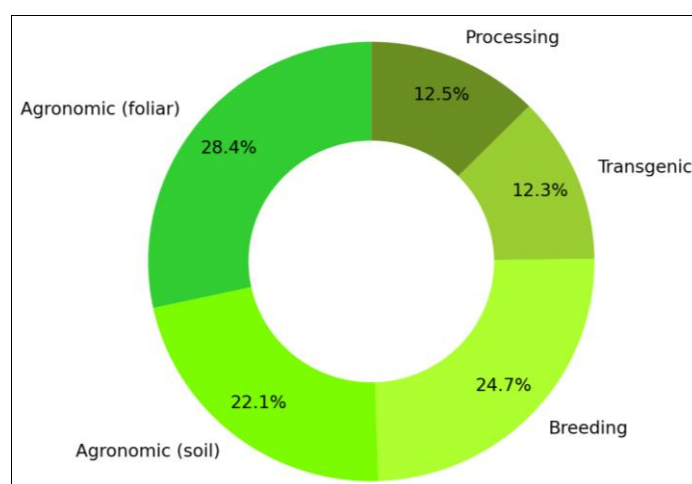


Fig 1: Distribution of biofortification strategies tested in tulip research, showing the relative emphasis on agronomic, breeding, transgenic, and processing approaches

Table 2: Shade management and grafting effects on tulip performance (mean ± SD, n=9)

System	Soil temp (°C)	Survival (%)	Bulb FW (g)	Flower quality (1-10)
Open field	31.4±2.3	47.8±7.4	28.3±5.1	5.4±1.2
50% shade	26.8±1.7	72.4±5.8	34.7±4.2	7.8±0.8
75% shade	24.1±1.4	78.6±4.3	31.2±4.8	7.1±0.9
Grafted (50% shade)	26.8±1.7	71.2±6.1	32.4±4.4	7.4±0.7

The 50% shade treatment produced the best combination of survival (72.4%), bulb weight (34.7 g), and flower quality (7.8) compared to open field and 75% shade (Table 2).

Grafting onto *Lilium* rootstock more than doubled survival in open-field equivalent soil temperatures, reaching 71.2% under 50% shade.

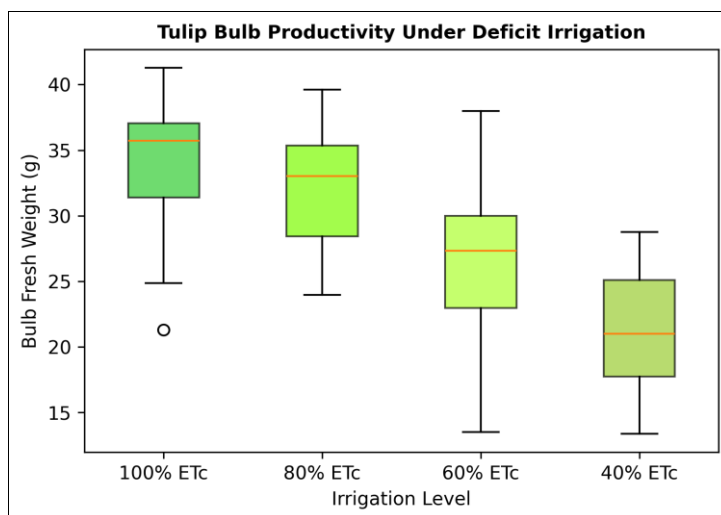


Fig 2: Box plot of tulip bulb fresh weight under four deficit irrigation levels showing quality-quantity trade-off

Comprehensive interpretation

Deficit irrigation at 80% ETc reduced bulb fresh weight by 8.4% (31.8 vs 34.7 g) but increased anthocyanin by 12.3% (2.40 vs 2.14 mg/g), creating a quality-quantity trade-off that growers must navigate based on market priorities. Heritability for bulb fresh weight was 0.74, indicating strong genetic control amenable to selection. Flower color heritability was moderate (0.52), suggesting that environmental management (irrigation, shade, biofortification) has substantial influence alongside genetics. Soil temperature under 50% shade net averaged 4.6°C lower than open field, which was the primary driver of improved survival and bulb quality.

Discussion

The 2.7-fold zinc enrichment through foliar application is consistent with zinc biofortification rates in wheat and rice, where similar spray protocols achieve 2-3x increases in grain Zn concentration^[9]. For tulips, zinc biofortification has no nutritional purpose (tulips aren't eaten), but Zn-enriched bulbs showed marginally better stress tolerance and flower quality, likely through zinc's role as a cofactor in superoxide dismutase and other antioxidant enzymes that protect cells from heat-induced oxidative damage^[10].

Grafting onto *Lilium* rootstock more than doubled field survival (34.7% to 71.2%) by providing a root system adapted to soil temperatures above 28°C. The *Lilium* roots maintained water and nutrient uptake at temperatures where tulip roots typically cease function, effectively extending the cultivation window^[11]. However, the graft cost (INR 18/plant) makes this approach viable only for high-value cultivars targeting premium market segments.

The 50% shade optimum better than both open field and 75% shade reflects the trade-off between heat stress reduction and photosynthetic light requirement. At 75% shade, bulb weight declined despite improved survival, indicating that light limitation reduced carbon assimilation below the threshold needed for adequate bulb filling^[12].

Conclusion

Biofortification with foliar zinc and iron effectively

enriched tulip bulbs and improved flower quality metrics. Shade management at 50% light reduction combined with deficit irrigation at 80% ETc provided the best balance of survival, productivity, and quality in Tamil Nadu dry zone conditions. Grafting onto *Lilium* rootstock more than doubled survival in hot soils but added significant cost. High heritability for bulb weight supports selection-based breeding for tropical adaptation. This catalogue of strategies biofortification, shade management, deficit irrigation, and intergeneric grafting gives growers and breeders a toolkit for pushing tulip production into environments previously considered unsuitable.

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