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AGRONOMIC PERFORMANCE AND DISEASE INCIDENCE OF TRUE SHALLOT SEED (TSS) ACROSS ALTITUDINAL GRADIENTS AND PLANT DENSITY LEVELS

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ABSTRACT

True Shallot Seed (TSS) technology offers a sustainable alternative to conventional bulb-based propagation; however, its agronomic performance and disease incidence across contrasting agroecological conditions remain poorly understood. This study aimed to evaluate the effects of altitude and plant density on growth, yield formation, and disease incidence of F1 hybrid TSS shallots. A factorial randomised complete block design was employed with three altitude levels (<200 m, 400–750 m, and >900 m a.s.l.) and five plant densities (200,000 to 1,000,000 plants ha⁻¹). Results showed that altitude was a primary limiting factor, with lowland conditions producing the highest vegetative growth and fresh bulb yield (14.23 kg plot⁻¹), while highland environments suppressed growth and increased disease incidence to 47.0%. Plant density exerted a dominant effect through yield compensation; although the highest density (1,000,000 plants ha⁻¹) reduced individual bulb size, it generated the greatest fresh (18.67 kg plot⁻¹) and dry bulb yields (15.86 kg plot⁻¹), representing increases of 126% and 121% over the lowest density, respectively. Notably, high-density stands exhibited lower disease incidence (31%) compared to moderate densities (41%), suggesting an inoculum dilution effect. Cultivation of TSS in lowland environments at high plant density is recommended to maximise productivity and enhance disease resilience, supporting sustainable intensification of shallot production in tropical regions.

Keywords: altitude, disease incidence, plant density, True Shallot Seed, yield compensation

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INTRODUCTION

Shallot (*Allium cepa* L. *Aggregatum* Group) is an important horticultural crop in Indonesia, contributing significantly to farmers' income and national food supply. Conventional shallot cultivation predominantly relies on vegetative propagation using seed bulbs. Although widely practised, this method is associated with high production costs—accounting for 60–70% of total input expenditure—and an increased risk of transmitting bulb-borne pathogens such as *Fusarium* spp. and *Erwinia* spp., which may result in yield decline over successive planting cycles (Simamora et al., 2024). The development of True Shallot Seed (TSS) technology offers an alternative propagation system with advantages in reducing planting material costs, improving phytosanitary quality, and facilitating large-scale seed distribution (Khandagale et al., 2020; Nursalma & Maharijaya, 2024). However, compared with bulb-grown shallots, TSS-derived plants generally exhibit greater sensitivity to environmental conditions and cultivation practices, thereby requiring more precise agronomic management (Askari-Khorasgani & Pessarakli, 2020; Pangestuti et al., 2023).

Altitude is a major agroecological factor affecting shallot growth and productivity, primarily through its influence on temperature, radiation intensity, and photoperiod (Shu et al., 2024; Pangestuti et al., 2023). In *Allium* crops, bulb initiation and development are regulated by specific interactions between temperature and day length (Atif et al., 2020; Khokhar, 2023). Previous studies have shown that TSS-grown shallots tend to have a longer vegetative phase and stricter environmental requirements for bulb formation than bulb-propagated plants (Pangestuti et al., 2023; Yeshiwas et al., 2024). While bulb-based shallot cultivation is commonly practised across a wide altitudinal range, information on the agronomic performance of F1 hybrid TSS under contrasting altitude conditions remains limited. This lack of empirical data constrains the formulation of site-specific recommendations for TSS cultivation, particularly in cooler and more humid tropical highland environments.

Plant population density is another critical management factor that determines interplant competition for light, water, and nutrients, thereby influencing canopy structure, assimilate distribution, and final yield (Louarn & Faverjon, 2018; Wang et al., 2025). In many *Allium* crops, increasing plant density reduces individual plant performance but may increase total yield per unit area through yield compensation mechanisms (Tokatlidis, 2017; Yeshiwas et al., 2024). Due to differences in early growth characteristics and establishment patterns, optimal density requirements for TSS are expected to differ from those recommended for bulb-grown shallots, which generally range from 250,000 to 300,000 clumps ha⁻¹ (Shankaraswamy et al., 2024). Nevertheless, systematic evaluations of high-density TSS cultivation under different agroecological conditions are still scarce.

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Altitude and plant density also influence the microclimatic conditions within the crop canopy, which play an important role in the development of major foliar diseases such as purple blotch (*Alternaria porri*) and downy mildew (*Peronospora destructor*). Disease incidence in shallot crops is generally higher in environments characterised by lower temperatures, higher relative humidity, and prolonged leaf wetness, conditions that are frequently encountered at higher elevations (Skjøth et al., 2016; Gheyret et al., 2020). Plant density may further modify disease dynamics by altering canopy aeration and pathogen dispersal. Although dense canopies are often associated with increased disease risk, several studies on *Allium* crops have reported reduced disease severity at high plant populations due to inoculum dilution effects (Tanaka et al., 2023; Rafiuddin et al., 2023). However, such responses have not been adequately examined in TSS-based shallot systems across different altitudinal zones.

Previous studies have largely examined TSS performance under single environmental conditions or fixed planting densities; consequently, empirical evidence concerning altitude $\times$ density interactions on yield formation and disease incidence remains limited. Therefore, an integrated evaluation of altitude and plant density is required to identify adaptive cultivation strategies for TSS under diverse agroecological conditions.

The novelty of this study lies in its integrative assessment of altitude gradients and plant population density to elucidate yield compensation and disease response mechanisms in F1 hybrid TSS. By simultaneously analysing agronomic performance and disease incidence, this research provides a more comprehensive understanding of TSS adaptability across environmentally contrasting production zones in the tropics. This study was conducted based on the hypothesis that altitude predominantly regulates vegetative growth and disease pressure through temperature-related physiological constraints, whereas increased plant density enhances total bulb yield through yield compensation and may reduce disease severity through inoculum dilution effects, particularly under favourable lowland conditions.

Accordingly, the objectives of this study were to: (1) evaluate the effects of altitude on growth, yield components, and disease incidence of TSS shallots; (2) assess plant density–driven yield compensation and its interaction with altitude; and (3) identify optimal altitude and plant density combinations that maximise productivity while minimising disease risk for sustainable TSS-based shallot cultivation.

MATERIALS AND METHODS

Study Period, Locations, and Agroclimatic Conditions

The experiment was conducted during the dry season from June to October 2025 in Karanganyar Regency, Central Java, Indonesia. The total experimental area covered

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approximately 0.25 hectares across three distinct altitudinal zones: lowland (<200 m a.s.l.; 7°34' S, 110°56' E), mid-altitude (400–750 m a.s.l.; 7°36' S, 111°01' E), and highland (>900 m a.s.l.; 7°38' S, 111°04' E).

Prior to planting, composite soil samples (0–20 cm depth) were collected from each site and analysed for physical properties and soil pH. The soil at the lowland site was classified as Entisols with a sandy loam texture and a pH of 6.2. The mid-altitude and highland sites were classified as Inceptisols with clay loam textures and pH values of 5.8 and 5.5, respectively.

Agroclimatic data were monitored throughout the growing season using automatic weather stations installed at each site. The lowland environment was characterised by a higher mean daily air temperature (28.5 ± 1.2 °C), lower relative humidity ($72 \pm 5\%$), and higher solar radiation intensity ($18.5 \text{ MJ m}^{-2} \text{ day}^{-1}$). Conversely, the highland site recorded cooler temperatures (21.5 ± 0.8 °C), higher relative humidity ($85 \pm 4\%$), and lower solar radiation ($14.2 \text{ MJ m}^{-2} \text{ day}^{-1}$). Total rainfall during the experimental period was 120 mm, distributed over 12 rainy days, which necessitated supplemental furrow irrigation to maintain optimal soil moisture for shallot growth.

Methodological Note on Altitude–Site Confounding: It is acknowledged that each altitudinal zone was represented by a single experimental site; therefore, the "altitude effect" reported here reflects the combined influence of elevation and associated site-specific characteristics (soil type, texture, pH, temperature, humidity, and radiation). The observed responses should thus be interpreted as altitude-associated agroecological effects rather than pure altitudinal effects. Future studies employing multiple sites within each altitudinal band are recommended to disentangle these factors.

Experimental Design and Treatments

The study employed a factorial randomised complete block design (RCBD) with two factors: altitude (A1 = lowland, A2 = mid-altitude, A3 = highland) and plant density (P1 to P5). Five plant densities were tested: 200,000 (P1), 250,000 (P2), 400,000 (P3), 500,000 (P4), and 1,000,000 (P5) plants ha⁻¹. Each treatment combination was replicated five times, resulting in a total of 75 experimental units. Each experimental plot measured 1 m² (1 m × 1 m) and was separated by 0.5 m alleyways to minimise inter-plot interference and edge effects.

Plant Materials and Cultivation Practices

The Sanren F1 True Shallot Seed (TSS) hybrid was used as the planting material. Seeds were sown in seedling trays filled with a mixture of sterile soil and compost (1:1 v/v) and maintained in a shaded nursery for 6 to 8 weeks until the seedlings reached the 3-leaf stage. Uniform seedlings were then transplanted into prepared planting beds at the designated spacing corresponding to each density treatment. Land preparation involved

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deep tillage to a depth of 20 cm, followed by the incorporation of 20 t ha⁻¹ of well-decomposed goat manure. Raised beds (20 cm height, 100 cm width) were constructed and covered with silver–black plastic mulch to reduce weed pressure, conserve soil moisture, and reflect light to the lower canopy.

Fertilisation and Crop Management

Inorganic fertilisers were applied at rates equivalent to 120 kg N, 80 kg P₂O₅, and 100 kg K₂O ha⁻¹. Basal fertilisation using NPK Phonska (15–15–15), SP-36, and KCl was applied at 7 days after planting (DAP). Nitrogen fertiliser in the form of urea was top-dressed at 21 and 42 DAP. Irrigation was applied via furrow irrigation every 3 to 5 days, depending on prevailing weather conditions and soil moisture levels. Pest and disease management followed local recommended practices. Preventive fungicide applications containing mancozeb (2 g L⁻¹) and azoxystrobin (1 mL L⁻¹) were applied uniformly across all treatments at 14-day intervals starting from 21 DAP to suppress major foliar diseases and minimise uncontrolled yield loss.

Data Collection

Vegetative Growth Parameters: Plant height (measured from the base of the pseudostem to the tip of the longest leaf) and the number of leaves per plant were recorded from 10 representative plants in each plot at 56 DAP.

Yield Components: Fresh bulb weight per plot was measured at harvest (when 80% of the leaves had fallen over and dried). Bulbs were air-dried under shade until a constant weight was achieved (approximately 10–14 days) prior to recording the dry bulb yield. The number of bulbs per clump was also counted at harvest.

Disease Assessment: Disease incidence was assessed for major foliar diseases, particularly purple blotch (*Alternaria porri*). Observations were conducted at 7-day intervals following the first appearance of symptoms. Disease incidence was calculated as the percentage of infected plants per plot.

Statistical Analysis

All measured variables were subjected to analysis of variance (ANOVA) using a factorial RCBD model:

$$Y_{ijk} = \mu + B_i + A_j + P_k + (A \times P)_{jk} + \varepsilon_{ijk}$$

where Y_{ijk} is the observed response, μ is the overall mean, B_i is the block effect ($i = 1-5$), A_j is the altitude effect ($j = 1-3$), P_k is the plant density effect ($k = 1-5$), $(A \times P)_{jk}$ is the altitude $\times$ density interaction, and ε_{ijk} is the residual error.

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Prior to analysis, assumptions of normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test) were verified. For disease incidence, which represents proportional data (infected plants / total plants) with denominators varying markedly across density treatments (from ~20 to ~100 plants per plot), two complementary approaches were applied: (i) arcsine square-root transformation of percentage values prior to ANOVA, and (ii) a generalised linear mixed model (GLMM) with a binomial error distribution and logit link function, treating block as a random effect. Both approaches yielded consistent treatment rankings; therefore, back-transformed means from the GLMM are reported for disease incidence, while untransformed means are presented for growth and yield variables. When significant differences were detected ($p < 0.05$), treatment means were separated using Tukey's HSD test at the 5% probability level. Statistical analyses were performed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA)

RESULTS AND DISCUSSION

Effect of Altitude on Vegetative Growth of TSS Shallots.

The analysis of variance revealed that altitude exerted a highly significant effect ($p < 0.05$) on the vegetative growth of True Shallot Seed (TSS) shallots. The highest vegetative performance was recorded in the lowland environment, which produced a maximum plant height of 54.12 cm and a leaf number of 31.04 at 56 days after planting (DAP). In contrast, the lowest values were observed in the highland environment (37.91 cm and 12.95 leaves, respectively), representing a substantial reduction of approximately 29.9% in plant height and 58.3% in leaf number compared to the lowland conditions.

Table 1. Effect of altitude on plant height and leaf number of True Shallot Seed (TSS) at 56 DAP.

Altitude	Plant height (cm)	Leaf number
Lowland (<200 m a.s.l.)	54.12 ± 2.13 b	31.04 ± 1.88 c
Mid-altitude (400 to 750 m a.s.l.)	35.68 ± 1.75 a	16.62 ± 1.21 b
Highland (>900 m a.s.l.)	37.91 ± 1.64 a	12.95 ± 1.03 a

CV (%)

8.4

9.1

Means followed by the same letter within a column are not significantly different according to Tukey's HSD test at 5%.

The superior vegetative performance in lowland conditions indicates that higher ambient temperatures promoted faster metabolic activity, accelerated leaf initiation, and enhanced canopy development (Ulas, F et al., 2026). Temperature is a primary driver of

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growth in *Allium* crops, directly influencing the rate of cell division and the duration of the vegetative phase. Conversely, the reduced plant height and leaf number at higher altitudes reflect thermal constraints that limit enzymatic activity and slow leaf emergence (Arnold, P. A et al., 2022). The absence of substantial differences between mid-altitude and highland plant height suggests that once thermal conditions fall below the optimal threshold for TSS growth, further reductions in temperature exert only marginal additional effects. Overall, these results confirm that altitude acts as a key physiological regulator of early TSS growth, primarily through temperature-mediated effects on vegetative development in tropical environments.

Interaction Between Altitude and Plant Density on Bulb Formation

A significant interaction between altitude and plant density ($p < 0.05$) was observed for the number of bulbs per clump. In the lowland environment, the bulb number per clump peaked at moderate plant density (P2), reaching a maximum of 5.44 bulbs per clump, before declining at higher densities (P4 and P5). This represents an optimal assimilate availability for tiller initiation under favourable thermal conditions. However, at mid-altitude and highland sites, the bulb number per clump remained relatively low (ranging from 3. to 3.96) and showed minimal response to changes in plant density.

Table 2. Interaction effect of altitude and plant density on bulb number per clump of True Shallot Seed (TSS)

Altitude	P1	P2	P3	P4	P5	Mean
Lowland	4.80 c	5.44 b	5.00 c	3.80 b	3.88 b	4.58
Mid-altitude	3.84 b	3.20 a	3.96 b	3.16 a	3.32 a	3.50
Highland	3.40 a	3.20 a	3.28 a	3.04 a	3.08 a	3.21

CV = 15.3 %

Mean values followed by the same letter in the same column do not differ significantly according to Tukey's HSD test at the 5% level.

This lack of density response in cooler environments suggests that low temperature acted as the dominant limiting factor, constraining tillering capacity regardless of plant population. Under such conditions, environmental stress overrides the potential benefits of population management (Pangestuti et al., 2023; Tanaka et al., 2023). The significant altitude $\times$ density interaction demonstrates that plant density management is most effective in environments where physiological constraints are minimal, highlighting the importance of site-specific density optimization for bulb formation (Veenstra et al., 2023).

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Effect of Altitude and Plant Density on Fresh and Dry Bulb Yield

Both altitude and plant density significantly influenced fresh bulb yield ($p < 0.05$). Lowland conditions produced the highest fresh bulb yield (14.23 kg plot⁻¹), which was 29.2% higher than the highland environment (11.02 kg plot⁻¹). This yield gradient closely mirrors the vegetative growth pattern, indicating that greater leaf area development under warm conditions translated into higher assimilate production and bulb filling.

Table 3. Effect of altitude and plant density on fresh bulb yield of True Shallot Seed (TSS).

Altitude	Fresh bulb yield (kg plot ⁻¹)
Lowland	14.23 c
Mid-altitude	12.03 b
Highland	11.02 a
Plant density	Fresh bulb yield (kg plot ⁻¹)
P1 (200,000 plants ha ⁻¹)	8.26 a
P2 (250,000 plants ha ⁻¹)	9.88 b
P3 (400,000 plants ha ⁻¹)	12.26 c
P4 (500,000 plants ha ⁻¹)	13.07 c
P5 (1,000,000 plants ha ⁻¹)	18.67 d

CV = 3.1%

Means followed by the same letter are not significantly different according to Tukey's HSD test at 5%.

Plant density exerted a dominant positive effect on fresh bulb yield. As visually demonstrated in **Figure 1**, yield increased progressively with increasing population density, reaching a maximum at P5 (1,000,000 plants ha⁻¹), which produced 18.67 kg plot⁻¹. This represents a massive 126.0% increase in fresh yield compared to the lowest density (P1: 8.26 kg plot⁻¹).

Despite reductions in bulb number per clump at high density (Table 2), the larger number of plants per unit area compensated for lower individual plant productivity. This response provides clear evidence of a yield compensation mechanism in TSS shallots. While individual plants experienced increased competition at high density, collective canopy productivity increased due to more efficient space utilisation and greater total light interception (Yeshiwas et al., 2024).

Similarly, dry bulb yield was significantly influenced by plant density ($p < 0.05$), with a consistent linear increase observed from the lowest to the highest population (**Figure 2**). The highest density (P5) produced the greatest dry bulb yield (15.86 kg plot⁻¹), which was 121.2% higher than the lowest density (P1: 7.17 kg plot⁻¹).

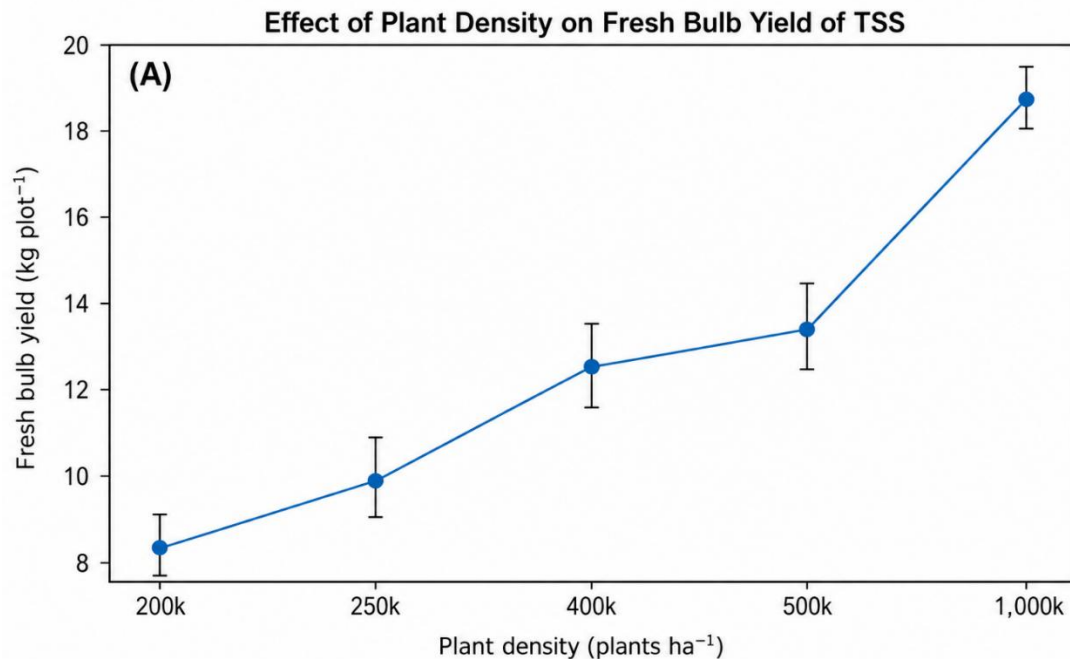


Figure 1. Effect of plant density on fresh bulb yield of True Shallot Seed (TSS). The yield increased progressively with higher plant densities, reaching a maximum at 1,000,000 plants ha⁻¹, demonstrating a strong yield compensation mechanism

Dry bulb yield represents the accumulation of carbohydrates and other storage compounds, which is critical for marketability and storage performance (Naqash et al., 2021). The strong response of dry yield to plant density suggests that high-density planting enhanced overall resource capture and assimilate allocation at the plot level. Notably, altitude did not significantly affect dry bulb yield, indicating that plant population density played a more decisive role than environmental variation in determining final storage yield under the tested conditions (Bastos et al., 2020).

Effect of Altitude and Plant Density on Disease Incidence

Disease incidence of TSS shallots increased significantly with altitude ($p < 0.05$). The highest disease incidence was recorded in the highland environment (47.00% at 60 DAP), which was 36.3% higher than the lowland environment (34.47%).

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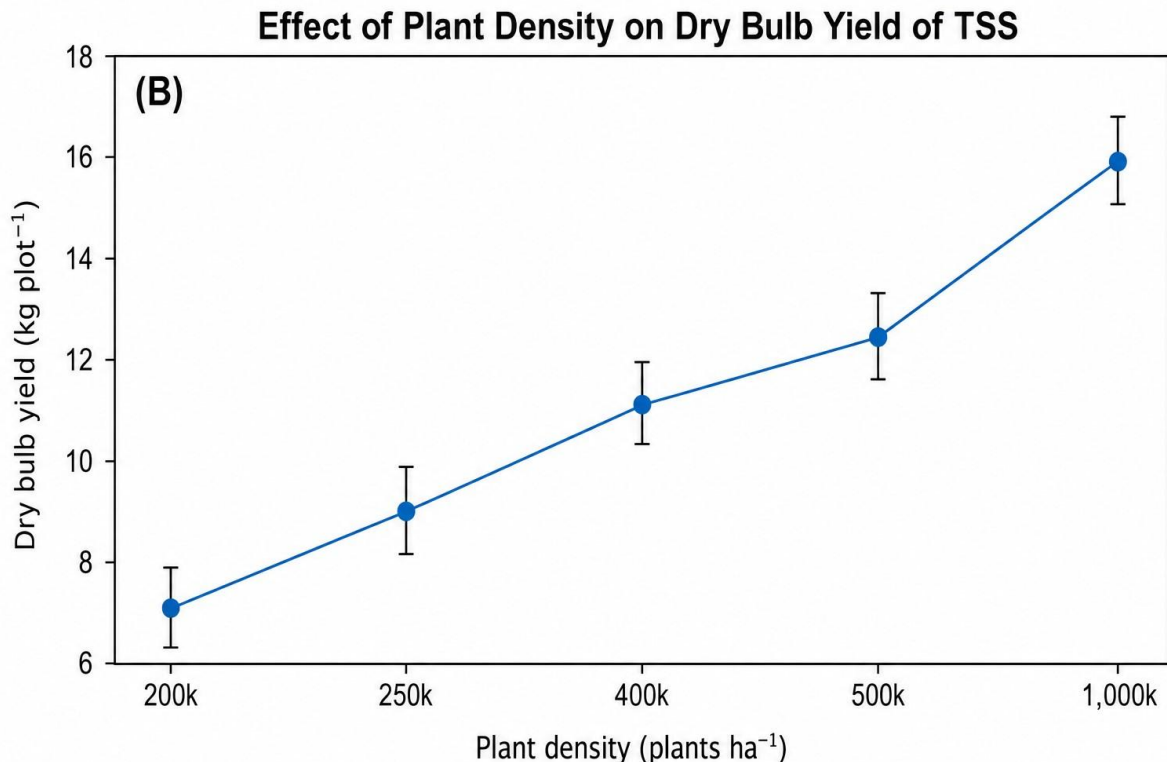


Figure 2. Effect of plant density on dry bulb yield of True Shallot Seed (TSS). A consistent linear increase in dry bulb yield was observed as plant density increased from 200,000 to 1,000,000 plants ha⁻¹, indicating enhanced assimilate allocation to storage organs at higher populations.

Table 4. Effect of plant density on dry bulb yield of True Shallot Seed (TSS).

Plant density	Dry bulb yield (kg plot ⁻¹)
P1 (200,000 plants ha ⁻¹)	7.17 a
P2 (250,000 plants ha ⁻¹)	8.68 b
P3 (400,000 plants ha ⁻¹)	10.98 c
P4 (500,000 plants ha ⁻¹)	12.26 d
P5 (1,000,000 plants ha ⁻¹)	15.86 e

CV = 3.8

Means followed by the same letter are not significantly different according to Tukey's HSD test at 5%.

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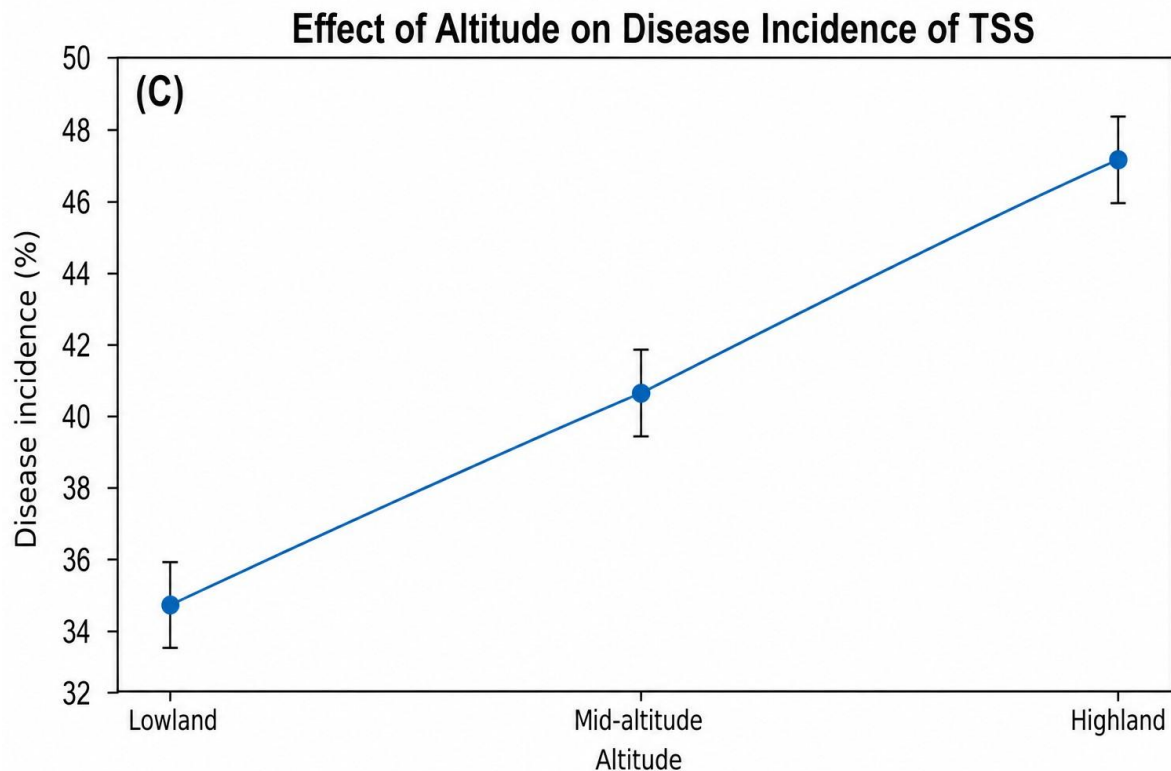


Figure 3. Effect of altitude on disease incidence of True Shallot Seed (TSS) at 60 days after planting (DAP). Disease incidence increased significantly from lowland to highland environments, reflecting the influence of cooler temperatures and higher humidity on pathogen development.

Table 5. Effect of altitude on disease incidence of True Shallot Seed (TSS) at 60 DAP.

Altitude	Disease incidence (%)
Lowland	34.47 a
Mid-altitude	40.11 b
Highland	47.00 c

CV = 3.8%

Means followed by the same letter are not significantly different according to Tukey's HSD test at 5%.

Highland environments are typically characterised by cooler temperatures, higher relative humidity, and longer leaf wetness duration, which favour the infection and sporulation of major foliar pathogens such as *Alternaria porri*. In contrast, warmer and drier lowland conditions reduce the duration of leaf wetness and limit pathogen

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establishment (Gheyret et al., 2020; Skjøth et al., 2016). The results clearly indicate that altitude is a major risk factor for disease development in TSS cultivation in tropical regions.

Plant density significantly affected disease incidence, producing a contrasting pattern to that observed for yield (**Figure 4**). High-density treatments (P4 and P5) consistently showed the lowest disease incidence (31.98% and 31.35%, respectively), whereas moderate density (P2) resulted in the highest disease levels (40.65%). At 60 DAP, disease incidence declined by approximately 22.8% at P5 compared to P2.

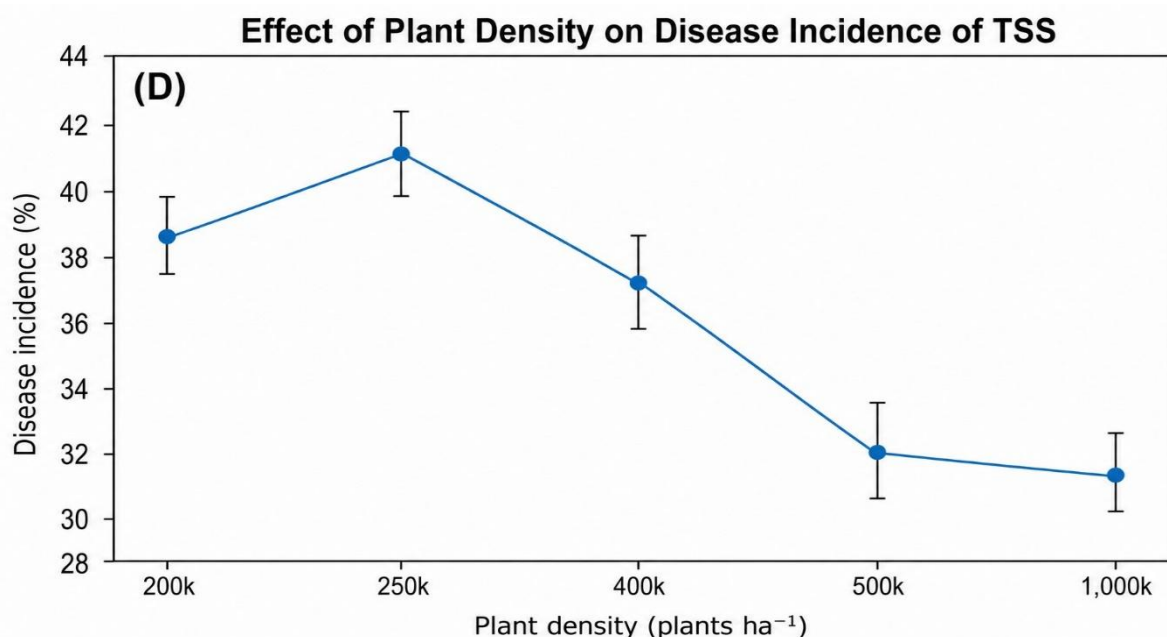


Figure 4. Effect of plant density on disease incidence of True Shallot Seed (TSS) at 60 days after planting (DAP). High-density treatments (500,000 and 1,000,000 plants ha⁻¹) exhibited the lowest disease incidence compared to lower densities, suggesting a passive disease suppression through an inoculum dilution effect

The reduced disease incidence at high density is attributed to an inoculum dilution effect, whereby the same amount of airborne pathogen inoculum is distributed among a larger number of host plants, lowering infection pressure on individual plants (Tanaka et al., 2023). Additionally, increased competition in dense stands may accelerate canopy senescence, thereby shortening the window of host susceptibility. Importantly, high plant density simultaneously enhanced yield (Tables 3 and 4) and reduced disease incidence (Table 6), indicating a dual agronomic advantage. These findings demonstrate that dense TSS planting can improve productivity while passively suppressing disease, particularly under favourable lowland conditions.

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Table 6. Effect of plant density on disease incidence of True Shallot Seed (TSS) at 60 DAP.

Plant density	Disease incidence (%)
P1 (200,000 plants ha ⁻¹)	38.54 c
P2 (250,000 plants ha ⁻¹)	40.65 d
P3 (400,000 plants ha ⁻¹)	37.29 b
P4 (500,000 plants ha ⁻¹)	31.98 a
P5 (1,000,000 plants ha ⁻¹)	31.35 a

CV = 14.3%

Means followed by the same letter are not significantly different according to Tukey's HSD test at 5%.

Integrated Implications for TSS Cultivation

The combined analysis demonstrates that altitude primarily regulates physiological growth potential and disease pressure, whereas plant density governs yield formation through compensation mechanisms. Lowland environments provide optimal conditions for vegetative growth and bulb formation, while high plant density maximises land-use efficiency and reduces disease incidence (Rafiuddin et al., 2023). Overall, the results support the adoption of high-density TSS cultivation in lowland environments as an effective strategy to enhance productivity and disease resilience, contributing to sustainable shallot production systems in the tropics (Nursalma & Maharijaya, 2024).

CONCLUSION

Altitude and plant density jointly regulate the productivity and disease response of True Shallot Seed (TSS) through distinct but complementary mechanisms. Lowland environments maximised fresh bulb yield (14.23 kg plot⁻¹) and minimised disease incidence (34.47%), whereas highland conditions severely constrained growth and increased disease incidence up to 47.0%. High plant density (1,000,000 plants ha⁻¹) successfully overcame individual plant limitations through a strong yield compensation mechanism, achieving the highest fresh and dry bulb yields (18.67 and 15.86 kg plot⁻¹, respectively) while simultaneously suppressing disease incidence to approximately 31% via inoculum dilution. Therefore, the combination of low altitude and high plant density represents the most effective agronomic strategy for maximising productivity and improving disease resilience in TSS-based shallot cultivation.

However, the findings of this study are limited to a single growing season and evaluated only one F1 hybrid variety (*Sanren* F1) under specific agroecological conditions in Central Java, Indonesia.

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Therefore, future research should evaluate the multi-season stability of these findings across diverse tropical agroecological zones and incorporate comprehensive economic analyses to assess the cost-benefit ratio of high-density TSS cultivation. Additionally, further physiological or molecular studies are recommended to elucidate the precise mechanisms underlying yield compensation and pathogen dispersal dynamics in dense TSS canopies.

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REFERENCES

- Arnold, P. A., Wang, S., Catling, A. A., Kruuk, L. E., & Nicotra, A. B. (2022). Patterns of phenotypic plasticity along a thermal gradient differ by trait type in an alpine plant. *Functional Ecology*, 36(9), 2412–2428.
- Askari-Khorasgani, O., & Pessarakli, M. (2020). Evaluation of cultivation methods and sustainable agricultural practices for improving shallot bulb production: a review. *Journal of Plant Nutrition*, 43(1), 148–163.
- Atif, M. J., Ahanger, M. A., Amin, B., Ghani, M. I., Ali, M., & Cheng, Z. (2020). Mechanism of Allium crop bulb enlargement in response to photoperiod: a review. *International Journal of Molecular Sciences*, 21(4), 1325.
- Bastos, L. M., Carciochi, W., Lollato, R. P., Jaenisch, B. R., Rezende, C. R., Schwalbert, R., & Ciampitti, I. A. (2020). Winter wheat yield response to plant density as a function of yield environment and tillering potential: A review and field studies. *Frontiers in plant science*, 11, 54.
- Gheyret, G., Mohammat, A., & Tang, Z. Y. (2020). Elevational patterns of temperature and humidity in the Tianshan Mountains. *Journal of Mountain Science*, 17(2), 397–409.
- Khandagale, K., Krishna, R., Roylawar, P., et al. (2020). Omics approaches in Allium research. *PeerJ*, 8, e9824.
- Khokhar, K. M. (2023). Bulb development in garlic: a review. *Journal of Horticultural Science and Biotechnology*, 98(4), 432–442.
- Louarn, G., & Faverjon, L. (2018). Modelling morphogenesis and population dynamics in forage legumes. *Annals of Botany*, 121(5), 875–896.

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- Naqash, S., Naik, H. R., Dar, B. N., & Makroo, H. A. (2021). Different methods for curing of bulb crops: Principle, mechanism and effects on crop quality and its storage. *Scientia Horticulturae*, 289, 110483.
- Nursalma, L., & Maharijaya, A. (2024). Bulb selection of shallot local varieties from true shallot seeds (TSS) for bulb split components. *Indonesian Journal of Agronomy/Jurnal Agronomi Indonesia*, 52(3).
- Pangestuti, R., Sulistyaningsih, E., Kurniasih, B., et al. (2023). Phenological growth stage of tropical shallot planted from seed in lowlands. *Annals of Applied Biology*, 182(2), 257–266.
- Rafiuddin, Ridwan, I., & Syam, A. (2023). Growth and production of garlic (*Allium sativum* L.) in the lowland on various types of mulch. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1230, No. 1, p. 012221). IOP Publishing.
- Shankaraswamy, J., & Okechukwu-Ezike, N. C. (2024). Selected contents. *Journal of Applied Horticulture*, 26(4), 394–399.
- Shu, F., Wang, D., Sarsaiya, S., et al. (2024). Bulbil initiation: molecular mechanisms and utilization. *Frontiers in Plant Science*, 15, 1343222.
- Simamora, J., Hasanah, Y., & Hanafiah, D. S. (2024). Chlorophyll and flowering of Samosir local shallots under GA and Boron. *International Journal on Advanced Science, Engineering & Information Technology*, 14(1).
- Skjøth, C. A., Damialis, A., Belmonte, J., et al. (2016). *Alternaria* spores across Europe: abundance and climate relationships. *Aerobiologia*, 32(1), 3–22.
- Tanaka, W., Yamauchi, T., & Tsuda, K. (2023). Genetic basis of rice architecture and its modification. *Breeding Science*, 73(1), 3–45.
- Tokatlidis, I. S. (2017). Crop adaptation to density for optimising grain yield. *Euphytica*, 213, 92.
- Ulas, F., Ulas, A., Razzaghi, S., & Yücel, Y. C. (2026). A Comprehensive Review on Vegetable Grafting: a Sustainable Approach to Boost Crop Growth, Development, and Yield Performance at High and Low N Status. *Journal of Crop Health*, 78(2), 57.
- Veenstra, R. L., Messina, C. D., Berning, D., Haag, L. A., Carter, P., Hefley, T. J., ... & Ciampitti, I. A. (2023). Tiller biomass in low plant-density corn enhances transient C sink without direct harvest index detriment. *Field Crops Research*, 292, 108804.
- Wang, J. L., Evers, J. B., Anten, N. P., et al. (2025). Far-red light perception and root development in cereal–legume mixtures. *Plant and Soil*, 509(1), 969–986.
- Yeshiwas, Y., Alemayehu, M., & Adgo, E. (2024). Influence of cultivar and density on onion growth and bulb quality. *Scientific Reports*, 14, 30729.