

## Effects of Transplanting Time, Variety, and Seedling Pruning on Shallot (*Allium cepa* var. *aggregatum*) Growth and Yield

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### Abstract

Transplanting is a critical stage in shallot (*Allium cepa* var. *aggregatum*) cultivation, particularly when using true shallot seed (TSS) seedlings, as it can trigger transplant shock due to sudden environmental changes. This study aimed to assess the effects of transplanting time, varietal selection, and seedling pruning on physiological responses, recovery, and yield performance of shallot plants. A factorial experiment was conducted using a randomized block design at the experimental farm of Hasanuddin University. The experiment involved three factors: two transplanting times (morning and late afternoon), three shallot varieties (Lokananta, Merdeka F1, and Sanren F1), and two pruning levels (unpruned and pruned to 50% leaf length), resulting in 12 treatment combinations with three replications each. Observed parameters included leaf yellowing percentage, number of dead leaves, duration of recovery, plant height, number of bulbs, bulb diameter, and total yield. The data were analyzed using analysis of variance (ANOVA) followed by Duncan's multiple range test at a 5% significance level. The results showed that late afternoon transplanting significantly reduced transplant stress, as indicated by a lower percentage of leaf yellowing (13.31%) and faster recovery time (5.20 days), compared to morning transplanting, which had 23.03% yellowing and a recovery time of 5.81 days. Furthermore, yield was notably higher in the late afternoon treatment (27.37 t ha<sup>-1</sup>) than in the morning (16.90 t ha<sup>-1</sup>). Seedling pruning also contributed to improved performance, with pruned plants producing 34% more yield than unpruned ones. Among the varieties tested, Sanren F1 exhibited the best adaptability and resilience to transplant stress. Significant interactions were observed between transplanting time and variety, as well as between transplanting time and pruning. These findings suggest that integrating late afternoon transplanting, pruning, and selecting resilient varieties such as Sanren F1 can improve TSS-based shallot cultivation, enhancing both survival and productivity.

**Keywords:** True seed, Bulb, leaf yellowing, Stress, Transplanting shock

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## 1. Introduction

Shallot (*Allium cepa* var. *aggregatum*) is an important and high-priority agricultural commodity, especially in Indonesia, where it significantly contributes to both the economy and national food security. Taxonomically, it is classified under the division Magnoliophyta, class Liliopsida, order Liliales, and family Liliaceae (Nasab et al., 2020). Its high demand is driven by its widespread culinary use and recognized health benefits, including antioxidant properties, cardiovascular protection, anti-inflammatory effects, and antimicrobial activity (Irianto et al., 2017; Sun et al., 2019). However, as population growth and the food industry continue to expand, the pressure to enhance shallot productivity has intensified. Increasing shallot production requires innovations in cultivation techniques, including optimizing planting materials, transplanting methods, and agronomic management. One promising approach is the use of true shallot seeds (TSS), which offers several advantages over traditional bulb propagation, like garlic, which is also commonly propagated using cloves or bulbs (Gülçebi and Akıncı, 2023), such as better seed viability, reduced dormancy, extended storage life, and lower seed input costs (Sopha et al., 2015, 2017). Despite these benefits, challenges remain in ensuring optimal seedling survival and growth, particularly during the critical transplanting phase.

The transplanting phase is a crucial period in shallot cultivation, as it exposes young seedlings to environmental stressors that can impact establishment and productivity. Transplanting shock, which results from root disturbance, water loss, and temperature fluctuations, can delay growth and reduce survival rates (Asih et al., 2022). Studies have shown that the success of transplanted seedlings depends on several factors, including the timing of transplanting, variety selection, and post-transplant management (Khan et al., 2020). Transplanting time plays a key role in minimizing stress, with morning transplanting exposing plants to rising temperatures and increased evaporation, while late afternoon transplanting allows seedlings to acclimate under cooler conditions (Velasco et al., 2020). Furthermore, variety selection is crucial, as different shallot genotypes exhibit varying levels of resilience to transplanting stress, light availability, and temperature fluctuations (Ohtaka et al., 2020; Hemon et al., 2022). Understanding these variety-specific responses is essential for optimizing shallot production under different environmental conditions.

In addition to transplanting time and variety, pruning has been identified as a beneficial agronomic practice that can enhance shallot growth and productivity. Pruning, which involves the removal of plant parts such as leaves or shoots, influences nutrient distribution, reduces competition for resources, and improves hormonal balance (Thakur et al., 2018a). Several studies have reported that pruning promotes seedling vigor, root development, and bulb formation in shallots and related crops (Sumerta et al., 2019; Kusumawati et al., 2021). Faried et al. (2024) demonstrated that pruning frequency significantly affects shallot seedling growth by enhancing leaf number, pseudostem diameter, root length, and biomass accumulation. Similarly, pruning has been linked to increased bulb weight and yield in onions, chili peppers, and other horticultural crops (Thakur et al., 2018b). However, the interaction between pruning and transplanting time remains unclear, particularly in the context of TSS-derived shallot seedlings.

Despite the existing knowledge on transplanting techniques, variety selection, and pruning effects, little research has been conducted to evaluate the combined influence of these factors on shallot seedling growth and productivity. Given the increasing importance of TSS technology and the need for efficient agronomic practices, further studies are required to determine the optimal transplanting strategies that maximize seedling establishment and yield potential. Understanding how transplanting time, variety, and pruning interact will provide valuable insights for improving shallot cultivation practices. Therefore, this study aims to investigate the effects of transplanting time, shallot variety, and pruning on seedling growth and productivity. Specifically, this research seeks to evaluate whether these factors interact to influence key agronomic traits, including seedling survival, growth rate, and bulb development. The findings of this study are expected to contribute to the development of more efficient shallot production systems, supporting sustainable agricultural practices and food security.

## 2. Materials and Methods

### 2.1. Study location

The investigation was carried out between June and August 2024 at the Experimental Farm of Hasanuddin University, situated at geographical coordinates 5° 7'40.07"S and 119° 28'48.94"E, with an elevation of 9 meters above

the mean sea level. The net house, encompassing an area of 120 square meters, is characterized by a flat roof oriented towards the west-south. The structure is comprised of an aluminum frame that incorporates an anti-aphid screen (50 mesh) affixed to the upper and lateral sides. The shallot varieties (*A. cepa* var. *aggregatum*) employed in this research were Lokananta, Sanren F1, and Merdeka F1. During the experimental period, the average temperature was  $32 \pm 0.81$  °C, with an average relative humidity of  $62 \pm 4.32\%$ .

## 2.2. Experimental design and cultivation

This investigation encompassed three distinct treatment factors (Figure 1). The primary factor related to the temporal aspect of transplanting, which was classified into morning and late afternoon. The subsequent factor involved variety, which included Lokananta, Merdeka F1, and Sanren F1. The tertiary factor was pruning, which comprised both unpruned and pruned seedlings. The culmination of these three factors produced 12 distinct treatment combinations, each replicated thrice, thus resulting in a total of 36 experimental units.

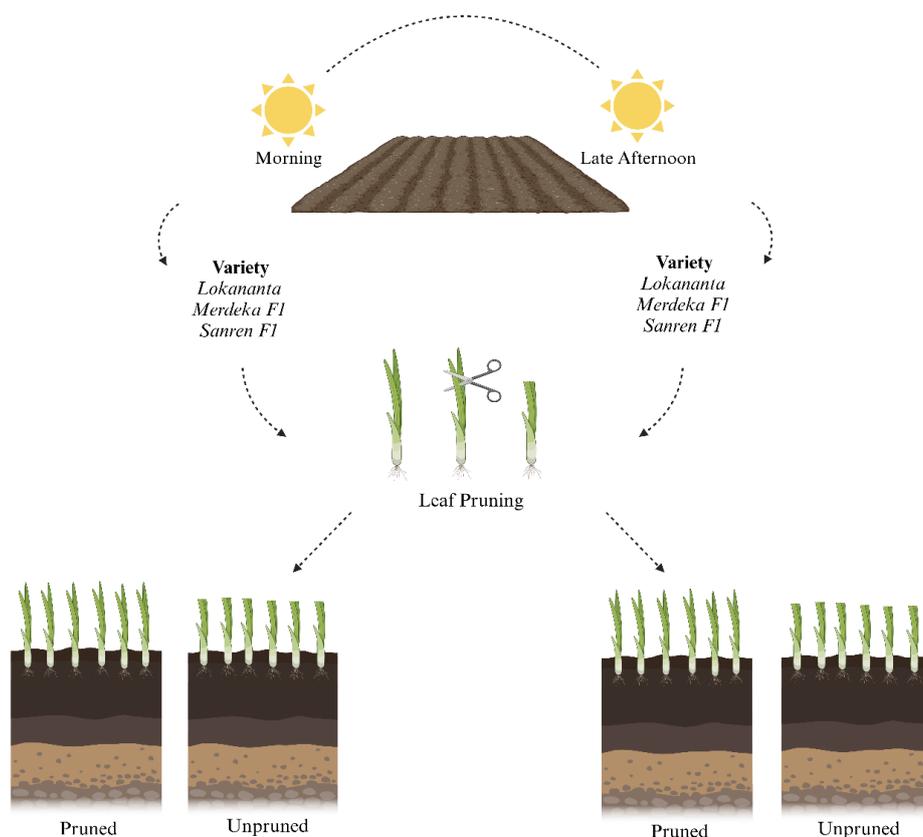


Figure 1. Illustration of the research treatments

The three shallot varieties were cultivated in seedling tanks filled with soil (identical to that utilized in the field) and chicken manure in an equal 1:1 ratio. The soil characteristics employed in this study include pH (6.58), C (3.52%), N (0.28%), C/N (13), P<sub>2</sub>O<sub>5</sub> (12.28 ppm), K (0.28 cmol kg<sup>-1</sup>), and CEC (19.65 cmol kg<sup>-1</sup>). Seeds were sown at a density of 0.5 g per row. The seedlings received maintenance for a duration of 45 days until they attained readiness for transplantation. The seedlings with four true leaves were selected for transplanting. The planting treatment was executed in the morning at 7:00 AM and in the late afternoon at 4:00 PM. The pruned seedlings experienced a 50% reduction in leaf length through the application of scissors. Following the pruning process, the seedlings were transferred into raised beds with an elevation of 30 cm, which were subsequently covered with silver-coated plastic mulch (0.5 microns in thickness). The planting arrangement was established at a spacing of 10 × 15 cm. The plants were then nurtured utilizing a sprayer for irrigation both in the morning and in the evening.

## 2.3. Data collection and analysis

The parameters that were systematically observed encompassed the percentage of yellowing leaves (%), the

percentage of dead leaves (%), and recovery day (days). The methods used to measure and determine these parameters are described in *Table 1* below.

**Table 1. Observed parameters and their measurement methods**

Parameter	Unit	Method	Period
Percentage of yellowing leaves	%	Counting the number of yellowing leaves relative to the total number of leaves per seedling; percentage calculated daily.	Daily for 4 days after treatment.
Percentage of dead leaves	%	Counting the number of dead leaves relative to the total number of leaves per seedling; percentage calculated daily.	Daily for 4 days after treatment.
Recovery day	day	Recording the day on which seedlings showed initial signs of recovery (i.e., reduced stress symptoms, new growth, or restoration of leaf color).	Observed from day 1 until seedlings showed recovery signs.

The duration of recovery was ascertained when the pre-existing young leaves prior to the transplantation exhibited an increase in length or when new young leaves emerged with a growth measurement exceeding 1 cm. Observations were conducted over a span of 14 days during the afternoon hours. The observed parameters after harvesting phase (which is delineated by the chlorosis and desiccation of foliar structures, along with the protrusion of bulbs above the soil surface) included plant height, number of leaves, number of bulbs, bulb diameter, and yield.

To see the significance of three factors observed, the analysis of variance was conducted, then to detect different between time transplanting, variety, and pruning individually or interaction among them, the Duncan test was used, with a p-value <0.05. The entire data analysis and visualization process was carried out using RStudio version 4.4 (R Core Team, 2024).

### 3. Results

#### 3.1. Analysis of variance

The analysis of variance (ANOVA) table presents the effects of transplanting time (TT), variety (V), and pruning (P), along with their interactions, on multiple phytometric parameters (*Table 2*). Significant effects ( $p < 0.05$ ) are observed for TT on LY1 ( $p = 0.03$ ), RD ( $p = 0.04$ ), NOB ( $p < 0.01$ ), and Y ( $p = 0.03$ ), suggesting that transplanting time plays a crucial role in these variables, particularly in influencing recovery, bulb formation, and overall yield. Similarly, variety (V) has a strong effect on most parameters, with significant differences observed for LY1 ( $p = 0.04$ ), LY2 ( $p = 0.04$ ), LY3 ( $p < 0.01$ ), LY4 ( $p = 0.01$ ), DL ( $p < 0.01$ ), RD ( $p < 0.01$ ), and PH ( $p = 0.59$ ), highlighting the genetic variation in plant responses to environmental and agronomic factors. Notably, the interaction between TT and V exhibits significant effects on LY2 ( $p < 0.01$ ), LY3 ( $p < 0.01$ ), LY4 ( $p = 0.04$ ), DL ( $p < 0.01$ ), and RD ( $p < 0.01$ ), indicating that the impact of transplanting time varies across different varieties.

**Table 2. Analysis of variance among traits**

Treatment	P-Value*									
	LY1	LY2	LY3	LY4	DL	RD	PH	NOB	BD	Y
TT	<b>0.03</b>	0.33	0.23	0.17	0.57	<b>0.04</b>	0.18	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>0.03</b>
V	<b>0.04</b>	<b>0.04</b>	<b>&lt;0.01</b>	<b>0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	0.59	<b>&lt;0.01</b>	0.86	0.68
TT × V	0.19	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>0.04</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	0.46	0.21	0.64	0.80
P	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	<b>0.03</b>	<b>&lt;0.01</b>	<b>&lt;0.01</b>	0.21	<b>&lt;0.01</b>	<b>&lt;0.01</b>
TT × P	<b>0.01</b>	0.29	0.20	0.34	0.54	0.88	0.63	0.85	0.27	0.14
V × P	0.09	0.33	0.64	0.76	0.65	0.93	0.07	0.40	0.24	0.17
TT × V × P	0.09	0.43	0.12	0.76	0.65	0.35	0.85	0.58	0.97	0.51

Note: TT (transplanting time), V (variety), P (pruning), LY1 (leaf yellowing day-1), LY2 (leaf yellowing day-2), LY3 (leaf yellowing day-3), LY4 (leaf yellowing day-4), DL (dead leaves), RD (recovery day), PH (plant height), NOB (number of bulb), BD (bulb diameter), and Y (yield).

Pruning (P) shows a highly significant influence on all leaf yellowing stages ( $p < 0.01$ ), DL ( $p = 0.03$ ), RD ( $p < 0.01$ ), PH ( $p < 0.01$ ), and Y ( $p < 0.01$ ), demonstrating its potential role in improving plant health and productivity. However, the interaction effects between TT and P are largely non-significant, except for LY1 ( $p = 0.01$ ), suggesting

that the influence of pruning is largely independent of transplanting time. The combined interaction of TT, V, and P does not exhibit any strong effects, as most p-values exceed 0.05, implying that while individual factors are important, their three-way interaction does not contribute significantly to variation in phytometric traits.

### 3.2. Effect of transplanting time

The data show that morning transplanting resulted in significantly higher leaf yellowing on the first day (LY1= 23.03%) compared to late afternoon transplanting (13.31%), suggesting that seedlings experience greater transplant shock when exposed to the high temperatures and intense sunlight of the morning (Table 3). Recovery duration (RD) was also affected, with late afternoon transplanting leading to a shorter recovery period (5.20 days) than morning transplanting (5.81 days), likely due to lower evapotranspiration and reduced physiological stress. However, the number of bulbs per plant (NOB) did not show a significant difference between treatments, with both morning and late afternoon transplanting producing comparable values (2.44 and 2.94, respectively). Interestingly, bulb diameter (BD) and total yield (Y) were significantly higher in the late afternoon transplanting treatment. Plants transplanted in the late afternoon developed bulbs with an average diameter of 31.50 mm, while those transplanted in the morning had a smaller diameter of 21.16 mm. Similarly, yield was markedly greater in the late afternoon transplanting group (27.37 t ha<sup>-1</sup>) compared to morning transplanting (16.90 t ha<sup>-1</sup>).

**Table 3. Effect of transplanting time on several traits**

Transplanting Time	LY1 (%)	RD (d)	NOB	BD (mm)	Y (t ha <sup>-1</sup> )
Morning	23.03±0.46a	5.81±0.15a	2.44±0.16b	21.16±3.23b	16.90±1.31b
Late Afternoon	13.31±2.21b	5.20±0.07b	2.94±0.16a	31.50±3.71a	27.37±4.07a

Note: LY1 (leaf yellowing day-1), RD (recovery day), NOB (number of bulbs), BD (bulb diameter), and Y (yield). Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at p < 0.05.

### 3.3. Effect of variety

The results indicate that Lokananta exhibited significantly higher levels of leaf yellowing from day 1 to day 4 (LY1–LY4), with values of 21.70%, 31.94%, 44.61%, and 49.21%, respectively (Table 4). These findings suggest that Lokananta may be more susceptible to early transplant stress but also shows a consistent yellowing pattern indicative of uniform senescence. In contrast, Sanren F1 showed the lowest values across LY1–LY3, particularly on day 1 (LY1= 15.36%), indicating better early leaf retention. However, by day 4 (LY4), differences between varieties narrowed, with all showing increased yellowing. Dead leaves (DL) accumulation was significantly influenced by variety. Lokananta recorded the highest DL (1.81), followed by Merdeka F1 (1.59), while Sanren F1 had the lowest (1.48). Recovery day (RD) followed a similar pattern, where Lokananta recovered more slowly (5.95 days) compared to Merdeka F1 (5.56 days) and Sanren F1 (5.00 days), suggesting that Sanren F1 had better resilience to transplanting stress. Interestingly, the number of bulbs per plant (NOB) was significantly higher in Merdeka F1 (3.41) and Sanren F1 (3.08) compared to Lokananta (1.58).

**Table 4. Effect of variety on several traits**

Transplanting Time	LY1 (%)	LY2 (%)	LY3 (%)	LY4 (%)	DL	RD	NOB
Lokananta	21.70±1.70a	31.94±1.00a	44.61±2.73a	49.21±3.28a	1.81±0.02a	5.95±0.14a	1.58±0.09b
Merdeka F1	17.44±1.39ab	27.08±1.39b	38.28±0.45b	39.32±0.17b	1.59±0.04b	5.56±0.12b	3.41±0.09a
Sanren F1	15.36±1.87b	26.56±2.06b	36.89±1.11b	42.32±1.37b	1.48±0.03c	5.00±0.11c	3.08±0.25a

Note: LY1 (leaf yellowing day-1), LY2 (leaf yellowing day-2), LY3 (leaf yellowing day-3), LY4 (leaf yellowing day-4), DL (dead leaves), RD (recovery day), NOB (number of bulbs). Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at p < 0.05.

### 3.4. Effect of transplanting time × variety

The interaction between transplanting time and variety (Table 5) reveals differential responses among cultivars. Lokananta exhibited the highest LY2 (36.63%), LY3 (47.91%), and LY4 (51.21%) values under late afternoon transplanting, suggesting that this variety undergoes more prolonged senescence in response to evening transplantation. However, Sanren F1 showed the lowest leaf yellowing percentages under late afternoon conditions (LY2: 18.40%, LY3: 31.59%, LY4: 36.45%), indicating superior stress tolerance. Recovery days (RD) were also significantly affected, with Sanren F1 requiring less time to recover under late afternoon conditions (4.75 days) compared to morning transplanting (5.25 days).

**Table 5. Effect of transplanting time × variety on several traits**

Transplanting Time	Variety	LY2 (%)	LY3 (%)	LY4 (%)	DL	RD
Morning	Lokananta	27.25±3.86b	41.31±3.30b	47.22±2.10abc	1.72±0.04b	5.94±0.17a
	Merdeka F1	28.12±2.83b	41.14±3.63b	39.93±6.89bcd	1.58±0.07b	6.25±0.22a
	Sanren F1	34.72±0.85a	42.18±1.85b	48.26±2.77ab	1.63±0.01b	5.25±0.24b
Late Afternoon	Lokananta	36.63±2.66a	47.91±2.79a	51.21±3.02a	1.91±0.10a	5.97±0.17a
	Merdeka F1	26.04±3.62b	35.41±1.53c	38.71±3.44cd	1.61±0.04b	4.88±0.31b
	Sanren F1	18.40±1.72c	31.59±2.10c	36.45±0.24d	1.33±0.07c	4.75±0.07b

Note: LY2 (leaf yellowing day-2), LY3 (leaf yellowing day-3), LY4 (leaf yellowing day-4), DL (dead leaves), RD (recovery day). Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at  $p < 0.05$ .

### 3.5. Effect of transplanting time × pruning

The data indicate that leaf yellowing on the first day after transplanting (LY1) was significantly influenced by both pruning and the time of transplanting (Table 6). The highest LY1 was observed in unpruned seedlings transplanted in the morning (27.43%). In contrast, pruned seedlings transplanted in the morning showed a substantially lower LY1 value (18.63%), indicating that pruning helped reduce water loss and physiological stress during transplant establishment. The lowest LY1 values were recorded in late afternoon-transplanted seedlings, with no significant difference between pruned (12.26%) and unpruned (14.35%) plants.

**Table 6. Effect of transplanting time × pruning on several traits**

Transplanting Time	Pruning	LY1 (%)
Morning	Unpruned	27.43±0.85a
	Pruned	18.63±1.15b
Late Afternoon	Unpruned	14.35±1.66c
	Pruned	12.26±2.84c

Note: LY2 (leaf yellowing day-2), LY3 (leaf yellowing day-3), LY4 (leaf yellowing day-4), DL (dead leaves), RD (recovery day). Means in the same column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at  $p < 0.05$ .

## 4. Discussion

The findings from this study clearly demonstrate the significant impact of transplanting time, variety selection, and pruning practices on the physiological responses, growth performance, and yield of shallots. Transplanting in the late afternoon consistently resulted in reduced transplant shock, faster recovery, and enhanced bulb development. This advantage can be attributed to more favorable microclimatic conditions in the evening, such as reduced temperature and lower evapotranspiration rates, which mitigate the immediate post-transplant stress experienced by seedlings. These results support existing physiological theories, which indicate that morning transplanting subjects' plants to high intensity and thermal stress, exacerbating water loss and delaying root establishment and photosynthetic recovery (Hatfield and Prueger, 2015; Taiz et al., 2015).

In addition to environmental moderation, late afternoon transplanting promotes physiological stability by allowing plants to acclimate under low light and cooler conditions. This creates an optimal foundation for photosynthetic activity the following morning, leading to higher pigment retention and more efficient photosynthesis, as documented by Tan et al. (2023) and Song et al. (2023). Consequently, improved chlorophyll concentrations not only reduce visible symptoms of stress, such as leaf yellowing, but also support greater carbohydrate accumulation in bulbs, directly contributing to yield enhancement (Sudaryono, 2018).

Pruning emerged as another crucial agronomic practice influencing plant recovery and productivity. By removing older or excessive foliage, pruning reduces the transpiration load and enhances internal resource allocation. This promotes vigorous shoot regeneration, root development, and overall plant vigor, as also observed in related studies on shallots and other crops (Kahar et al., 2022; Ahmad et al., 2018; Faried et al., 2024). The 34% yield increase observed in pruned plants highlights the potential of this technique to improve light penetration and nutrient use efficiency, reinforcing its agronomic value. However, determining the optimal intensity and timing of pruning is essential to avoid excessive defoliation that might compromise photosynthetic capacity. Research conducted by Alan and Ilbi (2023) also found that cutting treatment on *Anethum graveolens* L. also has a higher yield rather than uncut plant.

Moreover, variety differences significantly influenced plant responses to transplanting and pruning. The variation in DL (dead leaves) among varieties under different transplanting times reveals the importance of genotype-environment interactions. For instance, Lokananta showed weak performance under morning transplanting, while Sanren F1 excelled in late afternoon settings, indicating that each variety possesses unique physiological adaptations related to water-use efficiency, root system architecture, and hormonal regulation (Blum, 2011). Sanren F1's consistently lower LY1 (leaf yellowing on day one) and faster recovery highlight its stress resilience and adaptability, affirming earlier findings that underscore its high productivity and superior foliage characteristics (Siregar et al., 2021).

The synergistic effect of combining late afternoon transplanting with pruning further amplified the positive physiological responses. This integrated practice reduced early stress symptoms, minimized leaf senescence, and improved overall plant vigor (Thomas and Heagney, 2011). Pruned plants transplanted in the evening showed the lowest LY1 values (12.26%), indicating minimal stress and maximum adaptation potential. This interaction suggests that adopting both practices simultaneously could serve as an effective strategy for improving seedling establishment, especially in environments prone to abiotic stress (Niinemets, 2016).

Leaves yellowing from day one to four, the number of dead leaves, and recovery time were all significantly influenced by transplanting time, variety, and pruning. These indicators are critical for early plant health assessment and serve as reliable predictors of final yield. For instance, morning transplanting allowed for a gradual increase in light intensity, preventing photooxidative damage and chlorophyll degradation (Velasco and Mattsson, 2020; Qu et al., 2023; Dhawi, 2024; Bo et al., 2024). Elevated temperatures enhance the production of reactive oxygen species (ROS) that contribute to oxidative stress, exacerbating leaf damage and senescence (Zhang et al., 2023). This oxidative stress can lead to cellular damage, culminating in increased rates of leaf drop as the plant prioritizes survival mechanisms under extreme conditions (Baloch et al., 2024). Additionally, cooler temperatures and higher relative humidity in the evening limited water loss through transpiration, reducing physiological stress and supporting faster recovery. These findings align with those of González-Salvatierra et al. (2013) and Shibuya et al. (2025), who demonstrated that low-stress transplanting environments enhance photosynthetic efficiency and post-transplant survival.

Furthermore, genetic variation in growth parameters such as leaf production, bulb diameter, and shoot regeneration underscores the need for careful variety selection tailored to local environmental conditions. While all tested varieties responded positively to late afternoon transplanting, Sanren F1 consistently outperformed others, reflecting its robust physiological traits and superior adaptability (Awes et al., 2010; Alemu et al., 2022). Such genotype-specific responses must be considered when designing transplanting and pruning protocols, especially for smallholder farmers aiming to optimize production under resource-constrained conditions. Önemli and Önemli (2023) also found that different plant genotypes have distinct morphological, phenological, and agronomic characteristics.

The interaction between transplanting time and pruning had a statistically significant impact on early-stage physiological responses, particularly on LY1 and DL. Evening transplanting, by minimizing stress, created favorable conditions for pruned plants to exhibit accelerated regrowth and recovery. These synergistic effects support the concept of integrating canopy management with environmental modulation to enhance crop resilience. According to Ozkaynak (2013) and Barman et al. (2021), such integrated practices can also influence phenological development and prolong the vegetative phase, potentially contributing to higher cumulative assimilation production and yield.

## 5. Conclusion

In summary, this study highlights the substantial agronomic benefits of optimizing transplanting time, pruning, and variety selection in shallot cultivation using true shallot seed (TSS). Transplanting in the late afternoon significantly reduced early transplant stress, as indicated by a 42.20% decrease in leaf yellowing on the first day (13.31% vs. 23.03%) and a 10.51% faster recovery (5.20 vs. 5.81 days) compared with morning transplanting. These improvements contributed to a marked increase in productivity, with late-afternoon transplanting achieving a 61.95% higher yield (27.37 t ha<sup>-1</sup> vs. 16.90 t ha<sup>-1</sup>). These findings offer concrete recommendations for farmers: conduct transplanting in the late afternoon, apply moderate pruning (50% leaf removal), and select stress-tolerant varieties such as Sanren F1 to maximize establishment and productivity. Future research should focus on detailed root architecture responses, water retention dynamics during recovery, hormonal mechanisms underlying pruning-induced regrowth, and multi-location assessments across contrasting soil and climatic conditions to validate and refine these practices.

**Ethical Statement**

There is no need to obtain permission from the ethics committee for this study.

**Conflicts of Interest**

We declare that there is no conflict of interest between us as the article authors.

**Authorship Contribution Statement**

Concept: Faried, M., Syam'un, E.; Design: Faried, M., Mantja, K.; Data Collection or Processing: Faried, M., Jalil, A., Cennawati, C.; Statistical Analyses: Faried, M., Putri, R. W.; Literature Search: Syam'un, E., Wijaya, P; Writing, Review and Editing: Faried, M., Syam'un, E., Mantja, K.

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