Agrotechnology Research Journal
Volume 9, No. 1, June 2025, pp. xx–xx

ISSN 2655-7924 (Print)
ISSN 2614-7416 (Online)
https://jurnal.uns.ac.id/arj
doi:10.20961/agrotechresj

Growth and Yield of Three Varieties of True Shallot Seed with Application of Plant Growth Regulators and Boron Formulations

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Received **February 7, 2025;** Accepted **March 20, 2025**

ABSTRACT

Optimization of shallot production can use True Shallot Seed (TSS) and Plant Growth Regulator (PGR) + Boron formulation**.** The purpose of the study was to identify superior varieties that respond to the concentration of PGR + Boron formulation and can provide the best results. The research location was at 7°32'30" N and 110°48'32" E, from October 2023 to February 2024. A randomized complete block design factorial with two treatment factors was used, each repeated three times. The first is the type of variety (Lokananta, Maserati, and Sanren), the second is the type of PGR + Boron formulation, the composition of GA3+BAP+Boron (ppm:ppm:kg.ha^{-1}) with four levels, that were 0:0:0, 50:25:2, 100:50:2, and 150:75:2. Conclusion, The Maserati variety of shallots from TSS with a PGR formulation of 100 ppm GA3 + 50 ppm BAP + 2 kg.ha^{-1} Boron produces better growth and yields than the Lokananta and Sanren varieties.

Keywords: Amaryllidaceae; Bulbs; Cytokinin; Gibberellin; Grumosol

Cite this as (CSE Style): Sulandjari S, Triharyanto E, Purnomo D, Muliawati ES, Putri HRSS. 2025. Growth and Yield of Three Varieties of True Shallot Seed with Application of Plant Growth Regulators and Boron Formulations. Agrotechnology Res J. 9(1):1–8.

INTRODUCTION

Shallots (*Allium cepa* var. *ascalonicum* L) are a prime horticultural commodity in Indonesia. This horticultural commodity belongs to the group of indispensable spices used as flavor enhancers in the food industry and in traditional medicine. According to (Maryanti and Wulandari 2023), shallots contain bioactive compounds such as flavonoids, saponins, quercetin, essential oils, alliin, and allicin. The demand for shallots in Indonesia continues to increase along with population growth and the industry of processed shallot products. This is supported by data (BPS tatistics Indonesia 2024) regarding the statistics of shallot consumption in Indonesia from 2021 to 2022, which increased by 6.86%. The increase in demand has been accompanied by an increase in productivity by 3.9% (BPS Statistics Indonesia 2023). However, this productivity is still below the maximum potential of 20 tons.ha^{-1}.

One of the reasons for the low productivity of shallots in Indonesia is the poor quality of planting materials, often caused by bulbs carrying diseases and viruses. True Shallot Seed (TSS) offers a solution because it is virus-free, easy to store, and efficient in distribution. According to Hantari et al. (2020), TSS can enhance plant health and shallot productivity by up to 61%. However, the use of TSS as planting material has not been widely adopted in Indonesia due to the need for improvements, development, and innovation in cultivation techniques for shallots from TSS.

Innovation in the cultivation technique can be achieved through the use of Plant Growth Regulator (PGR) formulations and additional nutrient supplementation. PGR formulations such as gibberellins, cytokinins, and boron can enhance the growth and yield of shallots. Ahmad and Samiullah (2006) demonstrated that gibberellins affect the height of seedlings, bulb diameter, and both wet and dry weights of the plant. According to Puspitorini and Kurniastuti (2019), cytokinins play an essential role in the growth of shoots and the size and number of plant cells. Boron is a crucial element for the growth, development, productivity, and quality of plants (Wimmer and Eichert 2013). As a micronutrient, boron is unevenly distributed in the soil due to its mobility, leading to frequent boron deficiencies in plants (Wimmer and Eichert 2013). However, excessive boron can cause antagonism with other micronutrients such as zinc, manganese, and iron (Hosseini et al. 2007h). The addition of boron along with PGRs is intended to synergize and enhance plant growth and yield.

The use of shallot varieties must be carefully considered to achieve optimal results. Selecting varieties that are adaptive to the environment and employing appropriate cultivation techniques are very important.

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Each variety has resistance to specific conditions, possesses different characteristics, and has different yield potentials. The use of PGR and Boron formulations in the cultivation of shallots from TSS has not been widely implemented. The purpose of this study is to examine the compatibility of shallot varieties from TSS with PGR and Boron formulations in enhancing growth and yield. This research is expected to provide a solution and bring technological innovation to shallot cultivation in Indonesia.

MATERIALS AND METHODS

The research was conducted at the cultivation land in Ngringo Village, Karanganyar District, with coordinates 7°32'30" S and 110°48'32" E from October 2023 to February 2024. The experimental design was a Randomized Complete Block Design (RCBD) factorial with two factors. The first factor was shallot varieties (Lokananta, Maserati, and Sanren), and the second factor was the formulation of GA3+BAP+Boron (ppm:ppm:kg.ha^{-1}) consisting of 0:0:0, 50:25:2, 100:75:2, and 150:75:2. The treatments were replicated three times.

The preparation of the PGR formulation involved dissolving GA_3 according to the treatment plan conversion with a little ethanol and Cytokinin (BAP) with a bit of NaOH, then mixed and made up to 100 ml with distilled water to soak the shallot seeds for 30 minutes, after which the viable seeds were selected. The preparation of PGR and Boron (B) started by using a small measuring tube. Gibberellin was first dissolved with a little ethanol and cytokinin with a little NaOH in a small measuring glass, then mixed and topped up with distilled water to 100 ml in a large measuring glass. The mixture was then homogenized using a hot plate stirrer. The PGR and Boron formulation during planting started with measuring the calibration amount according to the age of the plant.

The preparation of PGR and Boron was done at every treatment interval, namely every 3 weeks after planting (WAP), 5 WAP, and 7 WAP. After obtaining the calibration results, the PGR and Boron were converted and then dissolved with ethanol for gibberellin, NaOH for cytokinin, and distilled water for Boron in a small measuring glass. Once the formulation was dissolved, it was transferred to a larger measuring glass and topped up with distilled water to the required volume. The mixture was then homogenized again using a hot plate stirrer. For foliar application treatments following calibration, the volumes were 225 ml, 315 ml, and 450 ml. The formulation was applied to the foliar at 9, 11, and 13 WAP, with harvesting conducted at 112 Days After Sowing (DAS).

The preparation of the planting medium involved mixing soil, fertilizer, and rice husk ash in a 1:1:1 ratio and placing them into 30 x 30 cm polybags. Seeds were directly planted into the polybags, sown on rockwool substrates sized 1 x 2 cm that had been pre-soaked. Each polybag was planted with two shallot seeds until germination, after which one plant was retained. Follow-up fertilization was performed with NPK according to recommendations. Environmental conditions were monitored, initial soil analysis was conducted, and growth and yield parameters were observed. Variables observed included plant height, leaf number, root length, root weight, fresh weight of shoots, plant biomass, bulb diameter, number of bulbs, fresh bulb weight, and dry bulb weight. Data were analyzed using Analysis of Variance (ANOVA) at a 95% confidence level, and if significant, further tested with Duncan's Multiple Range Test (DMRT) at the same confidence level. Correlation analysis was conducted to determine relationships among the observed variables.

RESULTS AND DISCUSSIONS

Initial soil analysis indicated that the soil type used as the medium is Grumosol with a total nitrogen content of 0.54% (high), available phosphorus of 5.6 ppm (low), available potassium of 0.13 me% (low), pH of 6.23 (slightly acidic), and organic carbon of 0.63% (very low). These soil analysis results suggest that the research medium is not fertile, hence the recommendation to use manure as a basic fertilizer and rice husk ash to potentially improve soil nutrient content. NPK fertilizer (16-16-16) at a dosage of 650 kg.ha^{-1} or 68.67 g.$plant^{-1}$ was able to produce the best bulbs (Chikov and Akhtyamova 2019).

During the research implementation, weather anomalies occurred that changed rainfall and temperature. The average temperature in the field was 30.8°C – 32.8°C, exceeding the optimal temperature desired for shallots, which could result in increased photorespiration occurring faster than photosynthesis, thus reducing the output of photosynthesis (Chikov and Akhtyamova 2019).

Plant height

According to **Table 1**, neither the type of variety nor the application of PGR formulations significantly affected the height of shallot plants at 12 WAP from TSS. Each variety has the potential for plant height growth. However, the three tested varieties showed similar potential for plant height within a narrow range: Lokananta between 49.08-57.40 cm, Maserati between 46.31-54.03 cm, and Sanren between 54.03-56.50 cm (Putrasamedja and Suwandi 1996). The heights were nearly the same as those without treatment.

The plant height has a control mechanism against the application of exogenous PGRs, such as when exogenous PGRs at certain concentrations do not increase plant height. Shallots have an endogenous gibberellin hormone level of 230.67 ppm (Alwan et al. 2023). The content of endogenous gibberellins is sufficient to affect cell division, enlargement of cell size, expansion of plant tissue, and development of meristematic tissue, which allows the plant to grow tall even without the addition of exogenous gibberellins (Alwan et al. 2023). Boron is a micronutrient, while gibberellins and cytokinins are hormones needed by plants in optimum amounts. An excess of these two elements can inhibit growth (Sarti et al. 2023).

Table 1. Influence of variety and PGR plus Boron formulation on TSS shallot growth metrics

Treatment	Plant Height at 12 WAP (cm)	Root Length (cm)	Root Weight (g)	Fresh Shoot Weight (g)	Plant Biomass (g)
Varieties					
Lokananta	46.27±2.56	12.41±2.08a	1.04±0.67	25.29±7.16a	1.60±0.68
Maserati	45.33±4.79	13.18±2.75a	0.75±0.31	18.53±6.34b	1.29±0.44
Sanren	46.35±3.66	9.83±2.84b	0.71±0.35	24.31±6.43a	1.57±0.45
Formulation of GA3 + BAP + Boron (ppm + ppm + kg.ha^{-1})					
0+0+0	44.84±3.93	13.01±2.42a	0.92±0.65	21.19±9.74	1.41±0.82
50+25+2	46.32±3.11	11.91±3.26a	0.60±0.25	20.78±5.33	1.33±0.42
100+50+2	47.39±2.84	12.54±2.40a	0.99±0.27	27.30±6.23	1.77±0.39
150+75+2	45.37±4.74	9.75±2.72b	0.82±0.60	21.56±5.34	1.45±0.38
Sig. (*p*)	0.262	0.088	0.375	0.291	0.261
CV(%)	7.80	14.70	50.60	24.60	28.80

Remarks: Numbers followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=0.05; CV (%): Coefficient of Variation.

Root length

Anjaswari et al. (2020) reported that using Plant Growth Regulators (PGRs) can be beneficial in stimulating roots and increasing the percentage of root length. According to Table 1, the variety of shallots and the application of PGR formulations significantly affected the root length of True Shallot Seed (TSS) derived shallots. The root length of the Lokananta variety (12.41 cm) and Maserati variety (13.18 cm) was significantly different from the Sanren variety (9.83 cm). Genetic factors and environmental signals regulate the root system and continuously adapt to utilize the soil to obtain water and nutrients in specific, often changing environmental conditions. These factors are involved in the growth and development of roots, eventually affecting their morphology and their ability to adapt to their environment (Grossnickle and Ivetić 2022)

Applying a formulation containing 150 ppm GA3 + 75 ppm BAP + 2 kg.ha^{-1} Boron showed a reduction in root extension by 33.4% compared to the control and was significantly different from the other three formulations (Table 1). An inappropriate type of hormone and too high a concentration can disrupt hormonal balance, thus inhibiting root growth. Syamsia (2024) states that phytohormones, including auxins and cytokinins, mediate the formation and development of plant roots, but excessive application can result in underdeveloped roots, as it may inhibit the biosynthesis of endogenous auxins, while gibberellins at increasing concentrations can also inhibit root formation (Syamsia 2024).

Root weight

According to Table 1, neither the type of variety nor the application of Plant Growth Regulator (PGR) formulations significantly affected the root weight of shallots from True Shallot Seed (TSS). This could occur if the choice of PGR type or dosage is not appropriate. Each variety possesses distinct root characteristics. The Maserati variety has characteristics of long roots, whereas the Lokananta variety is characterized by a large number of root hairs, and the root morphology contributes to the resulting root weight (Mandasari et al. 2020). Pujawati et al. (2017) state that inappropriate hormones will produce roots almost the same as those without treatment, whereas the use of PGRs with the correct type of hormone and dosage can be beneficial in stimulating roots, increasing the percentage of root development and weight (Anjaswari et al. 2020).

Fresh shoot weight

Table 1 shows that the type of variety significantly affects the fresh shoot weight. In contrast, the application of PGR formulations does not significantly affect the fresh shoot weight of shallots from TSS. The fresh shoot weight of the Lokananta variety (25.29 g) and Sanren variety (24.31 g) was significantly different from the Maserati variety (18.53 g).

Fitria et al. (2021) stated that each variety has distinct growth characteristics, where genetic differences result in varying fresh shoot weights. Additionally, the fresh weight of plants is influenced by the plant's ability to absorb water (Kartini 2021).

Shallots contain endogenous gibberellins and auxins, which produce optimal and balanced plant growth (Purba 2023). These endogenous PGRs are sufficient to participate in metabolic processes, such as cell growth, cell development, and nutrient distribution. Applying exogenous PGR + Boron formulations on shallots does not affect the fresh shoot weight (Hariyadi et al. 2019).

Plant biomass

According to Table 1, neither the type of variety nor the application of Plant Growth Regulator (PGR) formulations significantly affects the biomass of shallots from True Shallot Seed (TSS). Unfavorable environmental conditions can hinder the genetic potential of each variety in the growth process. According to (Sumartono and Tini 2020), the interaction between genetic factors and the cultivation site's environmental conditions affects the varieties' characteristics. Saputri et al. (2022) added that high temperatures during the study reduced the solubility of CO2 in water, thus inhibiting the rate of photosynthesis. Low photosynthetic activity results in low biomass. Shallot plants have sufficiently high gibberellins and auxins that regulate growth and development and coordinate morphogenesis (Qiu et al. 2020). Therefore, shallot plants can grow well without applying exogenous PGR + Boron formulations. According to Prakash et al. (2023), suboptimal concentrations of exogenous PGRs have an impact that does not affect the addition enough to inhibit metabolic activities in the plant, which can restrict the photosynthesis process and prevent the translocation of photosynthates to the organs of the shallot plant.

Plant biomass is closely related to fresh shoot weight (r = 0.928), root weight (r = 0.741), and leaf count (r = 0.645). Root weight reflects the extensive absorption of nutrients, while plant biomass depends on the amount of nutrient absorption during the growth process (Nada and Abogadallah 2018). Biomass reflects the amount of nutrients absorbed by the roots or produced by photosynthesis. Leaf count is a photosynthetic organ that influences the plant's photosynthesis process. The more leaves there are, the more photosynthates are translocated to the parts of the plant (Hasnelly and Gatot 2020). The high accumulation of photosynthates in the organs of the plant results in high plant biomass.

Leaf count

According to Table 2, the interaction between the type of variety and the application of Plant Growth Regulator (PGR) formulations significantly affects the number of leaves on shallots at 12 Weeks After Sowing (WAS) from True Shallot Seed (TSS). The growth enhancement from boron application can be linked to its role in nitrogen metabolism and phytohormone regulation. Meanwhile, GA3 aids in cell division and enlargement (Qureshi et al. 2013). The interactive effect between GA3 and boron numerically increases the number of leaves. Improvements caused by boron can be associated with its role in cellular water relations, which promotes the translocation of significant nutrients and micronutrients which ultimately increases leaf production (Tiwari et al. 2020; Ijaz et al. 2023). Selecting appropriate varieties can be crucial in maximizing the effectiveness of the PGR and Boron formulations on shallots. Combining gibberellin and cytokinin accelerates cell division and elongation to produce many leaves rapidly. The high number of leaves formed is also influenced by boron in metabolism, respiration, and cell division, which GA3 maximizes by increasing cell size (Ermawati et al. 2018).

Number of bulbs

The number of bulbs for the Lokananta variety (2.47) and Sanren variety (2.83) was significantly different from the Maserati variety (1.69) (Table 3). This indicates a difference in the potential of each variety regarding the number of bulbs (Azizah 2023), as bulb formation is influenced by the plant's ability to distribute photosynthates to the bulbs or storage reserves.

The number of shallot bulbs with the application of 100 ppm GA3 + 50 ppm BAP + 2 kg.ha^{-1} Boron and 150 ppm GA3 + 75 ppm BAP + 2 kg.ha^{-1} Boron increased by 34.2% compared to the control (significantly different). Other researchers using 100 ppm GA3 + 50 ppm BAP increased the number of shallot bulbs (Pangestuti et al. 2023). The plant growth regulator BAP can enhance meristem cell division, development, and differentiation into new tissues. Tissues turn into buds, which then develop into shoots and eventually bulbs. Additionally, the application of boron at certain concentrations aids in the absorption and transport of photosynthates in shallots, affecting the growth and development of bulbs (Ningsih and Sudantha 2017).

The number of bulbs is closely related (r = 0.815) to the number of leaves. Leaves produce photosynthates from photosynthetic activity, and a relatively high number of leaves leads to high photosynthate accumulation. For bulbous plants, photosynthate accumulation occurs in the bulbs, which act as sinks. More leaves influence bulb formation due to increased photosynthesis for bulb growth (Despita et al. 2020).

Table 2. Effect of GA3, BAP, and Boron formulations on leaf number in true shallot seed of cv. Lokananta, Maserati, and Sanren at 12 weeks after sowing

Formulation of GA_3+BAP+Boron (ppm:ppm:kg.ha^{-1})	Number of Leaves
Lokananta	
No Formulation	16.00±4.17 cd
50:25:2	14.32±4.19 cd
100+50+2	21.33±4.48 b
150+75+2	17.00±4.66 bcd
Maserati	
No Formulation	8.11±1.26 e
50+25+2	12.56±3.37 de
100+50+2	12.22±2.59 cde
150+75+2	13.11±2.71 cde
Sanren	
No Formulation	14.78±3.97 cd
50+25+2	16.78±4.55 bcd
100+50+2	26.22±3.86 a
150+75+ 2	17.89±5.29 bc
Sig. (p)	0.050
CV (%)	17.40

Remarks: Numbers followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=0.05; CV (%): Coefficient of Variation

Table 3. Influence of Plant Growth Regulators and Boron Formulations on True Shallot Seed of cv. Lokananta, Maserati, and Sanren on the Yield of Bulbs

Treatments	Bulb Diameter (mm)	Number of Bulbs	Fresh Bulb Weight (g)	Dry Bulb Weight (g)
Varieties				
Lokananta	20.21±3.74b	2.47±0.52a	11.66±6.02	9.67±5.04
Maserati	26.68±2.65a	1.69±0.52b	14.03±3.10	12.11±2.66
Sanren	21.26±3.98b	2.83±0.85a	14.02±3.98	11.39±3.43
Formulation of GA3 + BAP + Boron (ppm + ppm + $kg.ha^{-1}$)				
0+0+0	23.80±4.51	1.96±0.72b	13.60±5.67	11.25±4.77
50+25+2	22.58±4.54	2.11±0.53ab	12.45±5.58	10.44±4.64
100+50+2	22.22±4.50	2.63±0.99a	13.85±3.87	11.93±3.36
150+75+2	22.14±4.92	2.63±0.75a	13.04±3.28	10.60±2.89
Sig. (*p*)	0.667	0.186	0.153	0.134
CV (%)	14.90	21.80	27.30	27.00

Remarks: Figures followed by the same letter within the same column are not significantly different according to Duncan's Multiple Range Test (DMRT) at α=0.05; CV (%): Coefficient of Variation

Bulb diameter

According to Table 3, the type of variety significantly affects the bulb diameter, while the application of PGR formulations does not significantly affect the diameter of shallot bulbs from TSS. The bulb diameter of the Maserati variety (26.68 mm) was significantly different from the Lokananta variety (20.21 mm) and Sanren variety (21.26 mm). The size of shallot bulbs is a manifestation of the influence of genetic and environmental factors (Saidah et al. 2019) because each variety has distinct characteristics that can affect their ability to distribute photosynthates to the bulb part. The bulb diameter of shallots is predominantly influenced by genetics. This makes the application of formulations less impactful as genetics play a more supportive role in the growth size of a bulb (Nababan et al. 2018). The bulb diameters produced are still below the potential yield of the varieties due to the use of unsuitable soil types. Parsottambhai and Rawat (2020) report that the low ability to absorb nutrients and the availability of nutrients in the planting media limit the growth of shallot bulbs. Although still below their potential, the obtained bulb diameters are considered large. Cokrosudibyo et al. (2023) state that bulbs grown using TSS are larger than those grown using bulbs.

Fresh bulb weight

The difference in varieties or the application of PGR formulations does not significantly affect the fresh bulb weight of shallots from TSS (Table 3). This difference indicates that the three varieties have distinct advantages in each growth variable due to inconsistent genetic potential. The Maserati variety excels in bulb diameter, while the Lokananta and Sanren varieties excel in the number of bulbs. This results in the fresh bulb weights from the three varieties being relatively similar. Bulb diameter and number are two component characteristics that directly influence the fresh bulb weight (Putri and Ashari 2019).

The fresh bulb weight is more dominantly influenced by the translocation of photosynthate accumulation in shallots and the interacting factors (Nikirahayu et al. 2021). Low photosynthate accumulation due to suboptimal environmental conditions disrupts the translocation process from leaves and stems to bulbs. The formation of shallot bulbs is directly affected by environmental conditions (Susanto et al. 2021), including high temperatures increasing respiration, while high air humidity decreases transpiration rates, resulting in hindered nutrient and water absorption (Sofiani et al. 2022).

Dry bulb weight

The type of variety and the formulation of Plant Growth Regulators (PGRs) do not significantly affect the dry bulb weight of shallots from True Shallot Seed (TSS) (Table 3). High rainfall (> 500 mm per month) during the phase when the plant begins bulb formation and filling leads to high water content. The remobilization of photosynthates to the bulbs is hindered due to the high water potential of the bulbs, resulting in low bulb weight. Excessively high rainfall can reduce productivity by more than 50% of the potential (Sholikin and Haryono 2019). Based on this, the shallots in this experiment did not reach the potential of the varieties.

The dry bulb weight of shallots with the application of PGR + B formulations is not higher than the control. The biomass, which does not differ significantly among PGR formulations, results in bulb yields, indicating that the rate of remobilization of photosynthates from stems and leaves to the bulbs is the same. Shallots will experience a disruption in photosynthate remobilization if there is high rainfall during the period leading up to harvest (Edi 2019).

The weight of the bulbs is closely related (r = 0.663) to the diameter of the bulbs. The diameter of the bulbs is a measure of the volume (size) of the bulbs, indicating the content of nutrients and water. After the bulbs are drained, some water is released; if the weight is almost the same, the nutrient content is similar. Nutrient reserves stored in the bulbs will increase the weight of the bulbs (Lencha and Buke 2017).

CONCLUSIONS AND SUGGESTIONS

Conclusion

The Maserati variety of shallots from TSS with a PGR formulation of 100 ppm GA3 + 50 ppm BAP + 2 $kg.ha^{-1}$ Boron produces better growth and yields than the Lokananta and Sanren varieties.

Recommendations

Further research should be conducted with the independent application of Boron, separate from the PGR (GA3 and BAP) applications, to adjust the needs of each element for the TSS origin shallot varieties.

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