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Enhancing Shallot Growth and Production: Roles of Zinc-Based Seed Priming Techniques

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ABSTRACT

This research aimed to study the effects of seed priming methods on the growth and yield of two shallot varieties available as seeds for propagation. The research site was at the Experimental Garden, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia. The research was conducted using a split-plot design, arranged as a randomized complete block design. The main plot was shallot variety, consisting of 2 varieties, namely Lokananta and Maserati. The subplot consisted of priming types in 6 treatments: control, hydropriming, IAA priming, ZnO priming, $ZnSO_4.7H_2O$ priming, and Zn-EDTA priming. The results showed an interaction between Lokananta varieties and $ZnSO_4.7H_2O$ priming on several parameters, i.e., bulb count, bulb diameter, and bulb shrinkage. The interaction between Maserati varieties and IAA priming on plant height parameters was significant. Treatment of the Maserati variety accelerated the arrival of its harvest stage. The Zn-EDTA priming treatment increased the percentage of surviving seedlings, number of bulbs, plant fresh and dry weight, bulb fresh and dry weight, bulb diameter, bulb height, bulb shrinkage, bulb moisture content, yield, and productivity. The ZnO priming treatment produced the lowest crown-to-bulb ratio and the highest harvest index. The $ZnSO_4.7H_2O$ priming treatment increased the number of leaves. Seed priming using Zn could increase the growth and yield production of shallots after a maintenance period.

Introduction

Seeds are the developmental result of reproductive processes in plants. Each seed contains an embryo capable of growing into a new plant. Traditionally, shallot farmers use bulbs from their harvest as planting material or purchase local and imported bulbs from the market (Adin et al., 2023). However, propagation through botanical seeds, or so-called true shallot seeds (TSS), can also be developed. The use of TSS has begun to become widespread, considering that one of the main problems in shallot plant cultivation is the availability of seeds in bulb form. Thus, TSS can be an alternative to overcome this problem (Makhziah et al., 2019).

According to Mantja et al. (2023), TSS origin is

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increasingly popular as planting material in Indonesia. There are various advantages to shallot cultivation using TSS, including requirements of fewer planting materials, being free from soil-borne diseases, high productivity, having a longer shelf life, easy distribution, and relatively low transportation costs (Sembiring et al., 2018). Based on several advantages of TSS, its use as a source of shallot seeds has good prospects for increasing the production and quality of shallot bulbs.

The scarcity of shallots emanates from a purchasing competition between farmers and household consumers. Therefore, the use of TSS presents an appropriate solution to this problem. However, shallot cultivation by seed encounters several challenges, including non-uniform seed growth and poor seedling quality, which affect the percentage of seedlings that survive in the field after planting (Faried et al., 2023).

Shallot seeds of botanical seed origin are susceptible to quality deterioration due to prolonged storage. Seeds that have undergone deterioration can become less affected by applications of invigorative technology (Tanjung et al., 2022). Triyadi et al. (2023) stated that invigoration involves physical, physiological, and biochemical treatments to increase seed viability, enabling faster and synchronized growth in diverse environments. One of the invigoration technologies is the seed priming method.

Seed priming treatment occurs before sowing seeds. Priming is an approach that involves treating seeds with different organic or inorganic chemicals. This seed treatment involves soaking the seeds in various solutions for a specified duration under controlled conditions. It is followed by drying the seeds to their original moisture content to prevent premature radicle emergence before sowing. This process stimulates various metabolic processes that enhance germination and mitigate the detrimental effects of seed damage (Pawar and Lawre, 2018). Seed priming is one way to overcome several constraints effectively. It is a simple, low-cost, low-risk intervention that can assist farmers with their livelihoods by improving crop emergence, development, and productivity (Saranya et al., 2017).

Seed priming techniques continue to be developed, optimized, and commercialized as effective methods to increase seed germination rate and vigor. Priming techniques are inexpensive and easy to use. Seed priming-based methods include various types such as hydropriming, osmopriming, drum priming, solid matrix priming, biopriming, hormonal priming, nanopriming, physical priming, halopriming, and nutripriming (Pagano et al., 2023; Rhaman et al., 2020).

Nutripriming involves applying nutrients in a solution to enhance seed quality by increasing the nutrient content of the seed. Micronutrients are essential for plant growth, playing crucial roles in photosynthesis and respiration. According to Pawar and Lawre (2018), to address this issue, micronutrients can be applied in three ways: soil application, foliar application to leaves, or direct seed application. Direct seed treatment is the most effective option for improving seedling growth and yield, requiring fewer micronutrients.

Zinc (Zn) is one of the primary micro-nutrients essential for plant growth and production since plants need Zn in small amounts for various enzymes and protein activities. The average range of Zn required by plants is 15-55 ppm. Zn toxicity and deficiency can adversely affect yield and crop health. Zn deficiency negatively impacts plant development, resulting in stunted growth, short internodes, small leaves, chlorosis, and delayed maturity. Therefore, maintaining Zn sufficiency is crucial for achieving optimal crop yield and quality (Vadlamudi et al., 2020; Hacisalihoglu, 2020). Based on the descriptions above, there is a need to conduct research on the specifics of Zn micro-nutrient application as seed priming agents to enhance shallot growth and production from botanical seeds.

Material and Methods

Study area

The research was conducted at the Experimental Garden, Faculty of Agriculture, Hasanuddin University, Makassar. The research site was located at coordinates 5°7'40.07 "S 119°28'48.94 "E at an altitude of 9 m above sea level. The time span of the experiments was from July to October 2023.

Shallot plants usually have a harvest period of up to 70 d after planting (DAP). The vegetative phase I and II are the initial growth phases of the plant that focus on forming the roots and crown. Generative phase I occurs where the true stem is modified into layered bulbs. Generative phase II is the final process of bulb maturation until it enters the harvest stage. Environmental observations are needed to determine the conditions that occur in the field during the research process (Tables 1 and 2).

Experimental design

A field research was organized using a split-plot design, arranged on a randomized complete block design. The main plot consisted of the variety (v), comprising 2 varieties, namely Lokananta (v0) and Maserati (v1). The subplots represented the type of seed priming (z), consisting of 6 types: control (z0), hydropriming (z1), IAA priming (z2), ZnO priming (z3), $ZnSO_4.7H_2O$ priming (z4), and Zn-EDTA priming (z5). With the number of treatments from each factor, 12 treatment combinations were obtained. Each treatment combination was repeated 3 times, resulting in 36 experimental plots.

Table 1. Potential hydrogen (pH), maximum air temperature (T_{max}), minimum air temperature (T_{min}), maximum air and soil humidity (Rh_{max}), minimum air and soil humidity (Rh_{min}).

Growth Phase	Soil			Air			
	pH	Rh_{min} (%)	Rh_{max} (%)	T_{min} (°C)	T_{max} (°C)	Rh_{min} (%)	Rh_{max} (%)
Vegetative I (1-20 DAP)	6.68	84.50	61.75	20.74	40.65	21.05	81.60
Vegetative II (21-40 DAP)	6.08	90.00	65.00	20.22	40.00	20.95	78.00
Generative I (41-60 DAP)	6.09	86.50	66.75	19.81	40.18	21.15	75.85
Generative II (60-70 DAP)	6.25	48.00	43.00	20.73	40.06	20.30	76.30

Table 2. Soil chemical characteristics before and after the study.

Soil Parameters	Unit	Before Research	After Research
pH	-	6.58	6.65
C (Walkey and Black)	%	3.52	2.14
N (Kjeldahl)	%	0.28	0.21
C/N	-	13	10
P_2O_5 (Olsen)	ppm	12.28	13.25
K (NH_4-Acetat 1N, pH7)	cmol kg^{-1}	0.28	0.25
Ca (NH_4-Acetat 1N, pH7)	cmol kg^{-1}	6.92	8.15
Mg (NH_4-Acetat 1N, pH7)	cmol kg^{-1}	1.68	1.65
Na (NH_4-Acetat 1N, pH7)	cmol kg^{-1}	0.46	0.41
KTK (NH_4-Acetat 1N, pH7)	cmol kg^{-1}	19.65	21.05
KB (NH_4-Acetat 1N, pH7)	%	48	50
Zn (AAS)	mg kg^{-1}	1.59	1.36

Research procedure

Seed priming preparation

Each solution was prepared with a Zn content concentration of 100 ppm. This was obtained by dissolving 125.72 mg L^{-1} zinc oxide (ZnO), 444.04 mg L^{-1} zinc sulphate heptahydrate ($ZnSO_4.7H_2O$), 700.77 mg L^{-1} zinc EDTA ($C_{10}H_{12}N_2O_8ZnNa_2.3H_2O$), and 100 mg L^{-1} indole acetic acid (IAA) in a distilled water solvent. Shallot seeds of Lokananta and Maserati varieties were used, with a shelf life of 15 months. A germination test was conducted by a paper method test in the laboratory. Shallot seeds were then primed according to the treatment. The seeds (4.5 g) were added to each treatment solution in a ratio of 1:20 (W/V) in a glass jar connected to an aerator. Then, the seeds were soaked for 20 h (Faried et al., 2023). The seeds were removed and dried to reach their initial moisture content.

Seed sowing

Primed seeds were treated with a mixture of 70% propineb fungicide and water. The solution was stirred thoroughly until the shallot seeds were fully covered, appearing white. Before sowing the seeds, the seeding bed was filled with soil and compost (5 t ha^{-1}), which was then well mixed. Then, furrows were made at spaces of 10 cm apart. The seeds were sown and NPK fertilizer was applied in each furrow (150 kg ha^{-1}) at 1, 15, and 30 d after sowing. The seedbed was watered twice daily, both in the morning and evening. Shallot seedlings, 45 d after seed sowing, were subsequently transplanted into previously prepared plots, with each hole hosting one plant. The process of transplanting the seedlings adhered to predetermined treatments. Selected seedlings had at least two leaves, exhibited good health, and were free from pests and diseases.

Seed bed preparation

The research area was initially cleared of garbage and dirt. Then, a pre-emergent herbicide (oxyfluorfen) was used (240 g L^{-1}) as a spray. Then, the plots were set up, measuring 70 cm × 150 cm in length and width, 30 cm in height, and with a distance of 30 cm between plots. Then, the area was covered with plastic mulch. Planting holes (8 cm) were made at a spacing of 10 cm × 15 cm. There were 70 plants per experimental plot.

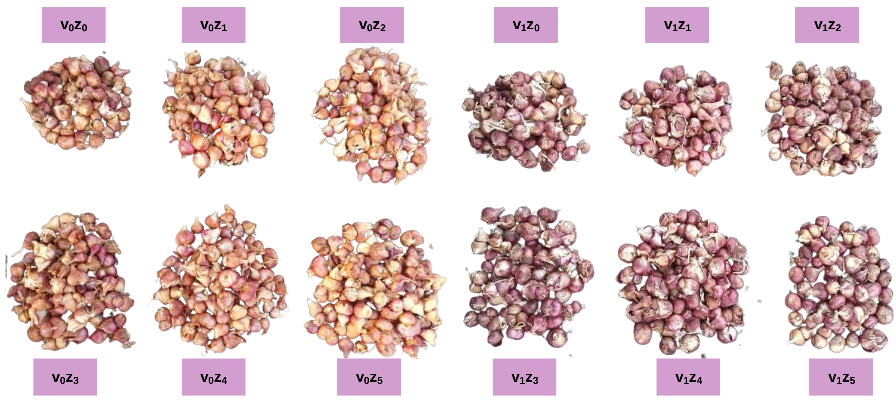
Plant maintenance

Shallots plants were maintained by watering, replanting, weed control, fertilizer application, pest management, and disease control.

Data collection

Measurable parameters included the percentage of surviving seedlings, plant height, number of leaves, leaf stomatal components, harvest age, number of bulbs, plant fresh weight, bulb fresh weight, plant dry weight, bulb dry weight, bulb diameter, bulb height, bulb shrinkage, bulb moisture content, crown to bulb ratio, harvest index, yield, and productivity (Fig. 1).

(A)



(B)

Fig. 1. Bulb characteristics in each treatment group (A), bulb yield per plot with seed priming treatments (B). Lokananta + control (v0z0), Lokananta + hydropriming (v0z1), Lokananta + IAA (v0z2), Lokananta + ZnO (v0z3), Lokananta + $ZnSO_4.7H_2O$ (v0z4), Lokananta + Zn-EDTA (v0z5), Maserati + control (v1z0), Maserati + hydropriming (v1z1), Maserati + IAA (v1z2), Maserati + ZnO (v1z3), Maserati + $ZnSO_4.7H_2O$ (v1z4), Maserati + Zn-EDTA (v1z5).

The percentage of surviving seedlings was calculated via the following equation:

$$\text{Surviving seedlings} = \frac{NOS}{TNOP} 100\%$$

Where, NOS is the number of surviving seedlings, and TNOP is the total number of plants.

Stomatal density was calculated by referring to Maylani and Wardhana (2019) using the following formula:

$$Stomatal\ density = \frac{Number\ of\ stomatal}{Area\ of\ field\ of\ view}$$

$$Area\ of\ field\ of\ view = \frac{\pi r^2}{mm^2}\ atau\ \frac{\pi r^2}{100cm^2}$$

To measure the density of stomata, a 40x magnification with a field of view diameter of 0.52 mm^2 was utilized, while the measurement of the non-stomatal area was conducted at 100x magnification with a field of view diameter of 0.52 mm^2. The stomatal opening area was determined using the formula πr^2, with the stomata observed under a microscope.

According to Priyantono et al. (2018), bulb shrinkage was calculated using the following formula:

$$\text{Bulb shrinkage} = \frac{Fresh\ weight\ bulb - Dry\ weight\ bulb}{Fresh\ weight\ bulb} \times 100\%$$

Bulb moisture content was calculated using the oven method (Dangtata, 2014) as follows:

$$\text{Bulb moisture content} = \frac{Initial\ bulb\ weight - Oven\ bulb\ weight}{Initial\ bulb\ weight} \times 100\%$$

Comparison of crown fresh weight to bulb fresh weight per plant.

$$\text{Crown to bulb ratio} = \frac{Crown\ fresh\ weight}{Bulb\ fresh\ weight}$$

According to Kassa (2018), shallot harvest index is calculated using the formula:

$$\text{Harvest index} = \frac{Fresh\ weight\ bulb}{Fresh\ weight\ plants}$$

Data analysis

The obtained data were normalized and then analyzed for variance. Duncan's Multiple Range Test (DMRT) was conducted ($P \leq 0.05$) after obtaining significant values from the analysis of variance.

Results

Macromorphology

The combination of the Maserati variety and IAA priming caused a 17.3% increase in plant height at 60 DAP treatment compared to the control treatment (Table 3). This increase was not significantly different from the combinations of the Lokananta variety and Zn-EDTA priming, Lokananta variety and $ZnSO_4.7H_2O$ priming, Maserati variety and hydropriming, Maserati variety and $ZnSO_4.7H_2O$ priming, and Lokananta variety and IAA priming, but it was significantly different from other combinations. Furthermore, the combination of the Lokananta variety and $ZnSO_4.7H_2O$ priming demonstrated an 80.4% increase in the number of bulbs compared to the control treatment. This increase was not significantly different from the combinations of the Lokananta variety and Zn-EDTA priming, Lokananta variety and the control, Lokananta variety and the ZnO priming, as well as the Lokananta variety and the IAA priming. However, the increase was markedly different from the other combinations.

Table 3. Interaction effect of plant height and number of bulbs in the two varieties in response to the six types of seed priming treatments.

Priming Agent	Plant Height (cm)		Number of Bulb	
	Lokananta	Maserati	Lokananta	Maserati
Control	46.02^{abc}	43.19^{cd}	1.78^{a}	1.02^{e}
Hydropriming	39.36^{d}	46.86^{abc}	1.46^{bc}	1.32^{bcd}
IAA	46.86^{abc}	50.67^{a}	1.57^{ab}	1.12^{de}
ZnO	43.13^{cd}	42.76^{cd}	1.75^{a}	1.19^{cde}
$ZnSO_4.7H_2O$	49.02^{ab}	45.64^{abc}	1.84^{a}	1.33^{bcd}
Zn-EDTA	47.69^{abc}	45.00^{bc}	1.78^{a}	1.46^{bc}

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

The combination of the Lokananta variety and $ZnSO_4.7H_2O$ priming caused a 24.9% increase in bulb diameter compared to the control treatment (Table 4). This increase was not significantly different from the combinations of the Lokananta variety and Zn-EDTA priming, Maserati variety and $ZnSO_4.7H_2O$ priming, and Maserati variety and Zn-EDTA priming, but was markedly different from the other combinations. Also, the combination of the Lokananta variety and $ZnSO_4.7H_2O$ priming resulted in a 4.77% decrease in bulb diameter compared to the control treatment. This difference was not significantly different from the combinations of the Lokananta variety and Zn-EDTA priming, the Maserati variety and ZnO priming, the Maserati variety and Zn-EDTA priming, as well as the Maserati variety and hydropriming, but it was significantly different from the other combinations.

Table 4. Bulb diameter and bulb shrinkage of the two varieties in response to the six types of seed priming treatments.

Priming Agent	Bulb Diameter (mm)		Bulb Shrinkage (%)	
	Lokananta	Maserati	Lokananta	Maserati
Control	41.23[bc]	34.04[d]	12.90[f]	10.60[b-f]
Hydropriming	39.57[c]	40.77[bc]	11.12[c-f]	8.56[ab]
IAA	41.44[bc]	42.92[bc]	11.04[c-f]	11.63[def]
ZnO	44.66[b]	41.30[bc]	12.18[def]	10.36[a-e]
$ZnSO_4.7H_2O$	51.50[a]	48.49[a]	8.13[a]	12.74[ef]
Zn-EDTA	50.88[ba]	49.20[a]	9.84[a-d]	8.77[abc]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

The $ZnSO_4.7H_2O$ priming treatment caused a 17.1% increase in the number of leaves at 60 DAP compared to the control treatment (Table 5), which was not significantly different from the Zn-EDTA priming treatment and IAA priming treatment, but was significantly different from the other treatment combinations. Similarly, the Zn-EDTA priming treatment resulted in an 84% increase in bulb fresh weight compared to the control treatment. This increase was not significantly different from the $ZnSO_4.7H_2O$ priming treatment but was significantly different from the other treatments.

Table 5. Number of leaves and bulb fresh weight of the two varieties in response to the six types of seed priming treatments.

Variety	Number of Leaves	Bulb Fresh Weight (g)
Lokananta	13.30 ± 0.67[a]	28.74 ± 3.16[a]
Maserati	11.75 ± 0.29[a]	28.34 ± 2.74[a]
Priming Agent	Number of Leaves	Bulb Fresh Weight (g)
Control	11.71 ± 0.48[b]	20.81 ± 1.83[c]
Hydropriming	11.60 ± 0.07[b]	23.01 ± 2.06[bc]
IAA	13.14 ± 0.90[ab]	26.25 ± 0.96[b]
ZnO	11.40 ± 0.79[b]	26.78 ± 0.31[b]
$ZnSO_4.7H_2O$	14.12 ± 1.83[a]	36.09 ± 0.12[a]
Zn-EDTA	13.17 ± 0.74[ab]	38.30 ± 1.94[a]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

The Zn-EDTA priming treatment caused a 73.3% increase in plant fresh weight compared to the control treatment (Table 6). This increase was not significantly different from the $ZnSO_4.7H_2O$ priming treatment but was significantly different from the other treatments. Moreover, the Zn-EDTA priming treatment resulted in an 82.2% increase in plant dry weight compared to the control treatment. This increase was not significantly different from the $ZnSO_4.7H_2O$ priming treatment but was markedly different from the other treatments.

The Zn-EDTA priming treatment resulted in an 18.8% increase in bulb height compared to the control treatment (Table 7). This increase was not significantly different from the $ZnSO_4.7H_2O$ priming treatment and ZnO priming treatment but was significantly different from the other treatments. Furthermore, the varieties and types of priming, as well as the interaction of the two treatment factors, did not significantly affect the bulb moisture content.

Table 6. Plant fresh weight and plant dry weight of the two varieties in response to the six types of seed priming treatments.

Variety	Plant Fresh Weight (g)	Plant Dry Weight (g)
Lokananta	40.20 ± 4.75[a]	27.99 ± 3.28[a]
Maserati	39.28 ± 3.47[a]	27.22 ± 2.50[a]
Priming Agent	Plant Fresh Weight (g)	Plant Dry Weight (g)
Control	30.70 ± 1.42[b]	20.45 ± 1.89[c]
Hydropriming	30.75 ± 2.67[b]	22.40 ± 2.49[bc]
IAA	37.86 ± 1.06[b]	25.14 ± 0.89[b]
ZnO	35.06 ± 0.03[b]	25.27 ± 0.09[b]
$ZnSO_4.7H_2O$	50.84 ± 1.10[a]	35.09 ± 1.66[a]
Zn-EDTA	53.22 ± 3.99[a]	37.27 ± 2.06[a]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

Table 7. Bulb height and bulb moisture content of the two varieties and six types of seed priming treatments.

Variety	Bulb Height (mm)	Bulb Moisture Content (%)
Lokananta	30.16 ± 1.09[a]	72.30 ± 1.31[a]
Maserati	29.55 ± 0.69[a]	64.12 ± 1.92[a]
Priming Agent	Bulb Height (mm)	Bulb Moisture Content (%)
Control	27.24 ± 0.32[d]	70.80 ± 3.24[a]
Hydropriming	27.68 ± 1.14[cd]	67.23 ± 2.81[a]
IAA	29.80 ± 0.57[bc]	72.52 ± 1.78[a]
ZnO	30.19 ± 0.57[ab]	68.36 ± 8.52[a]
$ZnSO_4.7H_2O$	31.85 ± 0.21[ab]	66.58 ± 2.51[a]
Zn-EDTA	32.37 ± 1.29[a]	63.77 ± 5.68[a]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

The ZnO priming treatment resulted in a 54.8% decrease in the crown to bulb ratio compared to the control treatment (Table 8). This difference was not significantly different from the effects of $ZnSO_4.7H_2O$ priming, Zn-EDTA priming, and hydropriming, but it was markedly different from the other treatments. Similarly, ZnO priming resulted in a 13.2% increase in the harvest index compared to the control treatment. This difference was not significantly different from the water priming treatment but was markedly different from the other treatments.

The Zn-EDTA priming treatment caused a 2.34-fold increase in yield compared to the control treatment (Table 9). This difference was not significantly different from the $ZnSO_4.7H_2O$ priming treatment but was markedly different from the other treatments. Moreover, the Zn-EDTA priming treatment resulted in a 1.89-fold increase in yield compared to the control treatment. This difference was not significantly different from the effect of the $ZnSO_4.7H_2O$ priming treatment but was markedly different from the other treatments.

Micromorphology

The two varieties and types of priming as well as the interaction between the two treatment factors had no significant effect on the stomatal density and stomatal opening area (Table 10).

Table 8. Crown to bulb ratio and harvest index in the two varieties in response to the six types of seed priming treatments.

Variety	Crown to Bulb Ratio	Harvest Index
Lokananta	0.39 ± 0.02[a]	0.72 ± 0.01[a]
Maserati	0.39 ± 0.03[a]	0.72 ± 0.02[a]
Priming Agent	Crown to Bulb Ratio	Harvest Index
Control	0.48 ± 0.06[b]	0.68 ± 0.03[b]
Hydropriming	0.34 ± 0.01[a]	0.75 ± 0.01[a]
IAA	0.44 ± 0.01[b]	0.70 ± 0.01[b]
ZnO	0.31 ± 0.01[a]	0.77 ± 0.01[a]
$ZnSO_4.7H_2O$	0.40 ± 0.04[ab]	0.72 ± 0.02[b]
Zn-EDTA	0.39 ± 0.03[ab]	0.72 ± 0.02[b]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

Table 9. Yield and productivity in the two varieties in response to the six types of seed priming treatments.

Variety	Yield (kg m^{-1})	Productivity (t ha^{-1})
Lokananta	1.68 ± 0.23[a]	17.99 ± 2.09[a]
Maserati	1.60 ± 0.22[a]	17.76 ± 1.71[a]
Priming Agent	Yield (kg m^{-1})	Productivity (t ha^{-1})
Control	1.02 ± 0.14[c]	12.83 ± 0.96[c]
Hydropriming	1.22 ± 0.06[c]	14.55 ± 1.49[bc]
IAA	1.52 ± 0.04[b]	16.29 ± 0.55[b]
ZnO	1.49 ± 0.01[b]	16.61 ± 0.04[b]
$ZnSO_4.7H_2O$	2.22 ± 0.09[a]	22.66 ± 0.63[a]
Zn-EDTA	2.39 ± 0.09[a]	24.32 ± 1.10[a]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

Table 10. Stomatal density and stomatal opening area in the two varieties in response to the six types of seed priming treatments.

Variety	Stomatal Density (Number of Stomatal mm^{-2})	Stomatal Opening Area (mm^2)
Lokananta	53.50 ± 1.89[a]	171.52 ± 19.89[a]
Maserati	54.07 ± 2.03[a]	197.12 ± 21.72[a]
Priming Agent	Stomatal Density (Number of Stomatal mm^{-2})	Stomatal Opening Area (mm^2)
Control	58.60 ± 0.85[a]	206.06 ± 10.07[a]
Hydropriming	55.20 ± 4.25[a]	213.65 ± 43.83[a]
IAA	53.50 ± 5.94[a]	126.12 ± 13.87[a]
ZnO	54.35 ± 1.69[a]	184.34 ± 64.76[a]
$ZnSO_4.7H_2O$	48.41 ± 0.85[a]	220.45 ± 11.12[a]
Zn-EDTA	52.65 ± 1.69[a]	155.30 ± 24.47[a]

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

Percentage of surviving seedlings and harvest time

The Zn-EDTA priming treatment resulted in a 25.1% increase in the percentage of surviving seedlings compared to the control treatment (Table 11). This increase was not significantly different from the effect of the $ZnSO_4.7H_2O$ priming, ZnO priming, and IAA priming, but it was significantly different from the other treatments. However, the results revealed a significant difference in the harvest time of the Maserati variety, which was 5.67 d earlier than the Lokananta variety.

Table 11. Surviving seedlings and harvest time in the two varieties in response to the six types of seed priming treatments.

Variety	Surviving seedlings (%)	Harvest Time (d)
Lokananta	92.70 ± 2.35^{a}	75.00 ± 0.40^{b}
Maserati	88.41 ± 4.13^{a}	69.33 ± 0.63^{a}
Priming Agent	Surviving seedlings (%)	Harvest Time (d)
Control	78.57 ± 5.71^{c}	72.67 ± 2.67^{a}
Hydropriming	84.76 ± 4.76^{bc}	72.67 ± 1.67^{a}
IAA	94.29 ± 0.95^{a}	71.33 ± 3.00^{a}
ZnO	89.52 ± 0.48^{ab}	73.17 ± 2.17^{a}
$ZnSO_4.7H_2O$	97.86 ± 1.67^{a}	72.50 ± 4.17^{a}
Zn-EDTA	98.33 ± 0.71^{a}	70.67 ± 3.33^{a}

Mean values of traits in each column with similar letters are not significantly different according to the DMRT approach.

Discussion

Based on the current research, the results indicated that the interaction between seed priming treatment and shallot varieties influenced parameters such as plant height, number of bulbs, bulb diameter, and bulb shrinkage. Individually, seed priming affected parameters such as the percentage of surviving seedlings, number of leaves, plant fresh weight, plant dry weight, bulb fresh weight, bulb dry weight, bulb moisture content, crown and bulb ratio, harvest index, yield, and productivity. The variety factor influenced the harvest age parameter. However, none of the treatments caused significant differences in stomatal density and stomatal opening area parameters.

The percentage of surviving seedlings indicates how many seedlings can survive after transplanting in the cultivation field. Generally, this parameter can reflect the quality of the planted seedlings. The treatment with Zn-EDTA priming exhibited a high percentage of surviving seedlings compared to the other treatments. Zn can promote robust seedling growth, facilitating better adaptation during planting. Additionally, the Zn-EDTA priming treatment yielded results that were not significantly different from $ZnSO_4.7H_2O$ priming and IAA priming concerning parameters such as plant height and number of leaves. This observation may result from providing Zn in plants that can stimulate the formation of growth regulators, such as auxins. Auxin functions as a growth regulator that contributes to cell division, particularly in the growth of plant shoots. When plants receive supplementary Zn, plants elongate, and the concentration of IAA increases.

Low concentrations of IAA in Zn-deficient plants may result from the inhibition of synthesis or increased degradation of IAA (Cakmak et al., 1989; Li et al., 2013). This study confirms the results obtained by Tariq et al. (2018), where Zn significantly increased plant height, number of leaves, and leaf length of onions compared to the treatment without Zn application.

As previously explained, Zn plays a crucial role in plant growth, catalyzing enzymes that form chlorophyll in plant leaves. Chlorophyll, in turn, is essential for producing the energy plants require to undergo photosynthesis. The rate of photosynthesis is influenced by the amount of light energy that can be absorbed. A higher rate of photosynthesis leads to increased production of photosynthate, which accumulates in plant organs, including leaves, resulting in greater plant biomass. Kirschbaum (2011) suggested that the assimilates that form during photosynthesis are subsequently allocated to all plant parts for growth and development.

The greater the plant height and the more abundant the leaves, the more significant the relationship with the assimilates produced by plants. This concept is evidenced by the notable increase in plant weight and the weight of bulbs produced in fresh and dry conditions, which differs significantly compared to the treatment control. Moreover, the Zn-EDTA priming and $ZnSO_4.7H_2O$ priming treatments yielded the best results in terms of bulb diameter and bulb height, directly impacting bulb production. The robust growth of the crown part of the plant also corresponds with the development of cell organs in the bulb part. Regarding the number of bulbs, bulb fresh weight, and bulb dry weight, it is evident that the provision of Zn-EDTA priming and $ZnSO_4.7H_2O$ priming yielded the best results. The enhanced bulb formation in these treatments is directly influenced by the efficient allocation of assimilates to the bulb part of the plant, thus aligning with observations regarding the crown-to-bulb ratio and the harvest index. They indicate that the smaller the crown-to-bulb ratio, the greater the value of the harvest index compared to the control treatment. All these parameters directly correlate with the increase in productivity. In a study conducted by Sharma and Singh (2018), the application of 0.5% Zn increased the yield of shallot bulbs by 46.67%. Likewise, Tariq et al. (2018) reported that Zn increased bulb diameter, bulb height, and yield of onion bulbs compared to the control. These significant results cannot be perceived without understanding the role of Zn as a nutrient crucial for various plant metabolic processes (Putri et al., 2024). Zn contributes to several physiological activities that enhance plant growth, development, and yield (Saleem et al., 2022). Zn also improves plant morphology, demonstrating significantly better results than treatments without Zn.

Bulb moisture content and shrinkage revealed a close relationship between the observation parameters. The higher the bulb moisture content, the greater the bulb shrinkage, whereas conversely, the lower the bulb moisture content, the lower the bulb shrinkage. The Zn-EDTA priming and $ZnSO_4.7H_2O$ priming treatments yielded the best results, demonstrating a decrease in bulb moisture content and shrinkage. Bulb moisture content and shrinkage significantly affected the quality and storability of bulbs. Low bulb moisture content and shrinkage indicated higher bulb density, leading to extended shelf life. The quality of bulbs is influenced by nutrient uptake, particularly potassium, which enhances shallot bulb development. Research conducted by Solanki et al. (2018) reported that applying 4 kg ha^{-1} Zn increased protein content, N, and K uptake, while P uptake increased following the application of 2 kg ha^{-1} Zn. This quality is particularly crucial in the post-harvest handling process of shallot bulbs.

Conflict of Interest

The authors indicate no conflict of interest in this work.

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