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Genetic Variability of Shallot Genotypes Induced by Salicylic Acid Under Drought Conditions

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Abstract

Genetic variability analysis is essential to support the selection of drought-tolerant shallot genotypes. This study aimed to estimate the quantitative genetic variability of five shallot varieties induced by 1 mM salicylic acid (SA) under drought stress conditions. The experiment was arranged in a split-plot design with three replications. Genetic analysis included variance, Genetic Variation Coefficient (GVC), and broad-sense heritability (h^2bs). The results showed that the application of 1 mM SA increased leaf length, number of leaves, number of bulbs, and dry weight of leaves, roots, and bulbs in all varieties under drought stress. The Genetic Variation Coefficient (GVC) value ranged from 8.32–31.66%, with a high category (>20%) for the characters of number of leaves per clump, leaf dry weight, root dry weight, number of bulbs, bulb dry weight, and bulb dry weight per clump. High heritability values (>50%) were obtained for number of leaves per clump, bulb dry weight, and bulb dry weight per clump. These characters have the potential to be used as selection criteria for the development of drought-tolerant varieties.

INTRODUCTION

Shallots (*Allium cepa* L. var. aggregatum) are a national strategic commodity with high economic value, but their productivity is highly susceptible to drought stress (Gökçe et al., 2022; Sansan et al., 2024). This condition is a main problem in the field because shallots have a shallow root system that limits the plant's ability to absorb water, making them highly sensitive to water deficits (Ghodke et al., 2018). Drought not only reduces plant water status but also inhibits photosynthesis and triggers oxidative stress due to increased reactive oxygen species (ROS) (Pamungkas & Farid, 2022), which ultimately reduces bulb growth and yield significantly, even by more than 60% under severe stress conditions (Salehi-Lisar & Bakhshayeshan-Agdam, 2020; Sumarianti et al., 2021). This situation poses a challenge in maintaining the stability of shallot production in production centers (Hadiawati et al., 2018; Sumarianti et al., 2021).

Efforts to increase drought tolerance through the application of salicylic acid (SA) have been widely reported to enhance plant physiological responses to stress through membrane stabilization and osmotic regulation (Liu et al., 2022; Khan et al., 2022; Ginting et al., 2024). However, the response to SA is genotype-specific, so its effectiveness is highly dependent on the genetic potential of each variety (Khotimah, 2022; Khotimah et al., 2024). To date, information on SA-induced quantitative genetic variability in shallots under drought stress conditions is still limited, particularly regarding selection parameters, such as the coefficient of genetic variation and heritability.

Addressing the impacts of drought requires a systematic breeding program, and breeding success is largely determined by the availability and analysis of

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genetic diversity in the tested population (Widyaningtyas et al., 2023). Understanding genetic diversity and trait inheritance will assist breeders in conducting efficient selection. Selection success is determined by genotypes with a high Genetic Variation Coefficient (GVC) (>20%) and dominant Broad-Sense Heritability (h2bs) (Abro et al., 2020; Ahmed et al., 2024).

Salicylic acid functions not only as an inducer in resistance mechanisms to biotic and abiotic stresses (Khan et al., 2020; Faroq et al., 2009) but also as a powerful inducer for unlocking genetic potential. SA induction under stress conditions limits environmental influences that mask genetic expression, allowing breeders to observe and quantify genetic variation truly associated with adaptation (Mahmood et al., 2021).

Genetic studies have shown that yield traits, such as bulbs dry weight and root dry weight, tend to have higher heritability than vegetative growth traits. Root dry weight is a critical trait under drought stress because it reflects the plant's ability to prioritize assimilate allocation to water retrieval and anchorage (Gökçe et al., 2022; Sansan et al., 2024). Identification of strong positive correlations between yield traits with high heritability and easily measurable secondary traits is also crucial for the efficiency of indirect selection (Ahmed et al., 2024). Therefore, this study was designed to specifically quantify genetic diversity and heritability in shallot varieties induced by SA under drought conditions. This study aimed to estimate the quantitative genetic variability of five shallot varieties induced by 1 mM salicylic acid (SA) under drought stress conditions based on morphological characters.

MATERIALS AND METHODS

The research was conducted at the Greenhouse of Muhadi Setiabudi University from August to October 2025. The research materials were 3-month-old shallot bulbs of Brebes, Bima Juna, Tajuk, Nganjuk Bauci, and Superphilip varieties and salicylic acid (MERCK). The experiment was arranged in a completely randomized design with a split-plot design and three replications. The main factor was shallot varieties (V), consisting of V1 = Bima Brebes, V2 = Bima Juna, V3 = Tajuk, V4 = Nganjuk Bauci and V5 = Superphilip, and the second factor was salicylic acid treatment, consisting of S0 = without SA (control) and S1 = 1 mM salicylic acid. Each replication consisted of 10 plants per variety, planted in 20 cm diameter pots. The planting medium consisted of a mixture of soil and compost (1:1 ratio). Drought stress was applied uniformly to all experimental units starting at four weeks after planting (WAP) to the critical phase of bulb formation. Drought conditions were maintained by controlling soil moisture content at 40% of Field Capacity (FC), which was measured using a gravimetric method. Salicylic Acid induction treatment at 1 mM was applied before drought stress through foliar application using a hand-sprayer in the morning and afternoon.

Observations were conducted during the harvest phase (50-60 days after planting) and included two variable categories. Morphological traits included leaf length (cm), the number of leaves per clump (blades), leaf dry weight (g), and root dry weight (g). Yield component traits included the number of bulbs per clump, bulb dry weight (g), and bulb dry weight per clump (g). In addition, the genetic coefficient of variation (GCV), genotypic variance (GV), and broad-sense heritability (h^2bs) were calculated for each trait using the standard variance component formula according to Allard's method (1960). The data collected were analyzed using ANOVA, and differences between varietal means were tested using Duncan's test at the 5% level.

RESULTS AND DISCUSSION

The results of the analysis of variance showed no significant interaction between varieties and salicylic acid treatment for any variables. This indicates that the variety's response to salicylic acid is relatively uniform under drought stress. Therefore, the differences are more influenced by the genetic factors of the varieties and the main effect of salicylic acid. All treatments in this study were applied under drought stress conditions, thus reflecting the genotype's response to the stressful environment. Drought stress inherently inhibits the growth of shallot genotypes, which is characterized by the lowest result in all morphological traits (leaf length, the number of leaves per clump, leaf dry weight, and root dry weight) in the stress control treatment (S0). The application of salicylic acid/SA (S1) proved to be an effective mitigation strategy in restoring vegetative growth in most varieties. Collectively, the application of 1 mM SA increased the average leaf length across all varieties, with the highest increase observed in Tajuk variety (V3), from 25.09 cm to 28.88 cm. This

Table 1. Morphological traits of shallot genotypes induced by salicylic acid under drought conditions

Shallot Varieties on SA Treatment	Leaf Length (cm)	Leaf Number per Clump (blades)	Leaf Dry Weight (g)	Root Dry Weight (g)
Bima Brebes				
0 mM SA (S0)	21.57 a	7.35 a	12.93 a	1.38 a
1 mM SA (S1)	25.72 b	9.80 b	14.33 b	2.15 b
Bima Juna				
0 mM SA (S0)	21.49 a	11.35 a	12.50 a	1.05 a
1 mM SA (S1)	24.23 b	13.46 b	13.83 a	1.37 a
Tajuk				
0 mM SA (S0)	25.09 a	12.12 b	14.44 a	1.25 a
1 mM SA (S1)	28.88 b	13.66 b	16.50 b	1.36 a
Nganjuk Bauci				
0 mM SA (S0)	24.29 a	5.61 a	12.90 b	1.38 a
1 mM SA (S1)	26.54 b	8.33 b	13.35 b	1.59 a
Super Philips				
0 mM SA (S0)	20.93 a	7.65 b	14.22 a	1.35 a
1 mM SA (S1)	25.03 b	8.33 b	16.13 b	1.50 a

Remarks: Means followed by the same letters in the same column are not significantly different based on the Duncan Multiple Range Test with an alpha of 0.05.

increase confirms the role of SA as a signaling molecule in plant growth. As explained by Indarwati et al. (2021), salicylic acid plays a role in enhancing plant growth by promoting cell expansion and stem elongation. These results are also corroborated by Pamungkas & Farid (2022) who stated that the mechanism of action of SA in reducing oxidative damage and maintaining cell turgor has been recognized as key to maintaining growth rates under water deficit.

An increase in the number of leaves per clump was also observed in all tested varieties after SA application, indicating that SA successfully optimized the production of primary photosynthates. However, the results showed that only Bima Brebes (V1) and Tajuk (V3) varieties showed a statistically significant increase in leaf dry weight after SA treatment. This indicates that although SA improves shoot growth, the ability to allocate carbon efficiently under stress is a specific genetic trait (Gökçe et al., 2022; Sansan et al., 2024). Varieties V1 and V3 likely have higher photosynthetic efficiency or assimilate translocation, which are critical selection criteria in stress-tolerant plant breeding.

Root dry weight is a crucial variable directly related to a plant's ability to access water and nutrients under drought stress (Pusparani et al., 2025; Mahmood et al., 2021). Of the five varieties tested, only Bima Brebes variety (V1) showed a statistically significant increase in root dry weight, from 1.38 g to 2.15 g after SA induction (S1). This response confirms that V1 variety is a superior genotype in responding to SA signals to prioritize biomass allocation to the root system. This mechanism is important because a strong root system ensures stable and sustainable water uptake (Pamungkas & Farid (2022); Fischer & Maurer (1978), which is positively correlated with high heritability and long-term drought resistance (Abro et al., 2020; Purwantoro et al., 2017). Therefore, V1 can be identified as the best candidate for drought tolerance breeding.

In contrast, Bima Juna (V2), Nganjuk Bauci (V4), and Super Phiip (V5) varieties showed significant increases in shoot morphology (leaf length and the number of leaves per clump) after SA treatment, but without significant increases in leaf dry weight or root dry weight. This may be due to the SA mechanism that increases water use efficiency (WUE) through partial stomatal closure (Ginting et al., 2024; Purbajanti, 2023; Indarwati et al., 2021). Although the plants were able to survive and exhibit vertical growth (leaf length) (Khotimah et al., 2024), carbon efficiency and biomass allocation in these three varieties might be lower, resulting in stable shoot and root dry weight accumulation (Purbajanti, 2023; Ginting et al., 2024). In addition, net photosynthesis

Table 2. Characteristics of the 70% decomposed chicken manure used in the experiment

Shallot Varieties on SA Treatment	Bulb Number per Clump (g)	Bulb Dry Weight (g)	Bulb Dry Weight per Clump(g)
Bima Brebes			
0 mM SA (S0)	3.77 a	4.32 a	17.42 a
1 mM SA (S1)	5.00 b	4.97 b	25.49 b
Bima Juna			
0 mM SA (S0)	4.55 a	4.12 a	20.49 a
1 mM SA (S1)	4.83 a	4.87 b	23.96 b
Tajuk			
0 mM SA (S0)	4.88 a	3.97 a	20.81 a
1 mM SA (S1)	6.16 b	5.14 b	31.74 b
Nganjuk Bauci			
0 mM SA (S0)	4.55 a	4.12 a	20.49 a
1 mM SA (S1)	4.83 a	4.87 b	23.96 b
Super Philips			
0 mM SA (S0)	4.11 a	4.25 a	18.36 a
1 mM SA (S1)	4.50 a	5.09 b	23.13 b

Remarks: Means followed by the same letters in the same column are not significantly different based on the Duncan Multiple Range Test with an alpha of 0.05

rates may be significantly inhibited due to stomatal CO_2 limitation, thus limiting assimilate production for dry biomass accumulation (Indarwati et al., 2021). This diversity of responses suggests that plant morphological diversity may occur due to specific genotype-environment interactions (Khotimah et al., 2024).

The data in Table 2 show that 1 mM Salicylic Acid (SA) treatment successfully improved shallot yield components under drought stress conditions. All tested varieties showed a significant increase in bulb dry weight per clump. This confirms the role of SA as a stress-buffering molecule that helps plants divert energy (assimilates) to storage organs, namely bulbs (Indarwati et al., 2021; Purbajanti, 2023). Variety V3 (Tajuk) showed the best response, with bulb dry weight per clump increasing from 20.81 g (S0) to 31.74 g (S1). This indicates efficiency in the conversion of photosynthetic results into bulb biomass. Meanwhile, V1 (Bima Brebes) variety showed a high and balanced increase in yield on bulb dry weight per clump and bulb dry weight. This difference in response indicates strong genetic diversity in how each variety modulates bulb formation signals under the influence of SA under drought stress conditions (Pamungkas & Farid, 2022; Salehi-Lisar & Bakhshayeshan-Agdam, 2020).

In contrast, Bima Juna (V2), Nganjuk Bauci (V4), and Super Phiip (V5) varieties showed significant increases in shoot morphology (leaf length and the number of leaves per clump) after SA treatment, but without significant increases in leaf dry weight or root dry weight. This may be due to the SA mechanism that increases water use efficiency (WUE) through partial stomatal closure (Ginting et al., 2024; Indarwati et al., 2021). Although the plants were able to survive and exhibit vertical growth (leaf length), carbon efficiency and biomass allocation in these three varieties might be lower, resulting in stable shoot and root dry weight accumulation (Ginting et al., 2024). In addition, net photosynthesis rates may be significantly inhibited due to stomatal CO_2 limitation, thus limiting assimilate production for dry biomass accumulation (Indarwati et al., 2021). This diversity of responses suggests that plant morphological diversity may occur due to specific genotype-environment interactions.

The genetic parameters in Table 3 illustrate the morphological traits and yield components that are influenced by genetic or the environment. The characters of bulb dry weight, bulb dry weight per clump, and root dry weight show high genetic variation coefficient (GVC)) values (>20%). A high GVC value indicates significant genetic differences between varieties, which is an important raw material for the selection process. A high GVC value

Table 3. Values of environmental variation, genetic variation, phenotypic variation, broad sense heritability, and genetic variation coefficient of red onion varieties induced by salicylic acid under drought conditions

Variables	σ^2g	σ^2g	σ^2p	h^2bs	GVC (%)
Leaf length	10.57	4.10	14.67	27.95	8.32
Leaf number per clump	4.32	4.75	9.07	52.37	20.39
Bulbs number per clump	1.03	0.82	1.85	44.32	20.62
Leaf dry weight	12.33	10.87	23.20	46.85	22.16
Root dry weight	1.03	0.82	1.85	44.32	20,62
Bulbs dry weight per clump	0.41	40.53	79.99	50.67	31.66
Bulbs dry weight	39.46	0.62	1.03	60.19	18.03

Remarks: σ^2e = environmental variation; σ^2g = genetic variation; σ^2p = phenotypic variation; h^2bs = broad sense heritability; GVC = Genetic Variation Coefficient. Broad-sense heritability estimates h^2bs <20% = narrow; 20%< h^2bs < 50% = Moderate; and h^2bs > 50% = High

indicates a small environmental error, meaning that the visible traits (phenotypes) are largely influenced by genetics (Widyaningtyas et al., 2023). Selection based on bulbs yield will be very efficient because the results are not easily affected by fluctuations in environmental conditions (Ahmed et al., 2024).

Table 3 presents broad-sense heritability (h^2bs), which is an estimate of the proportion of phenotypic variation caused by genetic factors, indicating the extent to which a trait is heritable. The analysis results show that bulb dry weight has the highest broad-sense heritability (60.19%), indicating that most of the observed variation in bulbs weight is under strong genetic control. This suggests that the bulb dry weight trait tends to be stable and has great potential to be passed on to the next generation, even under limiting drought stress (Purwantoro et al., 2017). Conversely, Leaf length has the lowest heritability (27.95%), indicating that phenotypic variation in leaf length is strongly influenced by environmental factors (σ^2e or relatively large environmental variance). Traits with low heritability, such as leaf length, indicate that genetic selection for improvement of this trait will be less effective, as the response to selection will be small, and the results obtained are more a result of environmental adaptation, rather than genetic progress (Setiawan et al., 2021).

The genetic variation coefficient (GVC)) is a critical parameter that describes the distribution of existing genetic variation available for selection. A high GVC indicates a broad genetic diversity within the population, which is highly beneficial for plant breeding. In this study, bulb dry weight per clump trait showed the highest GVC value at 31.66%, followed by the number of leaves per clump (20.39%) and the number of bulbs per clump (20.62%). High GVC values (generally considered high if >20%) for these key yield traits indicate a broad genetic pool among the test varieties; thus, direct selection on these traits is likely to result in significant and rapid genetic progress (Purwantoro et al., 2017; Naseem et al., 2015). Interestingly, although bulb dry weight had the highest heritability, its GVC was relatively low (18.03%). The combination of high heritability and low GVC implies that this trait is genetically controlled, but the selectable variation (difference between varieties) in the test population is not substantial. Therefore, selection to increase the bulbs dry weight per clump (high GVC) will be more effective than selection on bulb dry weight.

CONCLUSIONS

Based on the research results, it can be concluded that salicylic acid induction can improve the performance of morphological traits, including leaf length, the number of leaves per clump, leaf dry weight, and root dry weight, and yield components, such as the number of bulbs per clump, bulb dry weight, and bulb dry weight per clump. High genetic diversity was found in all tested traits except for leaf length. However, high broad-sense heritability estimates were found in the number of leaves per clump, bulb dry weight, and bulb dry weight per clump. This study used only a limited number of varieties, and the analysis was limited to morphological traits and yield components. That future research is expected to involve more genotypes and conduct tests under different environmental conditions. Furthermore, physiological and molecular approaches are also neccessary to gain a more comprehensive understanding of the mechanisms of drought tolerance.

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