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Promoting Flowering and Yield in Indonesian Shallot Varieties Through the Application of Gibberellins

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ABSTRACT

Shallot cultivation in Indonesia often encounters significant challenges due to the plant's reluctance to flower, leading to farmers' reliance on consumption bulbs as planting material. This practice results in increased farming costs, lowered production, and the risk of pathogen infection, thereby impacting yield adversely. This study aimed to investigate the role of gibberellin on the flowering and yield of diverse shallot varieties in Indonesia. A two-factor split-plot design was implemented within a completely randomized block structure. The first factor, gibberellin, was applied at three levels (without gibberellin, GA3, and GA4) as the main plot. The second factor, variety, was incorporated as a sub-plot with five levels (Bima Brebes, Biru Lancor, Superb Philip, Maja Cipanas, and Batu Ijo). Each treatment was replicated thrice, resulting in 30 experimental units. Analysis of Variance was performed at a 5% level, followed by the Duncan Multiple Range Test at the 5% level when influence was observed. A significant acceleration in shallot flowering by 35.67 days was noted when the Biru Lancor variety was treated with GA3. A correlation was found between flower fresh weight and the number of shallot seeds per inflorescence. Each variety exhibited different flowering capabilities, with the Maja Cipanas variety portraying the highest flowering percentage (13.78%). GA3 was observed to enhance the percentage of flowering plants and, when combined with the Batu Ijo variety, to support shallot bulb yield. The results indicate that GA3 can effectively promote the flowering and yield of shallots in Indonesia.

1. INTRODUCTION

Shallots, a primary horticultural product in Indonesia, have recently experienced inflation, predominantly attributable to production factors [1]. A significant issue impeding shallot production is the sourcing of planting material, with local farmers resorting to using consumable bulbs [2]. This practice accounts for a staggering 14% of the total production (approximately 254,162.3 tons), marking up farming costs to nearly 28% of the total expenditure [3]. Furthermore, these consumable bulbs have been found to be infected with various viruses, including the shallot yellow stunt virus, shallot latent virus, garlic common latent virus, and onion yellow dwarf virus, in 66% to 100% of cases [4, 5]. Such infections can result in yield losses of up to 45% [6, 7].

The crux of crop production is the quality of planting material, which directly affects the productivity and yield quality of shallots [8, 9]. The necessity for quality planting material arises from the inherent difficulty of inducing flowering in Indonesian shallots, and their typically low fertility once they do flower [10, 11]. As long-day plants, shallots require over 12 hours of sunlight to flower and produce seeds [12, 13]. Although it has been reported that both flowering and non-flowering shallot families in Indonesia share the same potential flowering gene, the flowering percentage in the flowering clumps was found to be significantly higher and correlated with endogenous gibberellin content [12].

The shallot varieties cultivated in Indonesia, including the widely grown Bima Brebes, are capable of natural flowering and seeding, although this is highly influenced by environmental factors such as light duration and temperature [14-16]. The Bima Brebes variety, for instance, has low flowering ability (19.57%) [17], yet continues to be a favored choice due to its adaptability to various regions and soil types in Indonesia, and potential for high tuber production [18]. Other varieties, such as the Superb Philip, Batu Ijo, and Biru Lancor, also offer unique adaptations to specific conditions and have different flowering times [19-21].

The duration of sunlight exposure and temperature are critical environmental factors that influence shallot flowering [22-24]. Shallot seeds can be naturally produced in highlands with temperatures below 20℃ [23]. Vernalization, or low-temperature treatment, has been shown to significantly affect flowering days, the number of flower stalks, and the percentage of flowering plants [25]. However, the production of flowering shallots in the lowlands remains a challenge due to the inability of all varieties to flower under these conditions.

This challenge can be surmounted by either vernalization or by the application of gibberellins [26, 27], which are phytohormones acting as endogenous signals at the flowering stage. Endogenous gibberellin regulates the passage of SOC1, a floral integrator, and the expression of messenger RNA [28, 29]. These pathways integrate flowering signals and then converge to set up a set of interest pathway integrators, including FLOWERING LOCUS T (FT), SUPRESSOR OF OVEREXPRESSION OF CONSTANS 1 (SOC1), and LEAFY (LFY) [30, 31]. Previous studies have demonstrated that gibberellins can accelerate flowering and increase the flowering percentage of the Bima Brebes variety [32].

The novelty of the current study lies in the combination of various shallot varieties with the application of two types of gibberellins, GA3 and GA4. As each shallot variety possesses a unique flowering ability, the application of gibberellin can initiate shallot flowering. This study aims to investigate the role of gibberellin in promoting the flowering and yield of various shallots in Indonesia. The hypothesis is that the appropriate combination of varieties and gibberellins can enhance the flowering and yield of shallots.

2. MATERIALS AND METHODS

The research was conducted from March to May 2022 in Gunungsari Hamlet, Ngringo Village, Jaten District, Karanganyar Regency, Central Java, Indonesia, with an altitude of 98 meters above sea level. The soil in the research location was a Grumusol soil type. The research area at coordinates 7°54'92.77" S 110°86'90.44" E. The temperature in the research area during the day is 31.43℃, while the morning temperature is 25.08℃. The average maximum air humidity in the study locations in March-May 2022 was 90.77%, and the average minimum air humidity was 71.32%. The average monthly rainfall at the research location in March-May 2022 is 316.33 mm. The study used a completely randomized block design with a two-factor split plot pattern with three replications. The first factor as the main plot is gibberellin with three levels, namely without gibberellins, GA3, and GA4. The second factor as a sub-plot is a variety with five levels: Bima Brebes, Biru Lancor, Superb Philip, Maja Cipanas, and Batu Ijo. Each treatment was repeated three times so that there were 30 experimental units. The plot size in each experimental unit was 1×1.5 m^2.

Gibberellins (GA3 100ppm and GA4 100ppm) were applied 2 to 7 weeks after planting by spraying 400ml.plot^{-1} of gibberellins on shallot plants. Making Gibberellin 100 ppm by 1) weighing 100 mg (0.1 gram) GA3 or GA4 using an analytical balance, then putting it in a 25 ml beaker, 2) dripping NaOH solution until GA3 dissolves then adding 10 ml distilled water, 3) adding in a 1000 ml measuring flask and add distilled water until the estimating flask limits, 4) stir using a magnetic stirrer for 5 minutes. The tools used in this study are hand sprayers, calipers, and digital scales. The materials used are topsoil, GA3 100 ppm, GA4 100ppm, Aquadest as a solvent, shallot seeds of the BimaBrebes, Biru Lancor, Superb Philip, Maja Cipanas, and Batu Ijo varieties of shallots, cow dung fertilizer. Land preparation was done by clearing weeds that grow in the study area. Next, make beds with a bed height of 15-30 cm and a ditch between the beds with a width of 30-40 cm. Land management was tillage with essential fertilizer with organic cow manure of 30 tonnes/ha. Planting shallot bulbs was done by planting shallot cloves at a depth of approximately 2 cm with a spacing of 0.002×0.0015 m^2. Harvesting was done 70 days after planting.

Observational variables observed were: days of flowering (observations were made during maintenance by paying attention to plots that had already appeared flowers), percentage of flowering plants (calculating the percentage of flowering plants using the comparison formula between flowering plants and the total plants in one plot then multiplied by 100%), number of flowering clumps, number of flowers, fresh weight of flowers, number of seeds per flower, number of bulbs per clump, the weight of bulbs per clump, the diameter of bulbs was carried out at harvesting i.e., 70 days after planting. Data analysis using the Statistical Package for the Social Sciences (SPSS) version 21 program. Data analysis used Analysis of Variance with a level of 5%. If there was an effect, it continued with the Duncan Multiple Range Test at a level of 5%.

3. RESULTS AND DISCUSSION

3.1 Shalot flowering potential

The results of the study showed that the combination of gibberellin and variety affected on the day the shallot flowers appeared, with a calculated F value of 5.293 and a significance value of 0.001 (Table 1). Application of GA3 on the Biru Lancor variety showed a faster flower appearance of 35.67 days. However, Biru Lancor variety without gibberellin showed flower appearance at 38.33 days and significantly differed from the GA3 application. Based on the variety description, Biru Lancor can flower 50 days after planting. This shows that the flowering time in the gibberellin treatment is faster because gibberellin regulates growth and promotes flowering, branching, and cell differentiation [33, 34]. Gibberellin can stimulate flowering by promoting the differentiation of cambium stem cells to produce xylem [35, 36].

The results showed that applying gibberellins and varieties affected the percentage of flowering plants (Table 2). The Maja Cipanas variety has the highest flowering percentage, namely 13.78%. The Maja Cipanas variety has a higher production level than the Bima Brebes [37]. The Lancor Blue variety had the lowest flowering percentage, namely 8.44%. The Biru Lancor variety has shallot production of 8.9 tonnes/ha, while its potential is more than 15 tonnes/ha. The percentage of shallot plants that produce flowers is still low because shallots require more than 12 hours of irradiation and are affected by temperature. So as to encourage the flowering of shallots in Indonesia with exogenous signals such as the application of gibberellins [38]. Based on the results of this study, the GA3 application showed the highest percentage of interest, namely, 16.27%. Meanwhile, without gibberellin, it showed the lowest percentage of flowering, namely 6.13%. This is because the application of GA3 encourages the initiation of flowering and plays a role in flower growth [39]. Gibberellins can control the generative growth stage and promote more intensive flowering [40].

The results showed that the variety and application of gibberellins affected the number of flowering clumps per plot (Table 3). The number of flowering clumps per plot indicated the number from each treatment in one planting plot. Each variety has a different number of flowering clusters. The Maja Cipanas variety had more flowering clumps per plot than the other treatments, namely 6.89. The Biru Lancor variety produced the lowest number of flowering clumps per plot, namely 4.22. Plants from flowering and non-flowering families can flower [12]. The number of flowering clumps per plot can be used as a benchmark in determining the flowering capacity of each variety. Flowering is a plant development that leads to the formation of flower organs [14, 41]. The results showed that the application of GA3 showed the highest number of flowering clumps per plot, namely 8.13. The flowering process will not occur if the environment is not supportive and no hormone activity supports the flowering process. Plants that flower have higher endogenous gibberellins [42], so to encourage flowering, they can increase exogenous gibberellins.

Table 1. Days of emergence of flowers (Days After Planting)

Gibberellins	Shallot Varieties					Average
	Bima Brebes	**Biru Lancor**	**Superb Philip**	**Maja Cipanas**	**Batu Ijo**	
Without Gibberellin	37.67 abc	38.33 bc	40.67 de	47.33 g	45.67 g	41.90 c
GA3	36.67 ab	35.67 a	37.33 abc	39.00 cd	41.00 de	37.93 a
GA4	37.67 abc	37.33 abc	37.33 abc	42.33 ef	43.33 f	39.60 b
Average	37.33 a	37.11 a	38.44 b	42.89 c	43.33 c	+

Note: Positive notation (+) in the column states that there is an interaction between gibberellins and varieties based on Analysis of Variance with a level of 5%.

Table 2. Percentage of flowering shallot plants (%)

Gibberellins	Shallot Varieties					Average
	Bima Brebes	**Biru Lancor**	**Superb Philip**	**Maja Cipanas**	**Batu Ijo**	
Without Gibberellin	7.33	4.67	5.33	8.67	4.67	6.13 a
GA3	18.00	12.67	16.67	19.33	14.67	16.27 c
GA4	12.00	8.00	10.00	13.33	9.33	10.53 b
Average	12.44 c	8.44 a	10.67 b	13.78 d	9.56 ab	-

Note: Negative notation (-) in the column states that there is no interaction between gibberellins and varieties based on analysis of variance with a level of 5%.

Table 3. Number of flowering clumps (fruits) per plant plot

Gibberellins	Shallot Varieties					Average
	Bima Brebes	**Biru Lancor**	**Superbb Philip**	**Maja Cipanas**	**Batu Ijo**	
Without Gibberellin	3.67	2.33	2.67	4.33	2.33	3.07 a
GA3	9.00	6.33	8.33	9.67	7.33	8.13 c
GA4	6.00	4.00	5.00	6.67	4.67	5.27 b
Average	6.22 c	4.22 a	5.33 b	6.89 d	4.78 ab	-

Note: Negative notation (-) in the column states that there is no interaction between gibberellins and varieties based on analysis of variance with a level of 5%.

Table 4. Fresh weight of flowers per plot (g)

Gibberellins	Shallot Varieties					Average
	Bima Brebes	**Biru Lancor**	**Superb Philip**	**Maja Cipanas**	**Batu Ijo**	
Without Gibberellin	5.25 de	4.18 bc	3.13 a	4.42 cd	3.23 ab	4.04 a
GA3	10.38 ij	9.83 hi	9.34 gh	11.31 j	9.07 gh	9.98 c
GA4	8.53 g	5.92 ef	6.21 ef	9.07 gh	6.32 f	7.21 b
Average	8.05 b	6.64 a	6.23 a	8.27 b	6.20 a	+

Note: Positive notation (+) in the column states that there is an interaction between gibberellins and varieties based on analysis of variance with a level of 5%.

Table 5. Number of seeds per flower of shallot plants

Gibberellins	Shallot Varieties					Average
	Bima Brebes	**Biru Lancor**	**Superb Philip**	**Maja Cipanas**	**Batu Ijo**	
Without Gibberellin	41.08 c	34.35 b	25.17 a	47.32 c	23.53 a	34.29 a
GA3	83.85 g	77.52 f	76.20 f	88.85 g	67.26 e	78.74 c
GA4	59.01 d	42.00 c	47.52 c	66.31 e	41.56 c	51.28 b
Average	61.31 c	51.29 b	49.62 b	67.49 d	44.11 a	+

Note: Positive notation (+) in the column states that there is an interaction between gibberellins and varieties based on analysis of variance with a level of 5%.

The combination of varieties and gibberellin application has an effect on the fresh weight of flowers per plot, with a calculated F value of 3.371 and a significance value of 0.001 (Table 4). The combination of G3 application on the Maja Cipanas variety showed the highest per plot flower fresh weight of 11.31g. At the same time, the combination without gibberellins on the Superbb Philip variety produced the lowest flower fresh weight per plot, namely 3.13 g. This is because GA3 plays a role in improving interest quantity and quality, which will affect interest weight [43, 44]. Gibberellins interact with the flowering locus during the installation of shallot development [45]. Gibberellin signaling and the flowering locus are required to control independent pathway flowering. Thus, the depletion of GA in shallots can shoot apical meristems resulting in delayed flowering under short-day irradiation conditions [46]. The results showed that the greater the fresh weight of the flowers, the greater the number of seeds per flower.

Shallot flowering supports the formation of botanical seeds. The combination of varieties with gibberellin application affects the number of seeds in the shallot plant's inflorescence (Table 5). The combination of the Maja Cipanas variety with the GA3 application showed the highest number of seeds, namely 88.85 seeds. Gibberellin GA3 produced the highest number of seeds per flower, with an average of 78.74 seeds per flower, while the lowest yield was in the treatment without gibberellins, with an average of 34.29 seeds per flower. This shows that applying gibberellins can increase shallot plants' productivity and seeds [47].

3.2 Shallot yield potential

The results showed that the variety and application of gibberellin had an effect on the dry weight of the bulb per clump with a calculated F of 17.800 and a significance value of 0.000 (Table 6). The combined application of GA3 on the Batu Ijo variety showed the highest bulb dry weight per clump, namely, 80.40 g. However, the combination of Batu Ijo varieties without applying gibberellin only produced a bulb dry weight of 61.07 g. These results indicate that GA3 can increase bulb dry weight because gibberellins can increase auxin levels in plants which function for the differentiation of plant cells and organs [48]. Differentiation of plant cells and organs can increase the size and mass of shallot bulbs. Gibberellin hormone can increase the size of the leaves because of increased cell division [49]. The ability of plants to enlarge and form bulbs depends on the potency of plants to form and translocate assimilates from leaves to bulbs. The formation of shallot bulbs is better if the conditions and nutrients needed are optimal [50]. The variety and application of gibberellin also influence the number of bulbs per hill, with a calculated F value of 8.438 and a significance value of 0.000 (Table 7). The number of bulbs per hill is related to the weight of bubls per hill. The more the number of bulbs, the greater the weight of the bulbs because the shallot bulbs are formed from the enlargement of the leaf layers, which then develop into bulbs. GA3 application showed the highest number of bulbs compared to those without gibberellin or GA4 application. This is because most of the GA produced by plants is in an inactive form and requires a precursor to become an active form. The single factor of variety also influences the number of bulbs per hill with a calculated F value of 11.741 and a significance of 0.000 (Table 7). The Biru Lancor variety showed the highest number of bulbs of clumps, namely 6.25. The number of bulbs is more influenced by the genetic properties of the plant in that the varieties have the potential for a different number of bulbs [51]. Based on the variety's description, the lancor blue variety has a shallot production of 8.9 tonnes/ha, while the potential is more than 15 tonnes /ha. The Batu Ijo variety showed the lowest number of bulbs, namely only 4.40.

The results showed that the interaction between gibberellins and shallot varieties had an effect on the diameter of the bulbs per cluster with a calculated F value of 3.885 and a significance of 0.005 (Table 8). The GA4 treatment with the Batu Ijo variety produced the largest bulb diameter of 26.09 mm, which was also not significantly different from the GA3 treatment. The smallest bulb diameter was found in the treatment without gibberellin with the Bima Brebes variety, which was 21.30 mm. In line with research conducted by study [52], gibberellins affect the diameter of shallot plants. The varieties of shallots also influence the difference in the diameter of shallots. Each shallot variety has a different diameter potential [53, 54]. In addition, the response of each variety to the gibberellin application is also different. Although the use of gibberellin showed a significant effect on the bulb diameter of shallot plants, the size of the bulb diameter was still below the variety's yield potential.

Table 6. Dry weight of bulbs per hill (g) of shallot plants

Gibberellins	Shallot Variety					Average
	Bima Brebes	Biru Lancor	Superb Philip	Maja Cipanas	Batu Ijo	
Without Gibberellin	65.84 f	49.59 a	56.60 bcd	52.74 ab	61.07 e	57.17
GA3	74.38 h	56.23 bcd	61.52 e	57.59 cde	80.40 i	66.02
GA4	71.44 gh	53.63 bc	60.01 de	55.07 bc	68.51 fg	61.73
Average	70,55	53,15	59,37	55,13	69,99	+

Note: Positive notation (+) in the column states that there is an interaction between gibberellins and varieties based on analysis of variance with a level of 5%.

Table 7. Number of bulbs per shallot plant

Gibberellins	Shallot Varieties					Average
	Bima Brebes	Biru Lancor	Superb Philip	Maja Cipanas	Batu Ijo	
Without Gibberellin	6.27	5.88	5.72	5.44	4.33	5.53 p
GA3	7.00	8.16	6.41	6.05	5.55	6.63 q
GA4	5.50	7.27	6.11	5.77	3.33	5.59 p
Average	6.25 q	7.11 r	6.08 q	5.75 q	4.40 p	-

Note: Negative notation (-) in the column states that there is no interaction between gibberellins and varieties based on Analysis of Variance with a level of 5%.

Table 8. Bulbs diameter per hill (mm)

Gibberellins	Shallot Varieties					Average
	Bima Brebes	Biru Lancor	Superb Philip	Maja Cipanas	Batu Ijo	
Without Gibberellin	21.30 a	21.72 a	21.51 a	22.65 ab	22.67 ab	21.97
GA3	22.40 ab	22.57 ab	22.53 ab	23.95 bc	25.70 de	23.43
GA4	20.98 a	22.04 a	22.25 a	24.32 cd	26.09 e	22.13
Average	21.56	22.11	22.09	23.64	24.82	+

Note: Positive notation (+) in the column states that there is an interaction between gibberellins and varieties based on Analysis of Variance with a level of 5%.

4. CONCLUSION

Combining the Biru Lancor variety with the GA3 application accelerated shallot flowering by 35.67 days. The fresh weight of flowers correlated with the number of shallot seeds per inflorescence. Combining the Maja cipanas variety with GA3 increased the fresh weight of flowers and the number of seeds per flower. Combining the Maja cipanas variety with GA3 increased the fresh flower weight (11.31 g) and the number of seeds per flower (88.85 seeds). Each variety has different flowering abilities. GA3 can increase the percentage of flowering plants. In addition, combining the green dress variety with GA3 can support the yield of shallot bulbs. The results of this research can support the growth and flowering of shallots in the lowlands of Indonesia because each variety has different flowering abilities, so gibberellins can be used to initiate flowering.

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