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Effect of GA_3 on morphological and yield traits in single and triple capsule sesame accessions under field conditions

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ABSTRACT

Phytohormones, such as gibberellic acid (GA_3), are integral to the regulation of plant development, influencing processes that enhance genetic potential and performance. To determine the effect of GA_3 on some morphological and yield components of sesame (*Sesamum indicum* L.), an experiment was conducted in a factorial arrangement based on a complete block design in three replications. The first factor involved two sesame genotypes: one producing a single capsule per leaf axil (CAP1) and another producing triple capsules per leaf axil (CAP2). The second factor was the concentration of GA_3 applied, with treatments at 0 ppm (control), 50 ppm, and 100 ppm. Significant differences were observed in plant morphology and yield components as influenced by GA_3 treatment. Notably, the CAP2 genotype treated with 50 ppm GA_3 as a seed priming agent exhibited the greatest plant height (102 cm). This treatment also resulted in the highest number of nodes with triple capsules and the maximum number of capsules per plant. In terms of biomass, the fresh and dry weights were significantly increased by 72% and 73%, respectively, in the CAP2 genotype primed with 50 ppm GA_3, compared to the lowest values recorded under the 100 ppm GA_3 foliar spray treatment. Furthermore, the 1000-seed weight was maximized under the 50 ppm GA_3 seed priming treatment in the CAP2 genotype. These findings underscore the efficacy of 50 ppm GA_3 seed priming in enhancing morphological and yield attributes in sesame, particularly in genotypes with triple capsules per leaf axil. The study suggests potential agronomic benefits in utilizing GA_3 to optimize sesame crop performance.

Highlights

- The study investigates the effects of GA_3 on the growth and yield components of two sesame varieties.
- The study focuses on different concentrations and application methods consisting of seed priming and foliar spraying.
- The study identifies that 50 ppm GA_3 is the most effective concentration for improving growth and yield traits in sesame.
- The paper shows that GA_3 treatment significantly improved yield components, with CAP2 plants.

1. Introduction

Sesame (*Sesamum indicum* L.) is a significant annual oilseed crop cultivated predominantly in tropical and subtropical regions. However, it exhibits relatively high yield performance in temperate climates (Alegbejo et al., 2003). The seeds of sesame are notably rich in oil content, comprising 50-60% oil, along with 20% protein and 14-20% carbohydrates. The presence of endogenous antioxidants such as sesamol and sesaminol, in combination with tocopherols, contributes to the excellent oxidative stability of sesame oil (Ball et al., 2000).

Sesame has a comparatively low yield potential relative to other crop species, which can be attributed to factors such as its low harvest index, susceptibility to diseases, tendency for seed-shattering, and indeterminate growth habits (Ashri, 1994). Notably, all currently available commercial sesame cultivars in Iran and other regions exhibit an indeterminate growth habit. Research indicates

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that cultivars with a determinate growth habit produce lower yields compared to indeterminate types under standard planting densities (Ashri, 1995).

The branching trait has been observed in some ecotypes of sesame, particularly under high input conditions, where it can enhance capsule production. In sesame, capsules are a primary yield component, forming at the axils of leaves. The development of capsules typically begins from the axils of leaves located at about the fourth to sixth node pairs and continues up to the apex of the plant. This trait is controlled by a recessive gene and results in the formation of triple capsules. However, the occurrence of this triple capsule is limited and dependent on agronomic management, climatic conditions and sesame variety type. (Langham and Wiemers, 2002).

The length of the culm or branch in sesame plants is influenced by the availability of moisture and agricultural inputs. Optimal agronomic management, characterized by sufficient water and nutrient supply, can enhance growth parameters such as the elongation of the main stem and branches. This, in turn, leads to an increased number of capsules per plant.

Gibberellic acid (GA_3), a phytohormone, plays a crucial role in promoting plant growth and development when applied in small quantities and at low concentrations. Gibberellins are terpenoid compounds composed of isoprene units that contribute to increased stem elongation and cell division. The elongation of stems in response to the exogenous application of gibberellic acid (GA_3) is primarily due to its effects on both cell division and cell enlargement. While cell division is an essential component of the growth process, it alone does not account for growth; it must be accompanied by cell enlargement. This synergistic effect of cell division and enlargement is what drives growth in response to the application of GA_3 (Moore, 2012). The exogenous application of gibberellic acid has also been reported to enhance stem elongation, dry matter accumulation and yield in soybean (Maske et al., 1998; Deotale et al., 1998).

Chory et al. (1987) demonstrated that the application of GA_3-induced changes in a specific group of translatable mRNAs and the accumulation of polypeptides in pea and corn plants, which are associated with genetic modifications that enhance stem growth. GA_3 application enhances polyamine biosynthesis and promotes internode elongation in pea seedlings (Dai et al., 1982; Ross et al. 2003).

Additionally, Kaur et al. (2000) reported that seed priming with gibberellic acid accelerated flowering and ripening, thereby increasing yield in chickpeas. Studies have also shown that the application of GA_3 results in increased yield and yield components in wheat (*Triticum aestivum* L.) (Zarehmanesh et al., 2010) and corn (*Zea mays* L.) (Ghodrat et al., 2010).

With the growing global population and the rising demand for oil, it is imperative to investigate factors that affect crop yield. This study was conducted to explore the effects of different concentrations of gibberellic acid (GA_3) applied as a seed primer and foliar spray. The objective was to determine the optimal exogenous concentration and application timing of GA_3 to effectively enhance the growth and yield of the sesame plant (*Sesamum indicum* L.).

2. Material and method

To investigate the effects of gibberellic acid (GA_3) on some agronomic traits and yield components of sesame plants, a field experiment was conducted using a factorial arrangement based on a complete block design with three replications, at the Khorasan razavi agricultural and natural resources research and education center in Mashhad, Iran. The first factor in the experiment involved two types of seeds derived from plants grown over three consecutive years. Initially, 13 accessions of sesame seeds were obtained from the Oilseeds Section of the Agriculture Organization of Khorasan. Preliminary tests were conducted to assess the performance of these accessions (Nezami et al., 2014). In the initial year, seeds were collected from plants that produced three capsules per leaf axil. Over the next three years, these seeds were grown in pots to obtain pure lines with consistently triple capsules per leaf axil. From these plants, seeds were harvested and categorized based on capsule formation: one group with three capsules per leaf axil (CAP2) and another with single capsules per leaf axil (CAP1). These two types of seeds served as the first factor in the experiment. The second factor in the experiment involved the application of three concentrations of gibberellic acid (GA_3): 0, 50, and 100 ppm. These concentrations were applied at two stages in the sesame plant's life cycle: seed priming and foliar spray 65 days after planting (DAP). This setup resulted in six treatment combinations, assigned to zero, 50, and 100 ppm in prime; zero, 50, and 100 ppm were used in the form of foliar spraying in 65 DAP, Consequently, the total treatments included combinations of the GA_3 concentrations for seed priming and foliar application, resulting in six treatments designated as T1, T2, T3, T4, T5, and T6.

The seeds were disinfected with fungicides prior to planting on May 10. After the seedlings reached the four-leaf stage, they were thinned to maintain a spacing of 7 cm between plants in a row. Concurrently, weed control was carried out using mechanical methods. The field was irrigated weekly. Upon crop maturation, 10 plants from each plot, excluding those affected by marginal effects, were selected for measurement. The morphological and yield component traits assessed included plant height, number of branches, branch length, number of nodes with single capsules, number of nodes with multiple capsules, total capsules per plant, seeds per capsule, 1000-seed weight, fresh weight, and dry weight per plant. Data analysis was conducted using SAS software version 9.2, and mean comparisons were made using Duncan's multiple range test at a significance level of $p < 0.05$.

3. Results

3.1. Comparison of CAP1 and CAP2 Treatments

The results presented in Table 1 indicated significant differences between plants grown from seeds with single capsules per leaf axil (CAP1) and those from seeds with triple capsules per leaf axil (CAP2) in several traits. Specifically, CAP1 plants exhibited 32% more branches, averaging 3.82 branches per plant, compared to CAP2 plants. However, CAP2 plants showed 24% more nodes with multiple capsules and an 18% higher number of seeds per capsule compared to CAP1 plants. No significant differences were observed between the treatments for other measured traits (Table 1).

Table 1. Analysis of Variance (ANOVA) for various traits of sesame plants under field conditions in Mashhad

S.O.V	Df	Length of plant	Number of branches	Length of branch	Node of one capsule	Node of multiple capsules	Number of capsules per plant	Number of seeds per capsule	Weight 1000 seed	Fresh weight	Dry weight
Block	2	27.4^{ns}	3.11^{*}	283^{ns}	8.86^{ns}	14.6^{ns}	654.6^{**}	166.2^{*}	0.24^{*}	1024^{**}	73.5^{**}
Capsule (CAP)	1	0.21^{ns}	12.2^{**}	74.1^{ns}	2.83^{ns}	73.1^{**}	1216^{**}	71.7^{ns}	0.02^{ns}	5.7^{ns}	17.7^{ns}
Gibbereline (GA_3)	5	127^{*}	23.2^{**}	645^{**}	38.3^{*}	8.57^{ns}	175^{*}	110^{ns}	0.27^{**}	1576^{**}	44^{*}
Capsule×Gibberelin	5	552^{**}	12.7^{**}	1248^{**}	2.18^{ns}	102.1^{**}	1317^{**}	350^{**}	0.4^{**}	2551^{**}	183^{**}
Error	22	33.7	0.687	122	11.35	6.71	106	44.5	0.06	135	11.57

ns, * and ** are non-significant and significant at the 5 and 1% probability level respectively

3.2. Effects of gibberellic acid (GA_3)

Application of 50 ppm GA_3 as a seed primer resulted in the maximum plant height, reaching 94.2 cm. The lowest plant height, 69.3 cm, was observed in the T1 treatment (control). The highest number of branches (6.8) and branch length (64.6 cm) were recorded in the T2 and T5 treatments, respectively. The lowest number of nodes with single capsules was observed in T2 with 7.8, while the highest was found in the T1 treatment (Table 3). Foliar application of 50 ppm GA_3 resulted in the highest number of capsules per plant (62.2) and the highest number of seeds per capsule (49.1). Additionally, the 50 ppm GA_3 treatment achieved the maximum fresh and dry weights, with values of 85.5 g and 22.7 g per plant, respectively (Table 3).

Table 2. Mean comparison of traits in sesame plants with one capsule (CAP1) vs. triple capsules (CAP2) per leaf axil

Treatment	Length of a plant (cm)	Number of branches per plant	Length of branch (cm)	Node of one capsule per plant	Node of triple capsule per plant	Number of capsules per plant	Number of seeds per capsule	Weight 1000 seed (g)	Fresh weight (g)	Dry weight (g)
CAP1	87.37	3.89	50.25	13.09	8.65	52.7	38.3	2.58	65.3	17.2
CAP2	87.22	2.72	47.38	12.53	11.50	64.4	42.2	2.64	66.0	19.1
significant	ns	**	ns	ns	**	**	ns	ns	ns	ns

CAP1 and CAP2: Denote the types of plants based on the capsule trait (one vs. triple capsules per leaf axil).

Table 3. Mean comparison of traits under different gibberellin (GA_3) treatments in sesame plants with one capsule (CAP1) vs. multiple capsules (CAP2) per leaf axil

Treatment	Length of a plant (cm)	Number of branches per plant	Length of branch (cm)	Node of one capsule per plant	Node of triple capsule per plant	Number of capsules per plant	Number of seeds per capsule	Weight 1000 seed (g)	Fresh weight (g)	Dry weight (g)
T1	79.3^{d}	3^{c}	52.1^{abc}	16.3^{a}	9.9^{a}	62.8^{a}	39.6^{bc}	2.2^{b}	80.7^{ab}	18.9^{bc}
T2	94.2^{a}	6.8^{a}	37.1^{d}	14.1^{abc}	7.8^{a}	56.1^{ab}	37.3^{c}	2.4^{b}	85.5^{a}	22.7^{a}
T3	82.9^{bc}	4.1^{b}	54.7^{ab}	14.5^{ab}	10^{a}	61.4^{a}	41.1^{b}	2.3^{b}	70.8^{bc}	19.2^{abc}
T4	88.5^{ab}	2.1^{cd}	39.2^{cd}	10.6^{bc}	10.9^{a}	57.9^{ab}	38.5^{bc}	2.4^{b}	51.5^{de}	15.7^{cd}
T5	87.2^{bc}	2.3^{c}	64.6^{a}	10.8^{bc}	11.1^{a}	62.2^{a}	49.1^{a}	2.9^{a}	44.5^{e}	15.1^{d}
T6	81.4^{c}	1.3^{d}	45^{bcd}	10.4^{c}	10.5^{a}	48.7^{b}	38.9^{bc}	2.7^{a}	61^{cd}	17.5^{bcd}

For each trait, the averages that have at least one common letter, do not differ significantly according to Duncan's test at the 5% probability level.

T1 to T6: Treatment codes representing different GA_3 concentrations and application methods.

3.3. Interaction of CAP and GA_3 Treatments

The analysis of variance revealed significant interactions between the CAP types and GA_3 treatments for all measured traits, except for the number of nodes with single capsules per leaf axil (Table 1). The longest plants were observed in the CAP2 group with 50 ppm GA_3 priming, measuring 102 cm, while the shortest plants were in the T1 × CAP1 treatment group (Table 4). The number of branches per plant ranged from 1 in the T6 × CAP2 treatment to 10 in the T1 × CAP1 treatment. The maximum branch length was obtained from the CAP2 group with 50 ppm GA_3 priming, which was approximately 81% longer than the minimum branch length observed in the CAP1 group with 50 ppm GA_3 priming. There was no significant difference in the interaction between GA_3 and CAP treatments (both CAP1 and CAP2) regarding the number of nodes with single capsules per leaf axil (Tables 1 and 4).

The highest number of nodes with triple capsules per leaf axil and the greatest number of capsules per plant were observed in the CAP2 treatment with 50 ppm GA_3 seed priming. According to Table 4, as the concentration of GA_3 increased, these two traits also increased. However, the efficacy of GA_3 was more pronounced in the CAP1 treatment compared to CAP2, resulting in higher values for these traits in CAP1 under the same GA_3 concentrations.

The highest number of seeds per capsule was obtained from the T1 × CAP2 treatment. The maximum 1000-seed weight was recorded in the CAP2 treatment with foliar application of 50 ppm GA_3, while the lowest was observed in the T4 × CAP1 treatment. The number of seeds per capsule was also highest in the T2 × CAP2 treatment, showing an increase of approximately 32% compared to the corresponding CAP1 treatment, which had 37.5 seeds per capsule. Fresh and dry weights were greatest in the CAP2 treatment with 50 ppm GA_3 seed priming, showing increases of approximately 72% and 73%, respectively, compared to the lowest values, which were recorded in the T6 × CAP2 treatment (Table 4). Overall, most traits studied responded positively to gibberellic acid in plants grown from seeds with triple capsules, particularly with the application of 50 ppm GA_3 as seed priming.

Table 4. Mean Comparison of Interaction Between Gibberellin (GA_3) and Capsule Type on Agronomic Traits in Sesame Plants

Interaction effect of treatments	Length of plant (cm)	Number of branches per plant	Length of branch (cm)	Node of one capsule per plant	Node of triple capsule per plant	Number of capsules per plant	Number of seeds per capsule	Weight 1000 seed (g)	Fresh weight (g)	Dry weight (g)
T1 × CAP1	80.3 ^{d}	10.0^{a}	46.5^{bcd}	16.9^{a}	5.7^{ef}	46.1^{c}	24.1^{e}	2.8^{abc}	50.8^{c}	15.6^{de}
T2 × CAP1	85.6 ^{cd}	4.3^{bc}	16.2^{e}	13.5^{a}	6.3^{def}	49.8^{c}	37.5^{cd}	2.7^{abc}	55.4^{c}	16.4^{cde}
T3 × CAP1	82. 7 ^{cd}	3.6^{bcd}	60.5^{b}	14.3^{a}	10.4^{bcd}	67.8^{ab}	43.8^{abc}	2.2^{ef}	90.1^{b}	19.7^{cd}
T4 × CAP1	86.1^{cd}	2.00^{ef}	38.4^{d}	12.9^{a}	13.7^{abc}	77.8^{a}	47.8^{abc}	1.9^{f}	55.9^{c}	17.6^{cde}
T5 × CAP1	90.9 ^{bc}	1.6 ^{ef}	58 ^{bc}	11.1^{a}	14.6 ^{ab}	73.0 ^{a}	36.6 ^{cd}	2.3 ^{def}	47.6 ^{cd}	17.5 ^{cde}
T6 × CAP1	98.3^{ab}	1.6^{ef}	53.1^{bcd}	11.4^{a}	9.6^{de}	71.7^{ab}	46.1^{abc}	2.7^{bcd}	91.8^{ab}	27.5^{ab}
T1 × CAP2	98.3^{ab}	3.6 ^{bcd}	57.8 ^{bc}	15.7 ^{a}	14.2 ^{ab}	62.4^{abc}	52.0 ^{a}	2.4^{cde}	86.1^{b}	22.1^{c}
T2 × CAP2	102 ^{a}	1.6^{ef}	86.6 ^{a}	14.7 ^{a}	18.0 ^{a}	79.6 ^{a}	55.9 $^{a.}$	2.5 ^{bcde}	110 ^{a}	28.1 ^{a}
T3 × CAP2	83.1^{cd}	4.6^{b}	48.9^{bcd}	14.8^{a}	9.6^{cde}	55^{bc}	38.3^{cd}	2.5^{cde}	80.8^{b}	21.7^{c}
T4 × CAP2	90.9b^{c}	2.3^{def}	40^{cd}	11.0^{a}	8.00^{de}	47.0^{c}	50.4^{ab}	3.1^{a}	47.2^{cd}	13.8^{e}
T5 × CAP2	83.4^{a}	3.00^{cde}	42.5^{bcd}	12.5^{a}	7.60^{de}	46.8^{c}	40.4^{bcd}	2.6^{bcde}	41.4^{cd}	12.7^{ef}
T6 × CAP2	64.5^{e}	1.00^{f}	37.0^{d}	11.9 ^{a}	3.00^{f}	25.7^{d}	31.7^{de}	2.9^{ab}	30.2^{d}	7.6^{f}

For each trait, the averages that have at least one common letter, do not differ significantly according to Duncan's test at the 5% probability level.
T1 × CAP1 to T6 × CAP2: Interactions between the six GA_3 treatments and the two capsule types.

4. Discussion

Primary growth in plants, characterized by the initiation of new leaves and branches, begins with the development of blossom buds in the shoots. This phase of growth, which follows the opening of the blossom buds, is crucial for the establishment of the plant's vegetative structure. Secondary growth, which results in an increase in the diameter of the shoot, occurs subsequent to primary growth. This process is essential for the thickening of the plant's stems and branches. Hormonal signals, produced by actively growing buds, play a critical role in regulating these growth activities in plants (Moore, 2012).

Interactions between environmental factors and plant hormones play a crucial role in manifesting the internal potential of plants. Plant hormones, or phytohormones, are key regulators of developmental activities and are primarily responsible for the plant's response to external physical conditions. According to Keshavarzi et al (2013), applying 100 ppm GA_3 during the stem elongation phase of corn (*Zea mays* L.) resulted in a 14% increase in plant height compared to the control. In the present study, seed priming with 50 ppm GA_3 in the CAP2 treatment led to an approximately 15% increase in plant height compared to the control. This suggests that the application of exogenous GA_3, in conjunction with the plant's endogenous GA_3, enhances cell division and elongation in the internodal regions, thereby promoting stem elongation (Moore, 2012).

In a study by Ashraf et al. (2002), the application of GA_3 in wheat (*Triticum aestivum* L.) was found to enhance dry weight and the photosynthetic process. Similarly, research by Keshavarzi et al. (2013) reported that foliar spraying of 150 ppm GA_3 resulted in the highest biomass in corn, with an increase of 21% compared to the control. The present study demonstrated that increasing the concentration of GA_3 from zero to 50 ppm in seed priming resulted in only a 5% increase in fresh weight compared to the control. Additionally, applying GA_3 at various concentrations as a foliar spray led to a decrease in both fresh and dry weight compared to seed priming.

These findings suggest that foliar application of GA_3 has a limited effect on the fresh and dry weight of sesame plants. Keshavarzi's model (2013) predicted that higher concentrations of GA_3 applied as foliar spray decrease biomass in corn plants. This effect might be attributed to the physiological role of GA_3 when used as a seed primer, potentially stimulating the production of amylase enzymes, which break down starch into glucose, thereby promoting growth (Paleg, 1965). This mechanism might explain the observed differences in biomass accumulation between foliar application and seed priming with GA_3.The application of exogenous GA_3 can stimulate the synthesis of new RNA, which is crucial for producing hydrolase enzymes. Additional evidence indicates that GA_3 enhances the synthesis of polyadenylated RNA (poly A RNA), leading to the production of specific polypeptides in seeds that promote growth (Moore, 2012). This effect was also observed in a study by Akter et al (2007), where the application of 50 ppm GA_3 resulted in the highest number of fertile siliques per plant (244.00) in mustard, compared to 152 siliques in the control.

In the present study, seed priming with 50 ppm GA_3 in the CAP2 treatment produced the highest number of nodes with multiple capsules (18), whereas the control in CAP1 had the lowest number (5.7). This suggests that GA_3 application may enhance the translocation of assimilates to reproductive organs, thereby increasing the growth and number of nodes with multiple capsules per plant, up to certain levels of GA_3 application (Uddin et al., 1986). This translocation likely contributes to the observed increase in reproductive structures, facilitating greater yield potential in sesame plants.

5. Conclusion

The findings from this experiment indicate that seed priming with 50 ppm GA_3 in CAP2 (plants grown from seeds with triple capsules per leaf axil) resulted in the greatest improvements in several key traits. These included maximum plant height, the number of nodes with triple capsules per plant, the number of seeds per capsule, and the fresh and dry weight per plant. This demonstrates the potential of GA_3 application to optimize the growth and yield of sesame plants under these conditions.

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