Asian Journal of Crop Science

ISSN 1994-7879

OPEN ACCESS

Asian Journal of Crop Science

ISSN 1994-7879
DOI: 10.3923/ajcs.2021.1.8

Research Article
Effects of Spraying Gibberellic Acid Doses on Growth, Yield and Oil Content in Black Sesame (*Sesamum indicum* L.)

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Abstract
Background and Objective: Gibberellic acid promotes the growth and elongation of plant cells, making it an important plant growth regulator. The objective of this field experiment was to determine the optimal quantity of gibberellic acid (GA_3) to increase seed yield and oil content of sesame (*Sesamum indicum* L.), as well as improve nitrogen, phosphorus and potassium uptake. **Materials and Methods:** The replicated pot experiment included foliar application of GA_3 at six rates; control (0), 25, 50, 75, 100 and 150 ppm. Application of GA_3 at 100 ppm at 25 and 35 days after sowing increased overall plant growth indicators, including plant height, number of leaves and biomass of sesame. **Results:** At 100 ppm GA_3, there was a significant ($p<0.05$) increase in leaf concentration of chlorophyll, nitrogen, phosphorus and potassium, as well as stoma conductance. Gibberellic acid significantly ($p<0.05$) increased the number of flowers per plant thereby increasing the number of pods per plant, seeds per pod and weight of seeds per plant. Foliar application of GA_3 at 100 ppm increased sesame yield by 1.4 times with compared to the control and significantly ($p<0.05$) oil content in sesame seeds (13.4%). **Conclusion:** Spraying 100 ppm GA_3 helps sesame plant to produce more the number of seeds per pod and seed weight per plant. Spraying GA_3 at a proper concentration increased sesame yield and oil content.

Key words: Gibberellic acid, black sesame, nutrient uptake, sesame yield, oil content

Citation: Thuc, L.V., J.I. Sakagami, N.Q. Khuong, S. Orgill, T.N. Huu, N.T.T. Lang and P.P. Nhan, 2021. Effects of spraying gibberellic acid doses on growth, yield and oil content in black sesame (*Sesamum indicum* L.). Asian J. Crop Sci., 13: 1-8.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Continuous rice production in the Mekong River Delta (Vietnam) has led to an increased susceptibility of these farming systems to plant diseases, pests and land degradation. Crop rotations are a commonly used practice that optimizes the land use during different seasons, as well as mitigating the build-up and impact of pathogens, pests and weeds. There are also economic benefits of crop rotations compared with continuous rice production. Sesame is an attractive crop to grow in rotation with rice due to relatively low nutrient requirements, resilience to low soil moisture (that is, not dependent on irrigation post-germination), heat tolerance and high economic return. These factors are becoming increasingly important as the impacts of climate change limit crop yield in the rice growing regions of the Mekong River Delta[1]. Gibberellic acid (GA_3) is an endogenous growth regulator in plants that plays an important role in plant cell growth and elongation[2]. Use of this plant growth regulator is becoming increasingly common on a variety of crops, such as soybean[3] based on its ability to help plants overcome abiotic stresses[4]. While sesame (*Sesamum indicum* L.) is natively drought tolerant crop[5], prolonged dry conditions reduce crop yield and make the crop more susceptible to pests and diseases. Gibberellic acid has been demonstrated to be effective in improving overall plant growth and yield of many crops[6], however, its effectiveness depends on the concentration and timing of application, as well as environmental conditions[7]. Furthermore, there is limited information on the benefits of GA_3 application on sesame plant growth and yield. The purpose of this study was to determine the optimum concentration of GA_3 for improving sesame plant growth, nutrient uptake (nitrogen, phosphorus and potassium), seed yield and oil content.

MATERIALS AND METHODS

Study area: The field experiment was conducted in Thoi Thuan area, Phuoc Thoi ward, O Mon district, Can Tho city from February to May, 2019.

Research protocol: Soil samples (0-20 cm) were collected for characterization using a hand auger at 5 random locations across the field. Soil samples were dried by dry oven at 40°C, the methods of analysis were used as described by Sparks *et al.*[8]. Briefly, soil organic carbon (SOC; soil samples were oxidation in sulfuric acid and titration with ferrous sulfate heptahydrate), total nitrogen (N_{tot}; the total nitrogen content was analyzed by the regular Kjeldahl method, after the process of organic N state in soil was destruction to convert inorganic N), total phosphorus (P_{tot} total phosphorus content was determined by colorimetric procedure at a wavelength of 880 nm), total potassium (K_{tot}; total potassium content was determined by using ICP-OES) and soil pH_{KCl} (pH_{KCl}: soil samples were separately extracted using 1 M KCl). Soil characteristics for the field site are pH_{KCl} (3.87±0.01), pH_{KCl} (4.81±0.01), EC (0.35±0.005 mS cm^{-1}), CEC (15.19±0.19 meq 100 g^{-1}), SOC (2.56±0.041% C), N_{tot} (0.19±0.001%), P_{tot} (0.03±0.001%), K_{tot} (1.47±0.03%). A local sesame variety was used (Can Tho black sesame) with traits including short duration growth (approximately 75-85 days), high height, number of capsule, drought tolerance and yield.

Experimental design: The field experiment was arranged in a randomized complete block design including six treatments (T) each with five replications. Plot size was 25 m^2. Treatments as follows were applied as a foliar spray:

- T_1: Control (spray water without GA_3)
- T_2: Gibberellin (25 ppm)
- T_3: Gibberellin (50 ppm)
- T_4: Gibberellin (75 ppm)
- T_5: Gibberellin (100 ppm)
- T_6: Gibberellin (100 ppm)

The GA_3 solution with different concentrations was applied directly on the total leaf surface area at the growth stage of flower bud formation (25 days after flowering, DAS) and flowering (35 DAS).

Seed density: Sesame seed was sown at 4 kg ha^{-1}, with seeds mixed with sand at ratio of 2:1 (sand: sesame) to ensure uniform seed distribution.

Fertilizers and amendments: Before planting, mineral fertilizer was applied at the recommended rate of 90 kg N, 60 kg P_2O_5 and 60 kg K_2O for hectare. Single super phosphate (P 16%) was applied as a basal application. Urea (N 46%) was applied as split applications, with 30, 40 and 30% applied at 15, 30 and 40 days after sowing respectively. Potassium chloride (K 60%) was applied as split applications, with 50% applied at 15 and 30 days after sowing respectively.

Growth parameters and yield of sesame: Plant height (cm) was measured from the soil surface to the highest growth peak of 20 plants per plot at harvest time. Height to first fruit (cm) was measured from the soil surface to the position of the first capsules of 20 plants per plot. Number of flowers per main plant (flower) was assessed by counting all open flowers. Percentage stained pollen (%): Detached pollen grains and stained with Aceto-carmine 5% was assessed according to Saini *et al.*[9]. Using a M-40X microscope objective, stained and unstained pollen in 5 frames on each flower were counted and recorded. The number of pods per plant (left) was assessed at harvest time. Stomatal conductance was determined using a SC-1 Leaf Porometer (Decagon Devices, Pullman, WA, USA) on the 12th leaf from the ground at 35 and 60 days after sowing. Results are the mean of four plants per replicate. Chlorophyll content was extracted with N, N-Dimethylformamide[10]. Leaves were analyzed for N, P and K content at 50 days after sowing following Jones *et al.*[11]. Number of seeds per pod (seed) was assessed in 20 randomly selected pods per replicate. Seed moisture was assessed by oven drying seeds at 45°C for 72 hrs. Weight (g) of 1,000 seeds was recorded at 8% moisture. Yield (kg ha^{-1}) was calculated using the weight of seed of the 25 m^2 plot at harvest based on 8% moisture. Lipid content of sesame seeds was assessed using the Soxhlet method[12].

Data analysis: The data presented in this paper are the mean values of five replications unless otherwise stated. All data were analyzed using one-way analysis of variance (ANOVA) using SPSS software package version 13.0 and comparison for significant differences for treatment effects using Duncan's test at $p<0.05$.

RESULTS AND DISCUSSION

Effect of GA_3 on plant height and number of leaves: Foliar application of GA_3 above 50 ppm significantly ($p<0.05$) increased plant height (Fig. 1). At 100 ppm GA_3, greatest plant height was recorded (mean 123.1 cm) and this was significantly ($p<0.01$) higher than the control (102.2 cm). There was no significant difference in plant height between GA_3 applications of 75 and 150 ppm (112.0 and 116.9 cm, respectively). There was significantly ($p<0.05$) more leaves per plant with GA_3 applications at 100 and 150 ppm compared with the control and no difference between these higher rates and the 25, 50 and 75 ppm treatments (Fig. 1). Current study results support the growing evidence that the application of GA_3 promotes overall plant growth; indicated here by plant height and number of leaves per plant[13]. This agrees with increased plant growth recorded for soybean[3].

Effect of GA_3 on chlorophyll content in leaves: Total chlorophyll a, b and chlorophyll index in plants where GA_3 was applied were higher than the control at 35 and 65 DAS (Table 1). There was no significant difference in total chlorophyll content between GA_3 supplementation treatments with concentrations of 50, 75, 100 and 150 ppm. Gibberellin is an important factor regulating chlorophyll content of plants[14] and the application of GA_3 has been reported to increase chlorophyll indicators in mung bean grown on sandy soils[15] and lettuce[16].

Effect of GA_3 on stomata conductance: The stomata conductance of sesame leaves at 35 and 60 DAS was significantly ($p<0.01$) different (Table 2). For example, GA_3

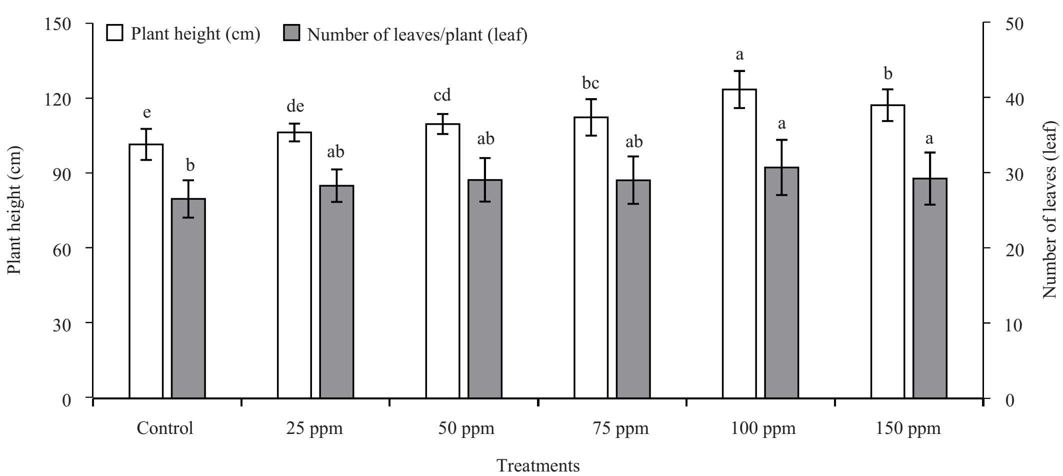

Fig. 1: Plant height (cm) and number of sesame leaves at harvest for different concentrations of GA_3
Letters within the column represent a significant ($p<0.05$) difference

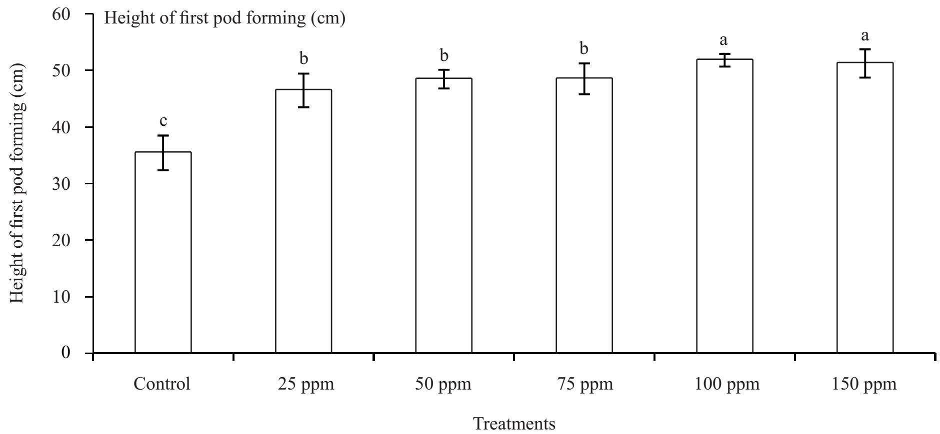

Fig. 2: Height (cm) of first pod forming at different concentrations of GA_3
Letters within the column represent a significant (p<0.05) difference

Table 1: Chlorophyll content in leaves at 35 and 60 DAS

	Chlorophyll 35 DAS			Chlorophyll 60 DAS		
Treatment	a	b	Total	a	b	Total
Control	7.6^{b}	1.9^{c}	14.1^{b}	12.4^{b}	2.2^{c}	22.6^{c}
25 ppm GA_3	9.3^{a}	2.2^{bc}	17.2^{a}	13.2^{ab}	2.7^{bc}	24.3^{bc}
50 ppm GA_3	9.4^{a}	2.3^{bc}	17.5^{a}	13.4^{ab}	3.3^{ab}	25.0^{abc}
75 ppm GA_3	9.6^{a}	2.6^{ab}	18.1^{a}	14.7^{a}	3.8^{a}	27.6^{ab}
100 ppm GA_3	9.8^{a}	3.1^{a}	18.7^{a}	14.9^{a}	3.8^{a}	27.9^{ab}
150 ppm GA_3	10.0^{a}	3.0^{a}	18.9^{a}	15.4^{a}	4.0^{a}	28.9^{a}
CV (%)	10.8	16.7	9.6	11.0	19.1	10.4

Letters within the column represent a significant (p<0.05) difference. DAS: Days after sowing

Table 2: Opening and closing of the stomata of sesame at 35 and 60 days after sowing

	Stomata conductance (mmol m^{-2} sec^{-1})	
Treatment (GA_3)	35 DAS	60 DAS
Control	$1,323.9^{c}$	$1,066.1^{c}$
25 ppm	$1,373.2^{c}$	$1,164.2^{c}$
50 ppm	$1,523.2^{b}$	$1,236.8^{bc}$
75 ppm	$1,542.8^{b}$	$1,296.7^{abc}$
100 ppm	$1,576.7^{ab}$	$1,500.7^{ab}$
150 ppm	$1,675.7^{a}$	$1,578.5^{a}$
CV (%)	5.4	16.4

Letters within the column represent a significant (p<0.05) difference. DAS: Days after sowing

applied at 100 ppm was 1,576.7 and 1,500.7 mmol m^{-2} sec^{-1} at 35 and 60 DAS. At 35 DAS, GA_3 applied at 50 ppm and above had significantly (p<0.05) higher stomata conductance compared with the control, while at 60 DAS only GA_3 applied at 100 and 150 ppm were significantly (p<0.05) higher. Concentration of GA_3 is regulates stomata opening and closing[17] and has been reported to slow stomatal closure in submerged lettuce[4].

Height (cm) of first pod forming: There was a significant (p<0.01) difference in the height (cm) of the first pod with GA_3 application; with all treatments being higher (range of first pod height 46.4-51.7 cm) than the control (35.3 cm; Fig. 2). However, there was no difference between GA_3 applied at 25, 50 and 75 ppm. Similarly, where GA_3 was applied at concentrations of 100 and 150 ppm height to the first pod forming was not statistically different (Fig. 2). These results agree with Hedden and Phillips[18] who reported that GA_3 promotes stem elongation, thus influences the height of first pod forming.

Effect of GA_3 on plant dry matter of sesame: Where GA_3 was applied at 100 ppm there was a significant increase (p<0.05) in plant dry matter compared to the control (9.4 g vs. 5.8 g per tree, respectively; Fig. 3). There was no difference in plant dry matter at GA_3 concentrations of 25, 50, 70 and 150 ppm. These results correlate with the increase in plant height and the number of leaves per plant (Fig. 1) and agree with research on chickpea (*Vicia faba* L.)[19] and leafy vegetables[13] which also reported increased dry matter with foliar application of GA_3.

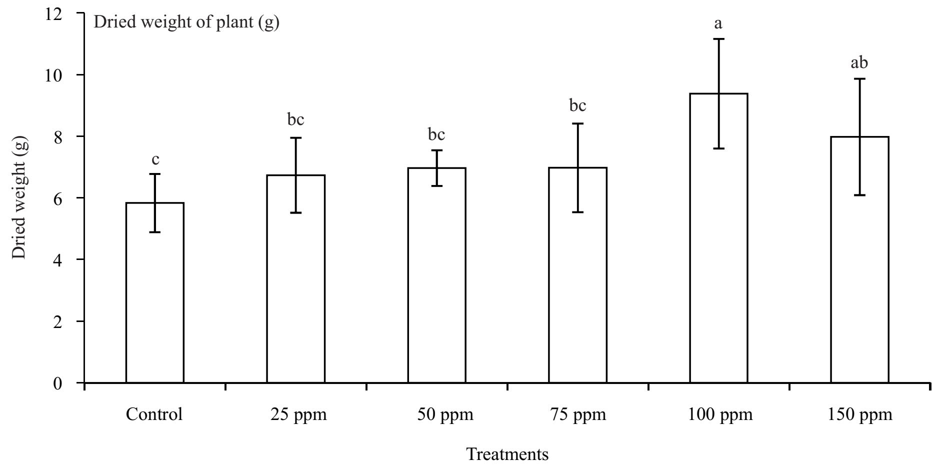

Fig. 3: Plant dry matter (g) with concentration of GA_3
Letters within the column represent a significant (p<0.05) difference

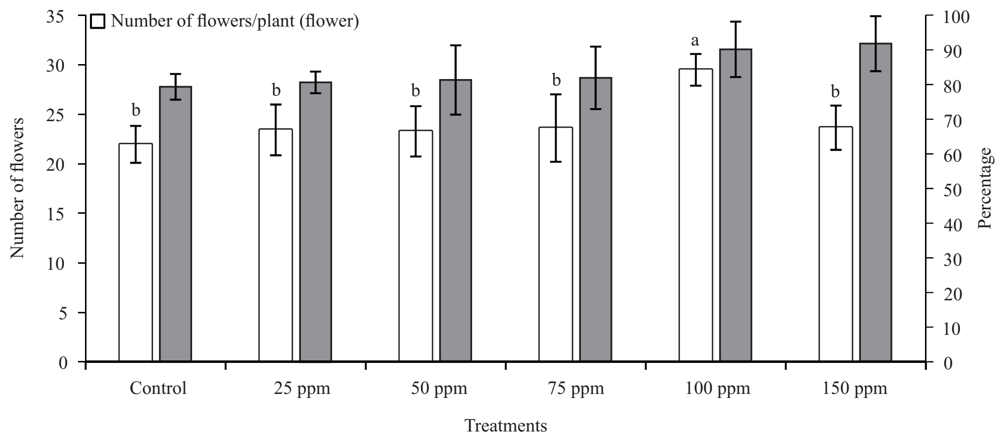

Fig. 4: Number of flowers/plant and percentage stained pollens
Letters within the column represent a significant (p<0.05) difference

Table 3: Leaf N, P and K concentration at 50 days after sowing

Treatments	N (%)	P (%)	K (%)
Control	2.59[b]	0.62[c]	0.27[b]
25 ppm GA_3	3.15[ab]	0.70[bc]	0.31[b]
50 ppm GA_3	3.26[ab]	0.70[bc]	0.32[b]
75 ppm GA_3	3.43[a]	0.70[bc]	0.47[a]
100 ppm GA_3	3.85[a]	0.82[a]	0.52[a]
150 ppm GA_3	343.00[a]	0.73[ab]	0.49[a]
CV (%)	14.8	11.1	16.5

Letters within the column represent a significant (p<0.05) difference. DAS: Days after sowing

Effect of GA_3 on leaf content of N, P and K 50 days after sowing: There was a significant (p<0.05) difference in leaf N and K concentration between GA_3 applied at 75, 100 and 150 ppm at 50 DAS compared to the control treatment (Table 3). At GA_3 100 ppm, there was significantly (p<0.05) higher P concentration in leaves (0.82%) compared to all other treatments with the exception of 150 ppm. Current results support the notion that application of GA_3 increases nutrient uptake and suggest an optimal rate of 100 ppm. This is consistent with findings of Shah *et al.*[20] and Pal *et al.*[21] who reported increased N, P and K uptake compared with the control for black fennel (*Nigella sativa* L.) cucumber, respectively.

Effect of GA_3 on number of flowers on main plant and percentage of stained pollen: The results presented in Fig. 4 show that the number of flowers on the main stalk in the treatments was statistically significant difference at 1%. The number of flowers on the main stalk was highest in the treatment applied 100 ppm GA_3 (29.4 flowers), among the treatments applied GA_3 with concentrations of 25, 50 and 75 ppm, the number of flowers on the main stalk was 23.3;

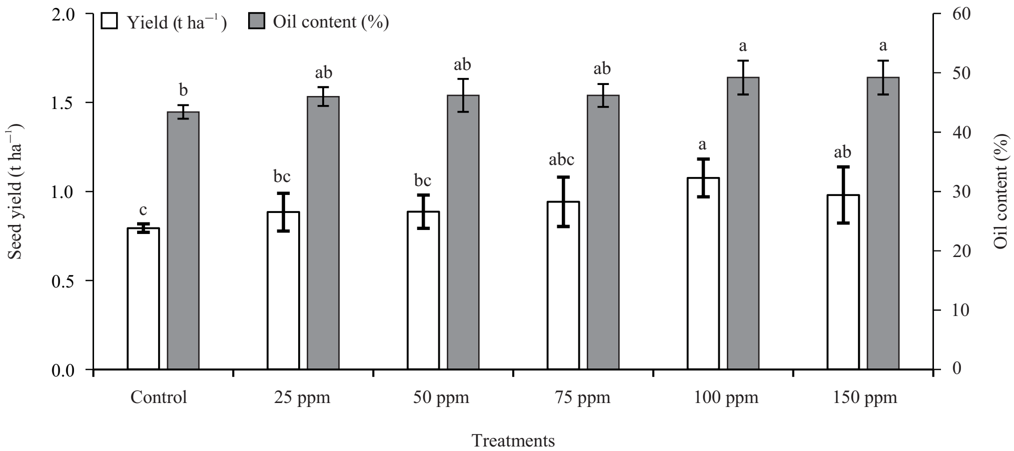

Fig. 5: Sesame seed yield and oil content in different GA_3 treatments
Letters within the column represent a significant (p<0.05) difference

Table 4: Sesame yield ingredient in GA_3 treatments

Treatments	Number of pods/plant(pod)	Seeds/pod (seeds)	Seed weight/plant(g)	Weight of 1000 seeds (g)
Control	18.4^{b}	81.3^{d}	3.62^{c}	3.1
25 ppm GA_3	18.8^{b}	86.3^{cd}	4.03^{bc}	3.2
50 ppm GA_3	21.1^{ab}	95.2^{bc}	4.47^{ab}	3.4
75 ppm GA_3	21.1^{ab}	94.6^{bc}	4.82^{a}	3.5
100 ppm GA_3	23.6^{a}	108.8^{a}	4.89^{a}	3.8
150 ppm GA_3	21.2^{ab}	103.3^{ab}	4.73^{a}	3.7
CV (%)	12.1	9.0	8.8	12.9

Letters within the column represent a significant (p<0.05) difference

23.2 and 23.5 flowers were no significant difference from the control treatment. Similar results were found when studying soybean sprayed with additional 100 ppm GA_{33}. The percentage of successful dyeing pollen grains ranged from 79.3-91.6%. The successful dyeing ratio of pollen grains tended to increase when spraying GA_3 with concentration gradually increasing from 25-150 ppm. However, there was no statistically significant difference between the treatments (Fig. 4).

Effects of GA_3 on sesame yield components: The results presented in Table 4 showed that the number of capsules per tree in the treatment applied GA_3 at 100 ppm was 23.6 fruits per tree, which was statistically significant difference at 5% from the non-sprayed treatments (18.4 fruits per tree). However, the number of capsules per tree decreased as the GA_3 concentration increased to 150 ppm. Similar to the results of the study obtained when spraying GA_3 on soybean G7R-315[22]. According to Pramanik *et al.*[23] GA_3 plays a role in helping plants increase fruit-set ability on trees. Applied 25 ppm GA_3 for sesame has begun to increase the weight of seeds per tree, but there was no statistically significant difference compared to the control treatment. Increased the concentration of GA_3 to 50, 75, 100 and 150 ppm further increased the weight of seeds per tree and was statistically significant difference at 1% from the control treatment (Table 4). The treatments applied from 75-150 ppm GA_3 was not significant difference in seed weight per tree. The lowest number of seeds per capsules is in control treatment (81.3 seed per pod). Applied GA_3 with a concentration of 25 ppm increased the number of seeds per capsule (86.3 seeds). Spraying 100 ppm GA_3 for the highest number of seeds per capsule (108.8 seeds per pod) when increased the concentration of GA_3 spray to 150 ppm the number of seeds on the fruit tended to decrease (103.3 seeds per pod). Similar to the BS-3 soybean study results, the number of seeds per capsule was higher when applied 100 ppm GA_3 but when increased to 200 ppm, the number of seeds per capsule decreased[3]. The results presented in Table 4 show that the weight of 1,000 sesame seeds of the treatments ranged from 3.1-3.8 g and there was no statistically significant difference between treatments when spraying GA_3. Similarly, the results of the study by Dathe *et al.*[22] on soybean when applied GA_3 did not increase grain mass.

Effects of GA_3 on sesame seed yield and oil content: The results presented in Fig. 5 show that in the treatment applied GA_3 with the concentration of 100 ppm has the highest yield was 1.076 ton ha^{-1}, there was a statistically significant difference at 5% compared to the control treatment (0.794 ton ha^{-1}). Sesame yield between treatments sprayed GA_3 with concentration from 25-75 ppm were not significant difference. Treatment applied GA_3 at a concentration of 100 ppm helps to increase grain yield recorded on many crops such as soybean[6,24]. The results presented in Fig. 5 show that the treatments applied GA_3 increased the oil content in sesame seeds compared to the control treatment. In particular, the treatment applied GA_3 with concentrations of 100 and 150 ppm had the highest oil content in sesame seeds, respectively 49.2 and 49%, which is significant difference from the control treatment did not apply GA_3. Different sesame varieties will have different in oil content in the seeds[25], however the oil content in seeds will range from 40.7-58.8%[26]. Besides, GA_3 is thought to help improve the oil content in sesame seeds[25].

CONCLUSION

Apply more of gibberellic acid at a concentration of 100 ppm at 25 and 35 DAS helps to increase growth indicators of plant height, the number of leaves and dry biomass of sesame plant. Content of chlorophyll, nitrogen, phosphorus, potassium in leaves and stomata increase when spraying gibberellic acid at a concentration of 100 ppm compared with no supplement of GA_3. Gibberellic acid helps increase the number of flowers on the main plant thereby increasing the number of pods on the sesame. At the same time GA_3 also increases the number of seeds per pod and the seed weight per plant. Sesame yield increased by 1.4 times when spraying GA_3 at a concentration of 100 ppm compared to without spraying GA_3. Applying GA_3 at a concentration of 100 ppm by spraying through the leaves helps to increase the oil content in sesame seeds.

SIGNIFICANCE STATEMENT

This study discovered an appropriate dose of GA_3 that can be beneficial for farmers. This study will help the researchers to determine the mechanism of GA_3 to support sesame growth.

ACKNOWLEDGMENT

This project was funded by the Upgrading Project of Can Tho University VN14-P6 with ODA loans from the Japanese Government.

REFERENCES

1. Lobell, D.B., W. Schlenker and J. Costa-Roberts, 2011. Climate trends and global crop production since 1980. Science, 333: 616-620.
2. Zang, Y.X., I.J. Chun, L.L. Zhang, S.B. Hong, W.W. Zheng and K. Xu, 2016. Effect of gibberellic acid application on plant growth attributes, return bloom, and fruit quality of rabbiteye blueberry. Sci. Hortic., 200: 13-18.
3. Sarkar, P.K., M.S. Haque and M.A. Karim, 2002. Effects of GA_3 and IAA and their frequency of application on morphology, yield contributing characters and yield of soybean. J. Agron., 1: 119-122.
4. Aharoni, N., A. Blumenfeld and A.E. Richmond, 1977. Hormonal activity in detached lettuce leaves as affected by leaf water content. Plant Physiol., 59: 1169-1173.
5. Li, D., K. Dossa, Y. Zhang, X. Wei and L. Wang *et al*., 2018. GWAS uncovers differential genetic bases for drought and salt tolerances in sesame at the germination stage. Genes, Vol. 9. 10.3390/genes9020087.
6. Vekaria, G.B., K.D. Rakholiya, V.D. Vora, J.T. Patel, G.S. Sutaria and P.D. Vekariya, 2017. Response of sesame (*Sesamum indicum* L.) to growth regulator under dry farming condition. Int. J. Curr. Microbiol. Applied Sci., 6: 1113-1120.
7. Roller, D., H.R. Highkin and O.H. Caso, 1960. Effects of gibberellic acid on stem apices of vernalizable grasses. Am. J. Bot., 47: 518-524.
8. Sparks, D.L., A.L. Page, P.A. Helmke, R.H. Loeppert and P.N. Soltanpour *et al*., 1996. Methods of Soil Analysis: Part 3 Chemical Methods, 5.3. Soil Science Society of America, American Society of Agronomy America, ISBN: 9780891188667.
9. Saini, N., N. Hedau, A. Khar, S. Yadav, J.C. Bhatt and P.K. Agrawal, 2015. Successful deployment of marker assisted selection (MAS) for inbred and hybrid development in long-day onion (*Allium cepa* L.). Indian J. Genet. Plant Breed, 75: 93-98.
10. Moran, R., 1982. Formulae for determination of chlorophyllous pigments extracted with *N*,*N*-dimethylformamide. Plant Physiol., 69: 1376-1381.
11. Jones, J.B. and V.W. Case, 1973. Sampling, Handling, and Analyzing Plant Tissue Samples. In: Soil Testing and Plant Analysis, Westerman, R.L. (Ed.)., Soil Science Society of America, America, ISBN: 9780891188629, pp: 249-270.

12. Helrich, K., 1990. Official Methods of Analysis of the Association of the Analytical Chemists. 15th Edn., Arlington, USA, ISBN 0-935584-42-0.
13. Miceli, A., A. Moncada, L. Sabatino and F. Vetrano, 2019. Effect of gibberellic acid on growth, yield, and quality of leaf lettuce and rocket grown in a floating system. Agronomy, 10.3390/agronomy9070382.
14. Rahim, H.U., S. Ahmad, L. Zada, Z. Khan, M.A. Khan, M. Haris and A.U. Usman, 2018. Yield and growth response of maize crop to urea and gibberellic acid potash salt (Ga-K salt) in calcarious soil. Hortic. Arboricul., 1: 35-39.
15. El Karamany, M.F., M.S. Sadak and B.A. Bakry, 2019. Improving quality and quantity of mungbean plant via foliar application of plant growth regulators in sandy soil conditions. Bull. Natl. Res. Cent., Vol. 43. 10.1186/s42269-019-0099-5.
16. Tsiakaras, G., S.A. Petropoulos and E.M. Khah, 2014. Effect of GA_3 and nitrogen on yield and marketability of lettuce (*Lactuca sativa* L.). Aust. J. Crop Sci., 8 : 127-132.
17. Pospisilova, J., 2003. Participation of phytohormones in the stomatal regulation of gas exchange during water stress. Biol. Plant., 46: 491-506.
18. Hedden, P. and A.L. Philips, 2000. Gibberellin metabolism: New insight revealed by genes. Trends Plant Sci., 5: 523-530.
19. Ibrahim, M.E., M.A. Bekheta, A.D. El-Moursi and N.A. Gaafar, 2007. Improvement of growth and seed yield quality of (*Vicia faba* L.) plants as affected by application of some bioregulators. Aust. J. Basic Applied Sci., 1: 657-666.
20. Shah, S.H., I. Ahmad and Samiullah, 2006. Effect of gibberellic acid spray on growth, nutrient uptake and yield attributes during various growth stages of black cumin (*Nigella sativa* L.). Asian J. Plant Sci., 5: 881-884.
21. Pal, P., K. Yadav, K. Kumar and N. Singh, 2016. Effect of gibberellic acid and potassium foliar sprays on productivity and physiological and biochemical parameters of parthenocarpic cucumber cv. 'seven star F1'. J. Horticult. Res., 24: 93-100.
22. Dathe, W., S. Castro, R. Lopez and G. Sembdner, 1984. Effect of gibberellin A_3 on fruit set and yield parameters in soybean (*Glycine max* (L.) MERR.). Biochem. Physiol. Pflanz., 181: 615-621.
23. Pramanik, K. and P.P. Mohapatra, 2017. Role of auxin and gibberellins growth, yield and quality of tomato - a review. Int. J. Curr. Microbiol. App. Sci., 6: 1624-1636.
24. Deotale, R.D., V.G. Mask, N.V. Sorte, B.S. Chimurkar and A.Z. Yerne, 1998. Effect of GA_3 and IAA on morpho-physiological parameters of soybean. J. Soils Crops, 8 : 91-94.
25. Behera, S., A.K. Padhiyari, S. Rout, A. Nayak, D. Behera and P.K. Nanda, 2017. Effect of plant growth regulators on morpho-physiological and yield parameters of some sesame (*Sesamum indicum* L.) cultivars. Int. J. Curr. Microbiol. App. Sci., 6: 1784-1809.
26. Kadkhodaie, A., J. Razmjoo, M. Zahedi and M. Pessarakli, 2014. Oil content and composition of sesame (*Sesamum indicum* L.) genotypes as affected by irrigation regimes J. Am. Oil Chem. Soc., 91: 1737-1744.