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Screening and response of growth regulators SA, ABA and CCC on morpho-physiological and yield parameters of soybean (*Glycine max* L. Merrill)

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Abstract
A field experiment was conducted during the *kharif* 2024 at Soybean Research Station, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. To study the "Screening and Response of Growth Regulators SA, ABA and CCC on morpho-physiological and yield parameters of soybean (*Glycine max* L. Merrill)". The investigation was carried out in Randomized Block Design with three replications in soybean cv. MAUS-725 was sown on 1st July 2024 by dibbling seeds in 45 cm between rows and 5 cm between plant spacing. The gross plot size was 2.70 m x 5.0 m and Net plot size was 2.25 m x 5 m. The experiment consisting of ten treatments *viz*., T_1, T_2 and T_3 (SA @ 50 ppm, 100 ppm and 200 ppm), T_4, T_5 and T_6 (ABA @ 2 ppm, 4 ppm and 8 ppm), T_7, T_8 and T_9 (CCC @ 200 ppm, 300 ppm and 400 ppm) respectively and T_0 (control), applied application of Plant growth regulators at 30 and 60 Days After Sowing (DAS).
The experimental results revealed that the application of various plant growth regulators had a significant influence on morpho-physiological and yield parameters all of which exhibited noticeable variation in response to the different treatments application of SA, ABA and CCC as compare to control in soybean. The application of plant growth regulators positively influenced plant height, days to 50% Flowering, days to maturity it was higher in treatment T_3 (SA @ 200 ppm) treated plants.
The photosynthetic productivity and partitioning of photosynthate finally lead to increases yield of soybean. The highest values for the number of pods/plant (68.70), seed yield/plot (3.16 Kg), 100-seed weight (16.02 g), biological yield (6182.64 Kg/ha) and harvest index (45.43%) was recorded under treatment T_3 (SA @ 200 ppm) at harvest. Significantly maximum seed yield/ha (2808.86 kg/ha) was also achieved treatment T_3 (SA @ 200 ppm).

Keywords: Morpho-physiological, growth parameters, grain yield, treatments, SA, ABA, CCC)

1. Introduction

Soybean (*Glycine max* L. Merrill) belongs to family "Leguminaceae", sub-family "Papilionaceae". This is native to East Asia, but is now widely cultivated and consumed across the world. Soybean is often recognized as the "Golden Bean", "Miracle Crop" or "Cow of the Orient" of the 21st century due to its exceptional nutritional composition, featuring a high protein content (36-40%) and oil content (16-20%).

Globally, soybean is cultivated on approximately 140.01 million hectares, producing around 394.96 million tonnes, with an average productivity of 2820 kg per hectare (ICAR-IISR, 2024). India ranks fourth worldwide in terms of cultivated area, covering 12.07 million hectares and stands fifth in production with 13.98 million tonnes. However, the country's productivity at 1158 kg per hectare, remains relatively low to meet the increasing demand (ICAR-IISR, 2024). The primary soybean producing states in India include Madhya Pradesh followed by Maharashtra and Rajasthan. Maharashtra stands as the second-largest soybean producer in India, contributing nearly 35% of the country's total production. The state cultivates soybean on approximately 5.02 million hectares, achieving an average yield of 1000 kg per hectare. (MH Agri Dept. 2024)

Plant growth regulators are organic, carbon based substances either naturally occurring or synthetically produced that are distinct from nutrients and play essential roles throughout the plant life cycle by modifying or restoring growth patterns (Davies, 2013) [4]. Certain microorganisms, such as fungi and bacteria, also produce similar compounds that can influence plant growth and development (Khan and Mazid, 2018) [8].

They are essential for regulating various physiological and developmental processes, including seed germination, root and flower development, seed maturation and storage, along with other vital functions in plants (Wu *et al.*, 2017) [16].

Salicylic acid (SA), also known as 2-hydroxybenzoic acid, is a naturally occurring phenolic compound synthesized in the cytoplasm and chloroplasts of plants. SA plays a vital role in regulating a wide range of biochemical and physiological processes in plants, including photosynthesis, nutrient transport, ion uptake, stomatal regulation, gas exchange, protein synthesis, flowering, seed germination, senescence and responses to environmental stresses. For instance, exogenous application of SA has been reported to enhance plant height, branch number and overall yield in cotton (Al-Rawi *et al.* 2014) [3]. Abscisic acid (ABA) is a crucial hormone involved in enhancing plant resistance to abiotic stress (Zhu *et al.*, 2013) [18] and also plays a significant role in regulating essential growth and developmental processes. In Arabidopsis, it promotes both root elongation and leaf senescence in seedlings (Zhao *et al.*, 2018) [17]. Similarly, in rice, ABA treatment led to leaf yellowing, a key sign of senescence. Cycocel (2-Chloroethyl trimethyl ammonium chloride) is a synthetic growth retardant widely utilized to induce dwarfing in plants and their organs. As an anti-gibberellin compound, it inhibits cell elongation, enhances chlorophyll production, promotes root development and strengthens plant structure, thereby reducing lodging.

2. Materials and Methods

The present field experiment was conducted during the *Kharif* season of 2024 at the Soybean Research Station, Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani. It located at 19°16' N latitude, 76°47' E longitude and 409 meters above mean sea level (MSL), falls in the Marathwada region and has a tropical climate. The area receives an average annual rainfall of 732.74 mm, based on a 35 years record, with July contributing around 27.4% of the total precipitation. The mean daily maximum temperature ranges from 30.96 °C in July to 31.59 °C in October, while the mean daily minimum temperature fluctuates between 23.4 °C in late July and 22.5 °C in October. The mean relative humidity (RH) of morning and evening hours was 90 and 65 per cent respectively. The mean sunshine hours per day was 4.4 hrs. day^{-1}. The mean wind velocity was 2.6 km h^{-1}.

Data was collected on morpho-physiological characters namely plant height at (30, 60, 90 DAS), days to 50% Flowering, days to maturity and yield parameter as number of pods/plant, 100-seed weight (g), seed yield/plot (kg), seed yield/ha (kg/ha), biological yield (kg/ha) and harvest index (%) at harvest in soybean.

Table 1: Treatment details:

Treatment	Plant Growth Regulators	Concentrations (ppm)
T_0	control	-
T_1	Salicylic acid	50 ppm
T_2	Salicylic acid	100 ppm
T_3	Salicylic acid	200 ppm
T_4	Abscisic acid	2 ppm
T_5	Abscisic acid	4 ppm
T_6	Abscisic acid	8 ppm
T_7	Cycocel	200 ppm
T_8	Cycocel	300 ppm
T_9	Cycocel	400 ppm

2.2 Preparation and Application of plant growth regulators

Salicylic acid (50 mg, 100 mg and 200 mg) and Abscisic acid (2 mg, 4 mg and 8 mg) powder dissolved in ethanol for preparation of (50 ppm, 100 ppm and 200 ppm) solution of SA and (2 ppm, 4 ppm and 8 ppm) solution of ABA. Cycocel solution (200, 300 and 400 micro litre) dissolved in distilled water to obtain (200, 300 and 400 ppm) concentrations**,** along with an untreated control, applied at 30 and 60 days after sowing (DAS).

3. Results and Discussion

This study contains the results of present experiment on "Screening and Response of Growth Regulators SA, ABA and CCC on morpho-physiological and yield parameters of soybean (*Glycine max* L. Merrill)". The result pertaining to various parameters *viz*., morpho-physiological and yield parameter as influenced by different plant growth regulators and their different concentration along with statistical inferences are presented in Tables and also illustrated graphically wherever found necessary.

3.1 Morpho-physiological characters

3.1.1 Plant height

Data on plant height was recorded at 30-day intervals following the application of treatments and are presented in Table No. 2. The application of plant growth regulators significantly influenced plant height at 60 and 90 DAS, whereas no significant effect was observed at 30 DAS. All concentrations of SA and ABA was found to significantly increase plant height, whereas all concentrations of CCC was significantly effective in reducing plant height at 60 and 90 DAS compared to the control.

At 30 DAS, plant height did not vary significantly among treatments, with values ranging narrowly from 17.68 cm (T_8) to 17.81 cm (T_4), indicating a non-significant response at the early growth stage.

At 60 DAS, significant differences was observed among the treatments. The tallest plants was recorded in T_3 (38.22 cm), it was statistically at par with treatments T_2 (38.08 cm), T_1 (37.84 cm), T_4 (37.19 cm), T_5 (37.06) and T_6 (36.41). while the shortest plants were noted in T_9 (34.19 cm), T_8 (34.88 cm) and T_7 (35.11 cm). The control treatment T_0 recorded 35.71 cm, which was lower than the SA and ABA treatments but higher than the CCC treatments.

Similar trends continued at 90 DAS; where T_3 again recorded the highest plant height (52.59 cm), it was statistically at par with treatments T_2 (51.31 cm), T_1 (50.89 cm), T_4 (49.81 cm), whereas the lowest plant heights were recorded in T_9 (45.97 cm), T_8 (46.19 cm) and T_7 (46.41 cm). The control treatment T_0 recorded 46.81 cm, which was lower than the SA and ABA treatments but higher than the CCC treatments.

The increase in plant height with growth regulator application can be attributed to their role in enhancing photosynthetic efficiency and promoting better assimilation of photosynthates, which in turn led to accelerated cell division and elongation in actively growing regions of the plant. All concentrations of SA and ABA resulted in a notable increase in plant height compared to the control. In contrast, all concentrations of CCC led to a reduction in plant height, indicating its growth-retarding effect. This reduction in height may have contributed to more compact growth, potentially enhancing biomass accumulation through improved structural balance and resource allocation. similar result found by Kuchlan *et al.*, (2023) [10] and Raksha (2010) [13].

3.1.2 Days to 50% flowering

Data on days to 50% flowering was recorded at the time of 50% flowering are presented in Table No. 2. The differences among treatments with respect to mean days to 50% flowering was found to be statistically significant at all tested concentrations. Among the various treatments, the application of growth regulator at (T_3) recorded the earliest 50% flowering (32.33 DAS), which was significantly superior to all other treatments. This suggests that SA at this concentration most effectively promoted floral initiation. T_3 was statistically at par with other concentrations of T_2 (32.92), T_1 (33.44) and T_4 (34.17) indicating their comparable effectiveness in hastening flowering. However, these treatments were significantly superior to all concentrations of CCC at treatment T_7 (35.19), T_8 (35.67), T_9 (35.99) and the control T_0 (36.04) days which showed delayed flowering.

The study revealed that SA was most effective in promoting early flowering, particularly at T_3, leading to a 3.71 days advancement compared to the control. ABA showed moderate effectiveness, while CCC had a minimal impact. Similar result found by Afshari *et al.*, (2013) [1] and Kaulage (2015) [7].

3.1.3 Days to maturity

The findings indicate that maturity of soybean as influenced by foliar application of various plant growth regulators (PGRs) revealed significant variation among treatments. The treatment T_3 exhibited the earliest physiological maturity, requiring only 91.63 days, indicating its effectiveness in accelerating senescence and crop development. This was statistically at par with other concentrations of treatment T_2 and T_1 which required 92.43 and 93.64 day respectively, to attain maturity. These treatments also promoted earlier maturation compared to the control, suggesting their potential to shorten the crop duration under field conditions. In contrast, the treatment untreated control (T_0) resulted in the longest duration to reach physiological maturity, taking 96.17 days, thereby delaying maturity when compared to the T_9 (95.97) days. Among ABA treatments, the earliest maturity was observed at the lowest concentration treatment T_4. CCC treatments had minimal impact on reducing days to maturity. While there was a slight reduction compared to the control. The earliness may be attributed to the role of SA in enhancing antioxidant activity, improving stress tolerance and accelerating metabolic and senescence-related processes.

3.2 Yield parameters:

3.2.1 Number of pods/plant

The data presented in Table No. 2 and Figure No 1 number of pods/plant increased by the application of different plant growth regulators as compared to control. At harvest, significantly higher number of pods/plant was recorded (68.70) in treatment T_3 and it was statistically at par with treatments T_2 and T_1 with 66.49 and 64.73 pods/plant while control T_0 (55.88) recorded minimum number of pods/plant.

The enhanced availability of photosynthesis, metabolites and essential nutrients for the development of reproductive structures appears to have contributed to an increased number of pods/plant. The application of plant growth regulators markedly improved the number of pods/plant and ultimately the seed yield per plant one of the key yield determining factors in soybean. Similar result was observed by Ali and Mahmoud (2013) [2]

3.2.2 100-seed weight (g)

The data presented in Table No 3 and Figure 1 The 100-seed weight of soybean was significantly influenced by the application of various plant growth regulators. Among the treatments, the highest 100-seed weight (16.02 g) was recorded with the application of treatment T_3 it was statistically at par with T_2 (15.87 g), T_1 (15.60 g) and T_8 (15.38 g), These values were significantly superior to the control T_0 (13.11 g), which recorded the lowest 100-seed weight. Among the ABA treatments, the response was relatively lower, with ABA at (T_5) yielding the highest among them at 13.99 g, while (T_4) and (T_6) recorded 13.18 g and 13.79 g, respectively. The differences among treatments were statistically significant.

The findings suggest that the application of plant growth regulators, especially at treatment T_3 can significantly enhance seed weight, which is a critical yield component in soybean. Similar result was observed by Ali and Mahmoud (2013) [2] and Sharma and Kaur (2003) [14].

3.2.3 Seed yield/plot (Kg)

The data presented in Table No 3 and Figure 1 revealed that significant differences existed among the treatments in respect of seed yield/plot. The highest seed yield/plot was recorded with the application of treatment T_3 is 3.16 Kg/plot which was significantly at par with T_2, T_1 and T_8, which recorded yields of 3.08 kg/plot, 3.04 kg/plot and 3.03 Kg/plot, respectively, while the minimum recorded in control T_0 is 2.66 Kg/plot. The treatments with ABA resulted in relatively lower yields compared to SA and CCC. T_6 produced the highest yield among the ABA treatments (2.75 kg/plot), while T_4, T_6 recorded yields of 2.71 kg/plot and 2.72 kg/plot, respectively. the study clearly indicates that treatment T_3, was the most effective in enhancing soybean yield/plot. Similar result was observed by Kothule *et al.*, (2003) [9] and Siamak *et al.*, (2015) [15]

3.2.4 Seed yield /ha (Kg)

The data presented in Table No 3 and Figure 2 revealed that significant differences existed among the treatments in respect of seed yield/ha. The highest seed yield/ha (2808.86 kg/ha) was recorded with the application of treatment T_3 which was significantly at par with T_2, T_1 and T_8, which recorded yields of 2737.75 kg/ha, 2699.23 kg/ha and 2693.31 Kg/ha, respectively, while the minimum recorded in control T_0 is 2364.42 Kg/ha. ABA treatments recorded comparatively lower yields, with T_5 yielding the highest (2444.05 kg/ha) among them, followed by T_6 with 2414.79 kg/ha and T_4 with 2411.83 kg/ha. While these values were marginally higher than the control, the increase was statistically significant.

The results clearly demonstrate that the application of salicylic acid, particularly at 200 ppm, significantly improved the grain yield of soybean on a per hectare basis. Salicylic acid is also known to improve stress tolerance, which can further contribute to increased productivity under field conditions. Similar result was observed by Kuchlan *et al.*, (2023) [10], Siamak *et al.*, (2015) [15] and Kaulage (2015) [7].

3.2.5 Biological yield (Kg/ha)

The data presented in Table No 3 and Figure 2 revealed that significant differences existed among the treatments in respect of biological yield (kg/ha). The highest biological yield (6182.64 kg/ha) was recorded with the application of treatment T_3 which was significantly at par with T_2, T_1 and T_8 which recorded yields of 6062.96 kg/ha, 6047.49 kg/ha and 6036.65 Kg/ha, respectively, while T_0 which recorded the lowest yield of 5629.33 kg/ha. Treatments with ABA resulted in relatively lower biological yields, with T_4 showing a yield of 5713.32 kg/ha, followed by T_5 and T_6 which recorded 5655.43 kg/ha and 5636.62 kg/ha, respectively. Similar result was observed by Patil (2019) [12], Kalyankar *et al.*, (2008) [6].

3.2.6 Harvesting index (%)

The data presented in Table No 3 and Figure 1 revealed that non-significant differences existed among the treatments in respect of Harvesting index (%). The highest harvesting index was recorded with the application of treatment T_3. did not vary significantly among treatments, with values ranging narrowly from 45.43% (T_3) to 42.00% (T_0), which recorded the lowest harvesting index indicating a non-significant response at the different growth stages.

Morpho-physiological characters

Table 2: Effect of plant growth regulators on plant height (cm), Days to 50% flowering and Days to maturity of soybean (*Glycine max* L. Merrill)

Plant height (cm)					Days to 50% flowering	Days to maturity
Tr.no	Treatment	DAS			At 50% flowering	At maturity
		30	60	90		
T_0	Control	17.73	35.71	46.81	36.04	96.17
T_1	SA 50 ppm	17.79	37.84	50.89	33.44	93.64
T_2	SA 100 ppm	17.74	38.08	51.31	32.92	92.43
T_3	SA 200 ppm	17.78	38.22	52.59	32.33	91.63
T_4	ABA 2 ppm	17.81	37.19	49.81	34.17	94.27
T_5	ABA 4 ppm	17.69	37.06	48.39	34.64	94.73
T_6	ABA 8 ppm	17.71	36.41	47.91	34.91	94.99
T_7	CCC 200 ppm	17.75	35.11	46.41	35.19	95.30
T_8	CCC 300 ppm	17.68	34.88	46.19	35.67	95.68
T_9	CCC 400 ppm	17.76	34.19	45.97	35.99	95.97
	SE±	0.2	0.8	1.12	0.65	0.79
	CD 5%	NS	2.41	3.36	1.96	2.36

Growth parameter

Table 3: Effect of growth regulators on no. of pods/plant, 100-seed weight (g), seed yield/plot, seed yield/ha, biological yield (kg/ha) and harvest index (%) of soybean (*Glycine max* L. Merrill).

Tr. no	Treatment	No. of pods/plant	100 Seed weight (g)	seed yield/plot (kg)	Seed yield /ha (kg)	Biological Yield kg/ha	Harvest Index (%)
T_0	Control	55.88	13.11	2.66	2364.42	5629.33	42.00
T_1	SA 50 ppm	64.73	15.60	3.04	2699.23	6047.49	44.63
T_2	SA 100 ppm	66.49	15.87	3.08	2737.75	6062.96	45.16
T_3	SA 200 ppm	68.70	16.02	3.16	2808.86	6182.64	45.43
T_4	ABA 2 ppm	56.43	13.18	2.71	2411.83	5713.32	42.21
T_5	ABA 4 ppm	58.23	13.99	2.75	2447.38	5655.43	43.27
T_6	ABA 8 ppm	57.14	13.79	2.72	2414.79	5636.62	42.84
T_7	CCC 200 ppm	59.07	14.23	2.82	2503.68	5706.53	43.87
T_8	CCC 300 ppm	61.72	15.38	3.03	2693.31	6036.65	44.62
T_9	CCC 400 ppm	59.33	14.70	2.93	2601.46	5865.33	44.35
	SE±	1.61	0.35	0.06	51.71	53.26	0.88
	CD 5%	4.83	1.03	0.17	154.83	159.47	NS

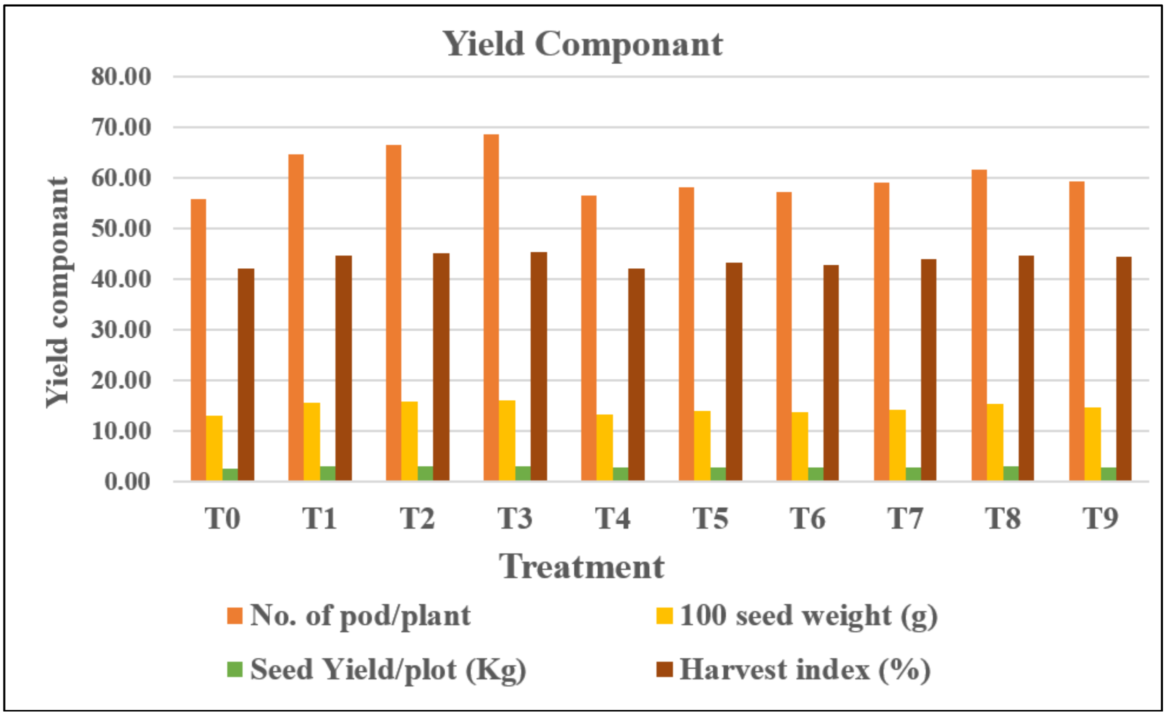

Fig 1: Yield componant

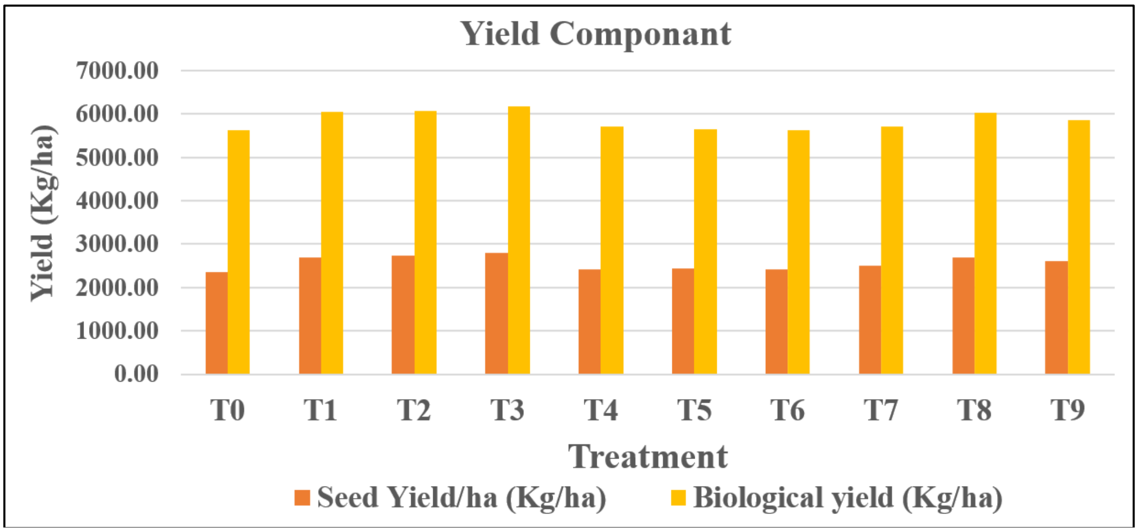

Fig 2: Yield componant

Conclusions

1. Plant height was significantly greater under the treatment T_3 (SA @ 200 ppm) compared to the control across all growth stages of soybean. There was considerable reduction in days required for 50% flowering with the concentration of treatment T_3 (SA @ 200 ppm) also the reduction in days required for maturity with the concentration of treatment T_3 (SA @ 200 ppm).
2. Analysis of yield and its parameters revealed that all yield parameters such as number of pods/plant, seed yield/plot, 100-seed weight, biological yield, harvest index (%) and seed yield/ha was significantly improved by the application of treatment T_3 (SA @ 200 ppm), followed by T_2, T_1 and T_8 relative to the control.

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