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Effect of Foliar Application of Selected Plant Growth Regulators on Growth and Yield of Soybean [*Glycine max* (L.) Merrill]

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ABSTRACT

Background: Soybean (*Glycine max*), a prized oilseed crop known for its nutritional richness, is the focus of a study aiming to boost production with minimal environmental impact. The research explores the application of plant growth regulators (PGRs), specifically Gibberellic Acid (GA3), Kinetin and Salicylic Acid, in field experiments during the kharif seasons of 2022 and 2023 in Beed, India.

Methods: The study applied Gibberellic Acid (GA3), Kinetin and Salicylic Acid at different concentrations in field experiments. A comprehensive analysis of growth and yield attributes, including plant height, primary branches, Leaf Area Index (LAI), root nodules and Crop Growth Rate (CGR), was conducted to assess the influence of PGR treatments on soybean growth. Yield attributes such as pod count, pod weight, seed count per pod and 100-seed weight were scrutinized to understand their effects on soybean productivity.

Result: The study highlighted significant effects of PGR treatments on soybean growth and yield. Notably, Kinetin at 500 ppm promoted the tallest plants, while GA3 at 200 ppm resulted in the shortest. Kinetin at 100 ppm increased primary branches and Salicylic Acid at 50 ppm exhibited the highest LAI and abundant root nodules. Kinetin at 500 ppm and Salicylic Acid at 50 ppm showed higher CGR, indicating efficient crop growth. For yield, Kinetin at 500 ppm excelled in pod count and weight. GA3 at 100 ppm was identified as the most effective PGR for enhancing various growth parameters and soybean seed yield, suggesting the potential of PGRs in sustainable cultivation, reducing reliance on chemical inputs.

Key words: *Glycine max* (L.) Merrill, Growth attributes, Plant growth regulators, Yield attributes.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill], a member of the Fabaceae family, is a highly valued oilseed crop with a chromosome number of 2n = 40. It is known as the "Golden Bean" of the twenty-first century due to its high nutritional value and versatility. Soybean is a nitrogen-fixing legume crop that is widely grown around the world, with India being one of the leading producers. Soybean seeds are a rich source of protein (about 40%) and oil (about 20%) (Chung and Singh, 2008). To achieve the highest soybean yields, quality and profitability, it is essential to provide the crop with a balanced supply of macronutrients and micronutrients. Starter fertilizers are used to boost early soybean growth and increase total plant biomass, which is then allocated to increased seed and oil yields at harvest (Osborne and Riedell, 2006).

Chemical fertilizer and pesticide combinations have initially boosted production, but their overuse has adversely affected both production and the environment. Any combination of resources used on a farm should promote production without damaging the environment (Khan, *et al.*, (2023). To avoid the damage caused by the intensive use of chemical fertilizers and pesticides, alternative resources must be tested. The productivity of soybean in major countries has already reached a plateau, making it necessary to improve soybean productivity. This can be achieved through the efficient use of techniques using plant growth regulators (Kannan, 2010).

Plant growth regulators (promoters, inhibitors, or retarders) play a major role alters the internal mechanism of plant growth by interacting with key metabolic processes such as nucleic acid metabolism and protein synthesis (Roberts, 2012). Growth retarders are known to reduce the internodal distance, thus improving the source-sink relationship and stimulating the translocation of photosynthates into seeds (Jawale *et al.*, 2020). Plant growth regulators (PGR) are organic compounds, also called biostimulants or bioinhibitors, that act inside plant cells to stimulate or inhibit specific enzymes or enzyme systems and help regulate plant metabolism (Magray, 2021). They are usually active at a very low level of concentration in plants. When produced endogenously by plants, they are often referred to as phytohormones (plant hormones) (Bhatla *et al.*, 2018).

Plant growth regulators play a crucial role in optimizing plant growth and yield, particularly in soybeans. These

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regulators act as traffic controllers, facilitating the efficient transfer of photosynthetic products (sugars) from source tissues (leaves) to sink tissues (developing flowers, pods and seeds). This ensures proper nourishment for the growing reproductive organs, leading to increased yield (Roberts, 2012). Remarkably, plant growth regulators can achieve these effects even at exceedingly low concentrations (Iqbal *et al*., 2011). Studies have consistently demonstrated their ability to enhance both plant growth and yield (Basra, 2000; E1-Otmani *et al*., 2000; Hai *et al*., 2003). In this study, we aimed to investigate the effectiveness of foliar application of plant growth regulators on soybean growth and yield in the willow area of Marathwada region, Maharashtra, India.

MATERIALS AND METHODS

Experimental design and treatment details

Field experiments were conducted during the Kharif seasons of 2022 and 2023 at the research farm of the Department of Botany, Balbhim College Beed, Maharashtra, India (18.9883°N latitude, 75.7598°E longitude). The experimental site, featuring slightly alkaline soil (pH 7.4), received 484.1 mm and 392.4 mm of rainfall in 2022 and 2023, respectively. The average temperature during the crop season ranged from 26°C to 33°C, with relative humidity varying between 60% to 75%. Soil nutrient analysis prior to experimentation revealed contents of total organic matter at 1.5%, nitrogen at 280 kg/ha and phosphorus at 45 kg/ha. The study utilized a randomized block design (RBD) with seven treatments, including three plant growth regulator treatments (Gibberellic Acid, Kinetin, Salicylic Acid) and two replications. Cultivation employed the Phule Sangam KDS-726 soybean variety, with seeds sourced from Mahatma Phule Krushi Vidyapith Rahuri. Prior to sowing, the soil was conditioned with the application of a balanced fertilizer mix consisting of urea, superphosphate and muriate of potash as per the recommended dose for soybean crops in the region, specifically providing 40 kg N/ha, 60 kg P_2O_5/ha and 30 kg K_2O/ha.

The entire plot was divided into seven random blocks and foliar spray of PGRs was conducted at the pod initiation stage. Treatment combinations for foliar spray comprised seven groups: T0, the untreated control; T1 with Gibberellic Acid (GA3) at 100 ppm; T2 with GA3 at 200 ppm; T3 with Kinetin at 100 ppm; T4 with Kinetin at 500 ppm; T5 with Salicylic Acid at 50 ppm; and T6 with Salicylic Acid at 100 ppm. The selection of varying PGR concentrations was based on a review of current literature and prior dose-response studies indicating that these particular concentrations could induce significant physiological changes in soybean crops. Preliminary trials were conducted to establish the effective range without causing phytotoxicity. Each treatment group was systematically designed to investigate the potential modulating effects of different plant growth regulator concentrations on the growth and yield of the experimental soybean crops.

Collection of data on growth, yield and its components

Five plants were randomly selected from each plot and marked for observation of plant growth parameters. Regular plant sampling was done over the years to monitor plant growth characteristics.

A. Growth attributes

Plant height (cm)

Five plants were randomly selected and marked in each plot, except for the border row. Plant height was measured from ground level to the tip of the main shoot. The average plant height in centimeters was calculated as the average of five labeled plants. Measurements were made on the 30th and 60th days after sowing (DAS) and at the time of harvest.

Number of primary branches per plant

The number of primary branches per plant was performed on the main stem of five marked plants in each plot at 30, 60 DAS and at harvest.

Leaf area index (LAI)

The leaf area index represents the ratio of the surface area covered by green leaves to the land area. It was determined indirectly by selecting ten leaves from plant samples. The central parts of the leaves were perforated using a punch with a radius of 1 cm. The area of these ten punched sheets was calculated by multiplying the area of the punch by the number of sheets. Subsequently, the samples from each treatment were dried in a hot air oven at 60°C until constant weight reached and their weight was recorded individually. The dry weight of these perforated leaves was used to calculate the leaf area index (LAI) according to the method suggested by Watson (1947). LAI was recorded at 30 and 60 DAS using the following formula:

$$\text{LAI} = \frac{\text{Total leaf area}}{\text{Total leaf area}}$$

Root nodule count per plant

A root nodule count was performed on five plants and the average was determined as the number of root nodules per plant at 30 and 60 DAS.

Crop growth rate (CGR) (g m^{-2} day^{-1})

Crop growth rate (CGR) at 30-60 DAS was calculated using dry matter accumulation (in grams) of plants from each plot at 30 DAS and 60 DAS, based on the formula developed by Watson (1956):

$$\text{CGR} = \frac{(W2 - W1)}{(t2 - tl)\ S}$$

Where

W1 and W2= The plant dry weights at times. t1 and t2= respectively and S soil area (in square meters) on which dry matter was measured.

B. Yield attributes

Number of pods plant^{-1}

The total number of pods from five marked plants was counted and the average was calculated as the average number of pods plant^{-1}.

Pod weight of plants^{-1} (g)

The weight of pods from five marked plants was taken and the average was calculated as the average number of pod plants^{-1}.

Number of seeds in pod^{-1}

The number of seeds in pod^{-1} of five marked plants was counted and the average was recorded as the number of seeds in pod^{-1}.

Weight of 100 seeds (g)

100 seeds were randomly counted from marked plants from each plot separately after threshing and cleaning. It was then dried properly in the sun and their weight was taken.

RESULTS AND DISCUSSION

A randomized block design with seven replications was used in the study effects of plant growth regulators on soybean growth and yield, conducted at the research farm of the Department of Botany, Balbhim College, Beed, during the 2022 and 2023 *Kharif* season. Research was focused on evaluating the effect of different plant growth regulators on the soybean variety Phule Sangam KDS 726, recommended by MPKV Rahuri. Findings regarding the influence of these regulators on soybean growth and seed yield are discussed below.

Impact of foliar application of growth regulators on soybean growth attributes

In this study, we investigated plant growth parameters under different growth regulator treatments. At 30 days after planting (DAS), no significant difference in plant height was observed between treatments. However, significant changes appeared at 60 DAS and harvest shown in Table 1. Especially at DAS 60, the tallest plants (47.39 cm) were observed in the treatment containing 500 ppm kinetin (T4) and the shortest plants (30.41 cm) in the group treated with 200 ppm GA3 (T2). The same trend was observed at harvest, so that T4 was the tallest plant (48.87 cm) and T2 was the shortest. This suggests that kinetin induces cell division and elongation, leading to increased plant height. Similarly, the number of primary shoots per plant did not show significant changes at 30 DAS, but showed significant differences at 60 DAS and harvest. T3 with 100 ppm kinetin produced the most primary shoots at 60 DAS (16), while T4 with 500 ppm kinetin produced the least (7). At the time of harvest, T3 retained the highest number of primary shoots (19) and the lowest number (13). This suggests that kinetin and salicylic acid may induce new shoot growth, leading to increased leaf area and yield.

Table 1: Effect of foliar spray of plant growth regulators on soybean growth attributes.

Treatment	Plant height (cm)			Number of primary branches plant^{-1}			Leaf area index			Number of root nodules plant^{-1}			Crop growth rate (g m^{-2} day^{-1})
	30 DAS	60 DAS	at harvest	30 DAS	60 DAS	at harvest	30 DAS	60 DAS	Average	30 DAS	60 DAS	Average	(30 -60DAS)
T0	26.68	28.43	32.67	3	7	12	0.28	0.33	0.44	9.12	10.11	14.17	2.32
T1	38.32	46.17	48.33	4	9	15	0.43	0.73	0.79	10.72	12.33	16.88	7.22
T2	27.04	30.41	46.67	6	12	17	0.52	1.91	1.42	12.19	14.07	19.22	6.57
T3	37.4	46.08	46.12	9	16	19	1.58	2.21	2.68	11.46	13.2	18.06	4.76
T4	38.6	47.39	48.87	4	7	13	1.57	1.93	2.53	17.5	23.11	29.05	9.22
T5	37.86	38.61	47.1	8	15	16	1.89	2.98	3.38	19.16	22.44	30.38	8.22
T6	27.4	30.65	33.67	9	13	15	1.79	2.07	2.82	18.33	22.78	29.72	5.2

Regarding the leaf area index (LAI), T5 treated with salicylic acid 50 ppm showed the highest leaf area index at 30 DAS (1.89) and harvest (3.38). Meanwhile, the number of nodules per plant was observed in T5 (30.38) followed by T6, the lowest number in T1 (16.88) treated with 100 ppm GA3, which was significantly different from the control. This shows that salicylic acid can promote leaf growth. Leaf area index is an important measure for plant growth and productivity because it is correlated with the amount of sunlight available to plants for photosynthesis Mohammadi, *et al*. (2017).

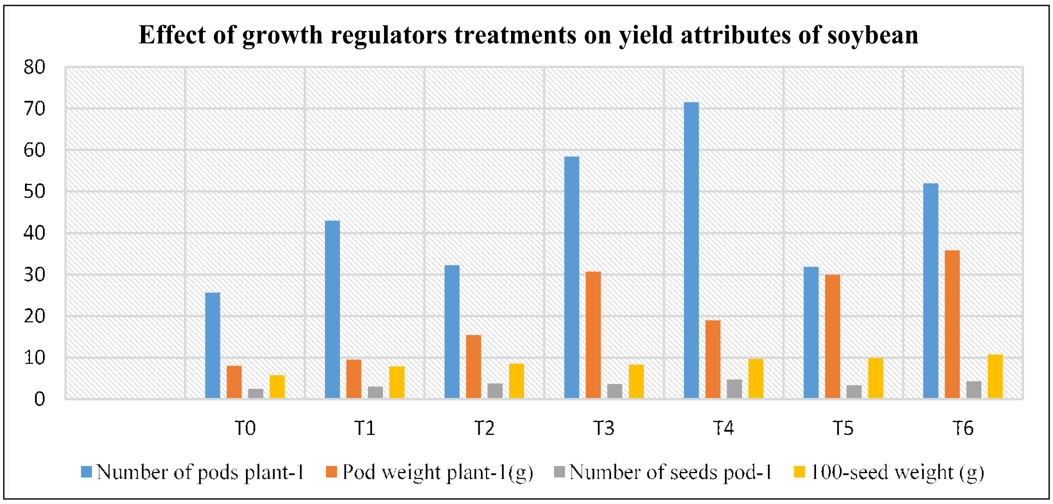
Lastly, crop growth rate (CGR) between 30 and 60 days was significantly higher in T4 (9.22 g m^{-2} day^{-1}) and T5 (8.22 g m^{-2} day^{-1}) compared to the control, with T3 and T6 displaying the lowest CGR values (4.76 g m^{-2} day^{-1} and 5.2 g m^{-2} day^{-1}, respectively). This suggests that kinetin can promote overall plant growth. CGR is an important measure of plant productivity, as it is calculated by dividing the change in plant biomass by the time period. Similar results were reported by earlier workers Kumar *et al*. (2015); Kaur *et al*. (2012); Kai *et al*. (2020); Yadav *et al*. (2019). Salicylic acid has been found to enhance fruit quality and reduce fruit splitting in mandarin, with effective concentrations being 100 ppm (Kaur *et al*., 2024). Further, it has demonstrated positive impacts on chickpea tolerance to salinity when used in concentrations up to 400 ppm, suggesting its role in improving stress resistance (Saif *et al*., 2023). Gibberellic acid (GA3), when applied at a concentration of 60 ppm, was most effective in improving the growth and yield of brinjal in saline soils, indicating its potential for enhancing crop performance under adverse conditions (Misu *et al*., 2023).

Effects of foliar application of growth regulators on yield attributes of soybean

The data in Table 2 and Graph 1, large treatment-related changes in several important parameters. The highest number of pods per plant was evident in T4 (71.54 and 58.43, respectively), which corresponded to a crop growth rate (CGR) of 9.22 g/m^2/day. T3 with 100 ppm kinetin showed a significant number of pods, which was statistically comparable to the control, while the lowest number of pods (31.87) was observed for T5 treated with 50 ppm salicylic acid. In terms of pod weight per plant, T3 and T6 (100 ppm kinetin, 50 ppm salicylic acid) showed the highest pod weight (35.82 grams and 30.69 grams, respectively) and are statistically comparable to were witnesses In contrast, the lowest pod weight (9.51) was largely attributed to T1 treated with 100 ppm GA3. In addition, significant results were

Table 2: Effect of foliar spray of plant growth regulators on yield attributes.

Treatments	Number of pods $plant^{-1}$	Pod weight $plant^{-1}$ (g)	Number of seeds pod^{-1}	100-seed weight (g)
T0	25.65	8.05	2.47	5.76
T1	42.97	9.51	3.03	7.89
T2	32.27	15.42	3.77	8.54
T3	58.43	30.69	3.63	8.34
T4	71.54	18.98	4.7	9.65
T5	31.87	29.95	3.33	9.87
T6	51.97	35.82	4.3	10.76
SD	13.76	10.26	0.7	1.61
SEm ±	6.5	4.83	0.33	0.76
CD (p=0.05)	11.35	8.36	0.57	1.32



Graph 1: Effect of growth regulators treatments on yield attributes of soybean.

recorded for the number of seeds per pod in the experimental years where T4 and T6 (500 ppm kinetin, 50 ppm salicylic acid) showed the highest number of seeds (4.7 and 4.3, respectively) which were comparable. As illustrated in Graph 1, the application of growth regulators significantly impacted the yield attributes of soybean plants. Treatments T2 and T3 showed a positive influence on pod number and weight compared to the control group. In contrast, T1 treated with 100 ppm GA3 had the lowest number of seeds per pod. Also, significant results were obtained in the weight of 100 seeds that T6 and T5 (100 ppm salicylic acid and 50 ppm salicylic acid) had the highest weight of 100 seeds based on the control (10.76 and 9.87 grams, respectively) they had. Meanwhile, the lowest 100 seed weight (7.89 g) was significantly associated with T1 treated with 100 ppm GA3. Improved crop yield in T4, T5 and T6 probably underlies the increase in pod and seed formation in these treatments. This phenomenon is consistent with the previous research of Mominova *et al.* (2022). Dwivedi *et al.*, (2021); Van Niekerk, J.L. (2020), highlighting the positive effects of the treatment on crop yield and quality. Salicylic acid at both 100 ppm and 200 ppm concentrations significantly increased soybean seed yield, with the most effective timing being the vegetative and pod filling stages. This aligns with findings from studies conducted at the ICAR-Indian Institute of Soybean Research (Kuchlan and Kuchlan, 2021). Additionally, the application of seaweed extract was compared with GA3 and salicylic acid treatments and found to elevate various growth and yield parameters in soybean, indicating alternative natural growth promoters (Kalambe *et al.*, 2021).

CONCLUSION

In this study, it can be concluded that the application of gibberellic acid (GA3) at both 100 ppm and 200 ppm was found to be most effective in improving various crop growth parameters such as plant height (cm), number of branches per plant, days to maturity, number of pods per plant, biological yield and seed yield. Notably, GA3 treatment at 100 ppm resulted in the highest increase in soybean seed yield compared to other treatments. This study highlights the importance of comparing the effects of GA3, kinetin and salicylic acid on soybean growth and yield, highlighting the potential of different plant growth regulators in promoting crop development and productivity.

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Conflict of Interest

All authors declared that there is no conflict of interest.

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