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Effect of Foliar Application of Gibberellic Acid at Different Concentrations on Growth, Yield and Quality of Soybean (*Glycine max L*) under Semi-Arid of Kabul conditions

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ABSTRACT: Soybean (*Glycine max* L.) is one of the most important legume crops cultivated worldwide for its high-quality protein and oil content. Using the Plant Growth Regulators (PGRs), particularly gibberellic acid (GA_3) for foliar application, is considered to have great potential in enhancing the yield of soybeans. This study was conducted to investigate the effect of foliar-applied GA_3 on the growth and yield of soybean under the semi-arid condition prevailing in the Kabul University research farm during the 2025 growing season (May-September). Different concentrations of GA_3, such as 0, 50, 100, and 150 ppm, were used at the V6, pre-flowering, and pod-setting stages. The results showed that GA_3 application significantly influenced the growth performance, yield attributes and, seed quality. The plants treated with 150 ppm produced the tallest plants (64.14 cm). The maximum branch number (6.1) and leaf area (42.4 cm²) were recorded in plants treated with 100 ppm GA_3, and there was no significant difference between 100 and 150 ppm. The maximum number of pods per plant (60.35), seed yield (2967.3 kg ha), harvest index (43.4%), 100-seed weight (15.17 g), and seeds per pod (3.07) were noted in plants treated with 150 ppm. However, for all these parameters, there was no significant difference between 100 ppm and 150 ppm treatments. Protein and oil contents were highest in the 100-ppm treatment (38.03 and 19 %).

KEYWORDS: gibberellic acid, growth, kabul, soybean, yield

Soybean is a major legume crop, ranking fourth in global production after wheat, rice, and maize, and plays a crucial role in human nutrition. (Dilawari et al., 2022). Its nutritive value is particularly important to the developing world, as these regions have an inadequate supply of food derived from animal sources (Wu et al., 2017). Among the legumes, soybean (*Glycine max L.)* Merr), is a unique and distinct crop belonging to the Fabaceae family, Order Fabales, and sub-family Papilionoideae (Henrique Braga Pierozzi et al., 2008). Soybean has a chromosome number of 2n = 40, and its flowers are arranged in clusters (Prasad Dixit et al., 2025). Soybean is often cultivated in marginal areas with limited inputs, resulting in lower productivity. The use of genetic enhancement and pesticides, along with improved farming techniques, has been utilized to enhance the productivity of soybean crops. (Zhang et al., 2024).

Nonetheless, specific measures have never focused on the physiological mechanisms responsible for decreasing crop yields. Plant Growth Regulators (PGRs) can be used to maximum yields of these crops because they possess many effects that affect plant performance, including flowering, growth, translocation, and fruiting (Castro-Camba et al., 2022). Using (PGRs) is one way to boost soybean yield and prevent flower abscission. Gibberellin is one of the plant growth regulators recognized for its ability to enhance yield and promote the intended growth per unit area and time. PGRs are also essential for germination, flower and root development, seed maturation, storage, and other functional processes in plants (Wu et al., 2017).

Gibberellins represent an important group of four-ring diterpenoid compounds that have many properties associated with their influence on plant growth and development. Gibberellic acid represents the most abundant and most produced gibberellin compound associated with plant growth and development. (Gupta & Chakrabarty, 2013). Additionally, gibberellins promote longitudinal growth brought about by meristematic tissue development (Bakshi et al., 2015). Afghanistan, a landlocked country in South-Central Asia, has an agriculture-based economy contributing ~33% to GDP(Habibi et al., 2017)..

Although several researchers have carried out different studies on the effects of GA_3 on the growth and production of soybean plants worldwide, no information exists on the effect of GA_3 on soybeans under the semi-arid conditions in Kabul. Drought stress,

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poor soil fertility, water scarcity, and drastic temperature variations may affect the effectiveness of GA_3 on soybean. Moreover, very limited information exists on the optimal dosage and timing for application GA_3 to promote growth, yield, and seed quality of soybeans in Kabul. This research gap has some important practical implications. In the absence of scientifically based guidelines, most Afghan farmers either refrain from using any plant growth regulators or follow unscientific means based on traditional knowledge and experience. This may lead to inconsistent and erratic growth of plants, low yield and ultimately financial losses, which prevent farmers from using modern farming technology. Considering the above factors, the current research is both relevant and imperative. Its objective is to establish empirical data regarding the efficacy of GA_3 in the context of Kabul and to make useful recommendations in order to maximize the yield of soybean farming in semi-arid areas. The specific objectives were to (1) evaluate the effect of different GA_3 concentrations on soybean growth parameters, (2) assess the impact of yield components, and (3) determine the optimal concentration for Kabul conditions

MATERIALS AND METHODS

The field experiment was conducted in the Research Farm of the Agriculture Faculty, Kabul University, Afghanistan, from 15 May 2025 to 24 September 2025. It is located at 34°N latitude and 69°E longitude at an elevation of 1809 m.

Soil Sample and Analysis

In order to determine the parameters of the soil, the soil samples were gathered from the experimental site (KUAF) using an auger soil sampling tool. We took ten samples were taken from the field, each obtained from a depth of 30 cm, and were thoroughly mixed to form a composite sample. The mixed soil samples from the experimental location were subjected to physical and chemical tests at the soil laboratory of Badam Bagh Research Farm, Kabul. According to the soil analysis, in order to increase the fertility of the soil and supply essential nutrients. DAP (diammonium phosphate) was applied at 100 kg ha^{-1}, and urea was applied in three splits: 30 kg ha^{-1} at sowing, 30 kg ha^{-1} at V6, and 30 kg ha^{-1} at flowering

Table 1. Physical and chemical properties of the experimental field

Soil Texture	Available Phosphorus (ppm)	CEC (cmol kg^{-1})	OM (%)	Total N (%)	(CaCo3)	EC (dS/m)	pH
Sandy loam	1.83	16.4	0.9	0.03	12	0.259	7.8

Treatments and Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with 2 sites × 3 reps × 4 treatments = 24 plots, consisting of three GA3 concentrations (50, 100, and 150 ppm) and a control (0 ppm). They were arranged to reduce the effect of environmental variability, with treatments randomly assigned within each block. Distilled water was used to prepare GA3 solutions at concentrations of 50 ppm, 100 ppm, and 150 ppm, which were then applied as a foliar spray.

Plant material and planting procedure

The soybean variety LD04 was supplied from the Banihisar Research Farm of the Ministry of Agriculture, Irrigation, and Livestock. The field was manually prepared using shovels in the spring of 2025. The soil had been thoroughly tilled to prepare a fine seedbed. Ridges and furrows were prepared at the time of sowing. The row spacing was 50 cm, and the plant spacing was 15 cm. Plot dimensions were fixed at 4 m². The spacing between adjacent plots was 40 cm, and the spacing between replications (blocks) was 50 cm. On 15 May 2025, two seeds per hole were planted directly after seedbed preparation, at a depth of 4 cm and a within-row spacing of 15 cm, on both sides of the ridges (40 cm wide). A total of 13 seeds were planted in each ridge, and 52 seeds in each plot. After germination, thinning was carried out to achieve the final plant density. The number of seeds planted depends on the seed size and germination percentage. Normally, the recommended seed rate is 90 kg ha.

GA_3 was applied as a foliar spray at three critical growth stages of soybean. These growth stages were selected based on the physiological sensitivity of soybean at these stages, so that the effect of the hormone on growth parameters could be evaluated. The first application of GA_3 was performed at the V6 stage (when the plants had six mature leaves (trifoliate leaves). The second application was carried out shortly before flowering, indicating that the plant had completed its vegetative stage and moved to the

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reproductive stage, whereas the third application was carried out after flowering at the pod-setting stage to evaluate how gibberellin affects pod setting and filling, and consequently seed production. The GA_3 was applied using a hand-held sprayer at a rate of 500 L ha^{-1}. To minimize photolysis and evaporation, the GA_3 was applied early in the morning (between 06:00 and 08:00 AM), without surfactant to avoid potential interactions with GA_3. Plots were harvested manually at physiological maturity (R8 stage). The seeds were collected, sun-dried, and properly labeled before packing. The samples were then taken to the Food Analysis Laboratory of the Directorate of Livestock Research in Kabul to determine their protein and oil percentages.

Data Analysis

The statistical analyses were carried out using the software STAR (V 2.0.1). Analysis of variance (ANOVA) was applied to determine significant differences between the various treatments. If significant variation was found using the F-test, the LSD test at the 5% probability level ($P < 0.05$) was used to separate treatment means based on the work of Acutis et al. (2012). The standard error of the mean (SEM) was computed for all measured parameters, including growth, yield, and yield-related agronomic traits.

RESULTS

Growth Parameters

The application of different concentrations of gibberellic acid (GA_3) significantly influenced the growth and yield parameters, as shown in Tables 2 and 3, respectively. Among the treatments, the tallest plant height (64.15 cm) was recorded in the 150-ppm treatment. This was significantly taller than the control (0 ppm; 39.8 cm) and the 50-ppm treatment (53.49 cm). However, there was no significant difference between the 100-ppm and 150 ppm treatments. There were statistically significant differences among treatments for branch number per plant. The 100 ppm and 150 ppm treatments produced 6.15 and 5.75 branches per plant, respectively, which significantly differed from the other treatments. The control and 50 ppm treatments had an average of 4.15 and 4.70 branches per plant, respectively, and showed no significant differences between them. Mean comparison showed that GA_3 application increased the leaf area compared to the control (0 ppm) significantly. Specifically, the treatments of 50 ppm, 100 ppm, and 150 ppm treatments had the following mean values for leaf area: 37.68 cm^2, 39.92 cm^2, and 42.40 cm^2 .There were no significant differences among the 50, 100, and 150 ppm GA_3 treatments.

Table. 2: Growth components of soybean as affected by gibberellic acid

Treatments	Plant Height (cm)	Number of Branches	Leaf Area (cm^2)
Control	39.80 c	4.15 b	32.24 b
50 ppm	53.49 b	4.7 b	37.68 a
100 ppm	57.28 b	6.1 a	39.92 a
150 ppm	64.15 a	5.7a	42.4 a
F-test	**	**	*
CV (%)	5.12	9.3	6.39
LSD 0.05 %	5.4955	0.9638	4.8591

LSD. *, ** significant at P≤0.05

Yield Parameters

The number of pods per plant varied significantly among treatments. The mean comparison revealed that the 150-ppm treatment (60.35) resulted in the highest number of pods per plant, followed by 100 ppm (53.10), 50 ppm (48.57), and the 0 ppm treatment (36.65). The increase in pod number with increasing GA3 concentration indicates a positive response of soybean to GA3 application.

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Table 3. Influence of foliar application of GA3 on the yield components

Treatments	Number of Pods Plant^{-1}	Pod Length (cm)	Number of Seeds Pod^{-1}	100 Seed Weight (g)	Shelling Percentage (%)	Seed Yield kg ha	Harvest Index
Control	36.65 c	2.23 b	2.02 b	13.07 b	57.7 b	2040 c	24.9 c
50 ppm	48.57 b	2.83 b	2.73 a	13.98 b	63.45 b	2290 b	32.7 b
100 ppm	53.1 ab	3.13 a	3.00 a	15.05 a	68.3 a	2880 a	41.9 a
150 ppm	60.35 a	2.98 a	3.07 a	15.17 a	69.42 a	2960 a	43.4 a
F-test	*	**	**	**	**	**	**
CV (%)	11.72	3.53	7.29	3.7	3.69	2.41	6.92
LSD 0.05 %	11.6305	0.1977	0.3940	1.0571	4.7765	0.1223	4.9454

LSD=least significant difference, CV=coefficient of variation, *, **, significant and highly significant, respectively.

Results showed that the highest pod length (3.13 cm) was observed in the 150 ppm treatment, which was significantly different from the 0 ppm and 50 ppm treatments (Table 3). Furthermore, a significant difference in the effect of GA3 concentrations on the number of seeds per pod. Treatments 150 ppm (3.07), 100 ppm (3.00), and 50 ppm treatments (2.73) were statistically similar, indicating no significant differences among them, while the 0-ppm treatment differed significantly from them. The 150 ppm treatment exhibited the highest number of seeds per pod, whereas the lowest number (2.02) was recorded in the 0 ppm treatment (Table 3).
The ANOVA results showed that GA3 concentration significantly affected 100-seed weight. 100 ppm and 150 ppm treatments, which had means of 15.05 g and 15.17 g, with no significant difference between them. Meanwhile, the 0 ppm and 50 ppm treatments had mean values of 13.07 g and 13.98 g, respectively. The highest seed weight was obtained from the 150 ppm treatment 15.17 g, whereas the lowest (13.07 g) was recorded in the 0 ppm treatment. Analysis of variance (ANOVA) showed a significant difference among the various treatments for shelling percentage. In comparison across all treatments, the maximum shelling percentage was observed in the 150 ppm treatment (69.43%), whereas the minimum (57.70%) was recorded for the 0 ppm treatment. Analysis of variance ANOVA showed a significant difference among the various treatments for seed yield (kg ha^{-1}). The mean comparison using the LSD mean comparison test showed that the 150 ppm treatment (2960 kg ha) recorded the highest value, while the 100 ppm treatment (2880 kg ha), was placed in the same statistical group. The 50 ppm(2290 kg ha) and 0 ppm treatments (2040 kg ha) were assigned to group (b), and both were significantly lower than the 100 ppm and 150 ppm treatments.

Seed Quality

Seed protein and oil contents varied among the GA3 concentrations (Table 4). The maximum protein content of 38.03% was achieved at the 100 ppm treatment. indicating that protein accumulation was positively affected by this treatment. Whereas the 150 ppm treatment showed the lowest value, 36.62%. Intermediate values were obtained from 50 ppm and 0 ppm treatments, with protein contents of 37.82% and 37.49%. Oil Content also varied among treatments. The highest oil content (19.44% was recorded from the 100 ppm treatment, indicating a positive effect of GA_3 on oil accumulation in the seeds. The lowest oil content 18.64% was observed from the 50 ppm treatment. Control and 150ppm treatment had fairly similar percentage oil content at 19.41% and 19.25%, respectively.

Table .4. Effects of GA3 concentrations on quality of soybean seed

Treatments	Protein (%)	Oil (%)
Control	37.49	19.41
50 ppm	37.82	18.64
100 ppm	38.03	19.44
150 ppm	36.62	19.25

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DISCUSSION

The results of this study demonstrate that different concentrations of gibberellic acid enhanced soybean yield through distinct physiological pathways. Foliar application of GA_3 significantly affected plant height. The 150 ppm treatment produced the tallest plants (64.15 cm) was recorded from the 150 ppm treatment. Similar results were reported by (Hamayun et al., 2010), who found that the application of GA3 greatly increased plant length and fresh/dry biomass. GA_3-treated plants, the shoot length of soybean was significantly promoted by elevated concentrations of GA_3. Maximum shoot length (55.06 cm) was recorded for the 5.0 μM GA3-treated plant. Foliar application of GA_3 had a considerable influence on the number of branches. The maximum number of branches (6.1) was produced from the 100-ppm treatment (Shan et al., 2021), reported that the lower concentrations of GA_3 had little effect on the vegetative growth of soybean compared to higher concentrations. These findings are fully consistent with previous reports, including (Solanke, 2018), who noted that GA3 foliar spraying at 3.0 mL L^{-1} increased plant height, leaf area index, crop growth rate, and number of branches.

The high leaf area measured at 150 ppm (42.4 cm²) and 100 ppm (39.92 cm²) confirms that GA_3 helps to increase leaf expansion and canopy formation. The findings further support the general concept that moderate levels of GA3 perform better than very high levels. This has been previously confirmed by (Erol & Arslanoğlu, 2022). In their work on soybean, they concluded that 100 ppm GA_3 was more effective than the higher levels tested. These findings indicate that GA3 application, particularly at the 100-ppm level and above, would be effective in improving the leaf area of soybean plants.

The findings of this study, supported by analysis of variance, showed a significant effect on the number of pods per plant. Our findings of 60.35 pods per plant at 150 ppm are consistent with the 109.10 pods reported by Azzahra, (2025) at 100 ppm, although the difference in absolute values may be due to variety and environmental conditions. This could be due to the reduced rate of flower abscission in the 100 ppm treatment, which resulted in a greater proportion of flowers maturing into pods. According to (Shahzad et al., 2024), foliar application of GA_3 at 125 ppm significantly boosted pod number per plant, seeds per pod, and seed yield in soybean.

In this study, the highest pod length (3.15 cm) was recorded in T_3 (100 ppm). The significant increase in pod length caused by GA_3 application suggested that exogenously applied gibberellin improved reproductive growth and pod development under the current environmental conditions (Amoanimaa-Dede et al., 2022). They found that the application of GA_3 greatly improved soybean pod length by increasing cell division and elongation activities during the reproductive stage. The application of GA_3 increased the number of seeds per pod, reaching a maximum of 3.07 at 150 ppm. However, this value was not significantly different from that obtained with the 100-ppm treatment. These findings are fully consistent with previous reports, including (Shahzad et al. 2024), who reported that foliar application of GA3 at 125 ppm significantly boosted pod number per plant, seeds per pod, and seed yield in soybean. In the present study, the 100 ppm and 150 ppm treatments, with mean values of (15.05 g) and (15.17 g), respectively, showed no significant difference between them. Applying GA_3 at 100 ppm to soybean genotypes M11 and L17 resulted in significant effects on 1000 seed weight (107.60 g) and economic yield Azizi, K., et al., 2012). These findings are fully consistent with previous reports, including Mahajan, G. et al (2014), who demonstrated that foliar GA3 application increases the number of seeds per pod and the weight of 100 seeds in soybean. Basuchaudhuri (2016) found that the use of gibberellic acid resulted in an increase in the total yield of the soybean crop, as well as in vegetative growth and leaf area. The ability of gibberellins to stimulate plant physiological activities could explain the high seed yields when plants were treated with GA_3. It is clear that gibberellins stimulate cell elongation, enzyme activation, and photosynthesis; consequently, plant growth and reproduction are enhanced (Davies, P. J., 2010). The higher GA_3 concentrations (100 and 150 ppm) used in this study may have helped in retaining flowers and pods, as well as in promoting the translocation of assimilates to the seeds. Likewise, (Safira & Damanik 2024) established that higher concentrations of GA_3 above 100 ppm in waterlogged environments did not result in further gains. This indicates that 100 ppm might represent a saturation level for a number of physiological responses in soybeans.

Protein and oil contents are important quality characteristics in soybeans because they impact the nutritional and industrial value of soybean seeds. In this present study, foliar application of a plant growth regulator had a positive effect on the protein percentage of soybean seeds. It is reported that the application of GA_3 affects seed quality parameters such as protein content, oil percentage, seed vigor, and germination percentage(Kuchlan et al., 2017). In agreement with these reports, our results showed the maximum protein content in the 100-ppm treatment. The highest protein percentage 38.03% was recorded from 100 ppm, and the lowest protein percentage (36.62%) was obtained from the control. Indicated that GA_3 can enhance the protein percentage of soybeans. The highest oil percentage (19.44%) was recorded from 100 ppm, whereas the lowest oil content 18.64% attainted form 50 ppm treatment. These findings suggest that an optimal level of GA_3 promotes oil synthesis, while lower or higher levels may not produce the same effect. The use of GA_3 during flowering and pod development resulted in a considerable increase in oil yield, which was significantly linked with soybean grain yield. Increased oil yield was directly connected with soybean grain yield. (Khatun et al., 2016) as cited in (Amoanimaa-Dede et al., 2022). . In contrast, the best values on protein and oil content were recorded using100 ppm treatment. These results suggest that an optimal GA_3 concentration, while higher or lower concentration may not have a same enhancing effect In summary, the application of GA_3 at 100-150 ppm enhanced the growth and productivity of soybean, with 100 ppm being cost-effective as there was no added benefits with higher concentrations. The experiment was carried out in one growing season only; thus, more trials should be done in the future.

CONCLUSION

This study comprehensively investigated the impact of foliar-applied Gibberellic Acid (GA_3) on the growth and yield of soybean. The findingس revealed that gibberellic acid (GA_3) had significant effects on the growth and productivity of soybean compared to the untreated control. The higher levels of GA_3 increased the majority of vegetative characters, such as height and leaf area. Maximum height (64.15 cm) and leaf area (42.4 cm²) were recorded at 150 ppm GA_3, while maximum branching (6.1 branches plant^{-1}) was recorded at 100 ppm. Yield parameters were significantly improved after GA_3 application. Treatments of 100 and 150 ppm increased the number of pods per plant, pod length, number of seeds per pod, 100-seed weight, shelling percentage, seed yield, and harvest index compared to the control treatment. Seed yield and harvest index reached 2960 kg ha^{-1} and 43.4%, respectively, were observed at the 150 ppm concentration gave results that were statistically similar for some yield parameters. Based on these findings, application of GA_3 at 100-150 ppm is recommended for soybean cultivation under Kabul's semi-arid conditions, with 100 ppm being the most economical concentration. Regarding protein content in the seeds, it was found that maximum protein content (38.03 %) was achieved at the 100 ppm treatment. Overall, it seems that the contribution of GA_3 in enhancing soybean growth, yield, and seed quality cannot be underestimated. Hence, it would be better to use GA_3 in the range of 100–150 ppm in soybean production depending on whether high yield or protein content is the goal.

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