PLANT SCIENCE TODAY
Vol 13(sp1): 1-6
https://doi.org/10.14719/pst.11835

eISSN 2348-1900

RESEARCH COMMUNICATION

Seed yield and quality enhancement in off-season soybean (*Glycine max* L.) through plant growth regulators

PC Bhamat*, J B Patel, R B Mori, D B Kothadiya, J R Sondarva & Shikha Dhiman

Department of Seed Science and Technology, College of Agriculture, Junagadh Agricultural University, Junagadh362 001, Gujarat, India

*Correspondence email - purvashibhamat@gmail.com

Received: 18 September 2025; Accepted: 24 December 2025; Available online: Version 1.0: 04 February 2026

Cite this article: Bhamat PC, Patel JB, Mori RB, Kothadiya DB, Sondarva JR, Shikha D. Seed yield and quality enhancement in off-season soybean (*Glycine max* L.) through plant growth regulators. Plant Science Today. 2026; 13(sp1): 1-6. https://doi.org/10.14719/pst.11835

Abstract

A field and laboratory investigation entitled "Seed yield and quality enhancement in off-season soybean (*Glycine max* L.) through plant growth regulators" was carried out during the summer of 2024 at the Department of Seed Science and Technology, College of Agriculture, Junagadh Agricultural University, Junagadh. The field experiment was conducted using a Randomised Block Design (RBD) with a factorial concept at Sagdividi Farm; the laboratory study was carried out using a completely randomised design (CRD) at the Seed Testing Laboratory with seeds obtained from the corresponding field trial. The treatments consisted of two factors: stages of spraying [S_1: 30 DAS, S_2: 45 DAS and S_3: 30 and 45 DAS] and plant growth regulators [P_1: distilled water, P_2: SA 400 ppm, P_3: SA 800 ppm, P_4: NAA 400 ppm, P_5: NAA 800 ppm, P_6: Thiourea 400 ppm and P_7: Thiourea 800 ppm] along with an absolute control. Results of the field study revealed that spraying PGRs at both 30 and 45DAS (S_3), particularly NAA at 400 ppm, significantly enhanced highest plant height at maturity (cm), number of clusters per plant, number of pods per plant, number of pods per cluster, number of seeds per pod, number of seeds per plant, biological yield per plant (g), seed yield per plant (g) and test weight (g), with the lowest days to 50 % flowering and maturity. Correspondingly, the laboratory evaluation indicated that seeds derived from NAA 400 ppm treatments with dual sprays (30 and 45 DAS) recorded the highest germination (%), shoot length (cm), root length (cm), seedling length (cm), seedling dry weight (mg), seedling vigour index I and seedling vigour index II.

Keywords: PGRs; seed quality; seed yield; soybean; stages of spraying

Introduction

Soybean [*Glycine max* (L.). Merrill], often known as the Golden bean and Miracle crop of the 20th century, is one of the worlds' most economically and nutritionally significant crops (1). Renowned for its versatility, soybeans provide a major source of vegetable protein and edible oil, earning additional titles such as the Wonder crop and the Gold of soil. Belonging to the *Fabaceae* family and *Papilionaceae* subfamily, soybean is closely related to other legumes such as peas, alfalfa and clover. It is an annual plant adapted to temperate climates, with optimal growth occurring at temperatures between 30–38 °C. Nutritionally, soybean is unique among edible legumes owing to its high protein concentration (40–42 %), significant oil content (approximately 20 %), (2). The protein in soybeans is abundant in valuable amino acids, lysine and tryptophan, that are typically deficient in cereals (3). In addition to proteins and oils, soybean provides essential minerals, vitamins (thiamine, riboflavin), carotene (a precursor of vitamin A) and essential fatty acids, of which about 85 % are unsaturated. Its health benefits include lowering serum cholesterol, reducing the risk of coronary heart disease (CHD), breast cancer and alleviating menopausal symptoms in women (4).

The effectiveness of plant growth regulators (PGRs) in enhancing crop yield is highly influenced by the growth stage at which they are applied. In soybean, critical developmental phases such as the vegetative stage, flowering stage and pod filling stage are particularly responsive to hormonal regulation. Applying PGRs during the vegetative stage can promote vigorous growth and root development, while spraying at the flowering stage helps in reducing flower and pod drop, thereby improving pod set. Application during the pod filling stage enhances seed development and final seed weight. Therefore, identifying the optimal stage of spraying is crucial for maximising the yield-enhancing effects of PGRs, especially under off-season (summer) conditions where crop performance may be limited by environmental stress (5). Off-season soybean cultivation faces major challenges such as temperature and photoperiod mismatch, moisture stress, higher pest–disease incidence and poor reproductive performance, resulting in reduced yield and quality.

Soybean seed quality declines rapidly due to numerous factors, with different varieties showing sensitivity to environmental changes in cultivation (6). Primarily, soybean seed production occurs during the kharif season. In recent years, continuous rainfall coinciding with the pod maturity stage has caused in-situ germination, leading to a faster decline in seed quality. These issues necessitate the adoption of strategies such as the provision of high-quality seeds, deployment of resistant soybean varieties against biotic stresses and improved management of abiotic stresses.

To enhance soybean productivity and overcome these challenges, bio-regulators play a crucial role. Thiourea, an organo-sulfur compound, acts as an effective bio-regulator by mitigating abiotic stress and improving nutrient management, as demonstrated in chickpea cultivation (7). Salicylic acid (SA), a naturally occurring phenolic regulator, contributes to plant growth, development, biotic interactions and stress tolerance (8). Similarly, naphthalene acetic acid (NAA), a synthetic auxin, is applied to increase flower production, reduce flower abscission and enhance seed yield. Foliar application of NAA promotes apical dominance, cell elongation and shoot development, ultimately contributing to better crop yield.

Materials and Methods

The present investigation on "seed yield and quality enhancement in off-season soybean (*Glycine max* L.) through plant growth regulators" was carried out during summer 2024 at the DSST, College of Agriculture, JAU, Junagadh, using the soybean variety GS-4. The study consisted of both field and laboratory experiments and a variety of GS 4. The field trial was conducted at Sagdividi Farm in a randomised block design with factorial concept as suggested by Cochran and Cox (8). The treatments comprised three stages of spraying, viz., 30 DAS (S_1), 45 DAS (S_2) and both 30 and 45 DAS (S_3), along with seven plant growth regulators, viz., distilled water (P_1), salicylic acid 400 ppm (P_2), Salicylic Acid 800 ppm (P_3), naphthalene acetic acid 400 ppm (P_4), naphthalene acetic acid 800 ppm (P_5), thiourea 400 ppm (P_6) and thiourea 800 ppm (P_7). An absolute control was also maintained for comparison. Data was collected for each treatment plot were recorded from a fixed net harvest area, excluding border rows to avoid edge effect and randomly selected sample plants within each plot; statistically analyzed for days to 50 % flowering, days to maturity, plant height at maturity (cm), number of clusters per plant, number of pods per plant, number of pods per cluster, number of seeds per pod, number of seeds per plant, biological yield per plant (g), seed yield per plant (g), test weight (g) and harvest index (%).

The laboratory experiment was conducted from summer 2024 onwards at the Seed Testing Laboratory of the department using freshly harvested seeds obtained from the corresponding field experiment. The experimental design adopted was a completely randomised design with factorial concept (9). The treatments used were the same as those in the field experiment. The seed quality parameters studied were germination (%), shoot length (cm), root length (cm), seedling length (cm), seedling dry weight (mg), seedling vigour index I and seedling vigour index II.

Results and Discussion

Effect of stages of spraying

Irrespective of PGRs application, the effect of different stages of spraying exerted a significant difference for all the characters studied except harvest index. Significantly higher days to 50 % flowering (42.48 days), days to maturity (89.86 days), plant height at maturity (28.01 cm), number of clusters per plant (14.20), number of pods per plant (30.96), number of pods per cluster (2.27), number of seeds per pod (2.46), number of seeds per plant (61.94), biological yield per plant (7.12 g), seed yield per plant (4.05 g) and test weight (8.16 g) was observed when spraying of PGRs was done at both 30 and 45 DAS. Significantly lower days to 50 % flowering (40.76 days), days to maturity (86.86 days), number of seeds per plant (58.70), biological yield per plant (6.48 g) and test weight (7.36 g) was observed at 30 DAS stage of spraying, whereas significantly lower plant height at maturity (26.38 cm), number of clusters per plant (13.15), number of pods per plant (28.67), number of pods per cluster (2.16), number of seeds per pod (2.35) and seed yield per plant (3.82 g) was observed at 45 DAS spraying stage. Plant growth regulators (PGRs) can significantly influence soybean yield by affecting various stages of crop growth. Different PGRs, applied at specific growth stages, can impact plant height, branching, chlorophyll content and ultimately, seed yield. Understanding the appropriate PGRs and their application timing is crucial for optimising soybean production.

When PGRs were sprayed two times at 30 and 45 DAS, in comparison to individual spray either at 30 DAS or 45 DAS. Spraying of PGRs at both 30 and 45 DAS is often more effective than spraying at 30 or 45 DAS, because it provides a more sustained impact on plant development. A PGR that is effective at 30 DAS might not be effective at 45 DAS due to changes in the plants' physiology and hormonal levels. PGRs that promote early vegetative growth might be beneficial at 30 DAS, while one that enhances flowering or fruit set might be more appropriate at 45 DAS. By applying both at 30 and 45 DAS, the impact can be more prolonged, ensuring that the plant receives the necessary hormonal support throughout the critical period of development. PGR application at both 30 and 45 DAS is more effective because 30 DAS corresponds to active leaf expansion and cell division (high auxin sensitivity), while 45 DAS involves reproductive organ formation and pod set (greater cytokinin/auxin responsiveness), ensuring continuous hormonal support across stages. A single spray at 45 DAS gives lower responses because plants miss the early vegetative hormonal regulation needed to build sufficient photosynthetic and structural capacity for later reproductive growth.

The obtained results are consistent with the (10) application of ethrel at 200 ppm to plants at both 40 DAS flower initiation and 60 DAS pod initiation, which led to enhanced vegetative growth and consequently delayed flowering relative to the control. In French bean, the application of PGR (SA) at the plant emergence stage had the lowest days to flowering in comparison to PGR spray at the flowering stage (11). Similar results were reported in groundnut (12). Irrespective of the stages of spraying, the effect of different PGRs was found to be significant for all the characters studied except harvest index. Significantly higher plant height at maturity (29.22 cm), number of cluster per plant (15.02), number of pods per plant (32.96), number of pods per cluster (2.33), number of seeds per pod (2.59), number of seeds per plant (65.22), biological yield per plant (8.09 g), seed yield per plant (4.19 g) and test weight (8.42 g) was observed with PGR NAA (400 ppm). The minimum days to 50 % flowering (38.89 days) and maturity (86.67 days) were recorded under the PGR treatment with NAA 400 ppm (P_4), while the maximum days to 50 % flowering (44.33 days) and maturity (91.00 days) were observed under the distilled water spray treatment (P_1). Significantly lower plant height at maturity (24.94 cm), number of clusters per plant (27.20), number of pods per cluster (2.07), number of seeds per pod (2.24), number of seeds per plant (56.74), biological yield per plant (5.95 g), seed yield per plant (3.56 g) and test weight (6.99 g) was observed in distilled water spray (P_1).

Plant growth regulators produced within a plant determine many growth and development processes, ultimately influencing yield components and yield. Plant growth regulators are known to improve the source-sink relationship, stimulating the movement of photo-assimilates in the process. This helps facilitate effective flower formation, fruit and seed development, ultimately increasing crop productivity. Growth regulators can boost physiological efficiency, encompassing photosynthetic capacity and increasing the efficient distribution of assimilates from source to sink in field crops (13). The majority of floral buds on soybean plants develop in abundance, but many ultimately fail to mature into pods. Auxin enhances source strength by promoting vegetative growth, leaf expansion and photosynthesis, while it improves sink strength by supporting pod set, reducing flower/ pod drop and facilitating seed development. Plant growth regulators (PGRs) play a vital role in improving crop yield by influencing various physiological and biochemical processes within plants. Furthermore, PGRs contribute to increased plant population per unit area, a key factor in maximising yield. Off-season soybean cultivation presents unique challenges and while PGRs can potentially mitigate some issues, their effectiveness requires careful consideration of these specific conditions.

Naphthalene acetic acid (NAA) plays a significant role in promoting flowering, fruit set and seed development, as well as stimulating cell division and elongation. These physiological effects contribute to an increase in the number of clusters per plant, pods per plant and pods per cluster, which in turn enhances the number of developing seeds per pod and per plant. In soybeans, the application of NAA has been found to increase plant height and the number of branches per plant, while reducing flower and pod shedding. This ultimately results in the production of more well-developed, bold seeds and a higher seed yield per plant. Research indicates that comparable results have been documented in ridge gourd and soybean (10, 14-17).

The interaction effect between stages of spraying and PGRs application (S × P) was found statistically non-significant for seed yield per plant and its attributes. It suggests that the effect of stages of spraying on the characters studied does not depend on the PGRs application and *vice versa*. In simple terms, the two factors, stages of spraying and PGR applications, don't influence each others' effects.

The analysis of control vs. all the rest of the treatments showed a significant difference for seed yield and all the yield attributes studied. Absolute control recorded the lowest values for seed yield per plant and all the yield attributes compared to the average of all the treatments. Significantly lower days to 50 % flowering (35.67 days), days to maturity (72.00 days), plant height at maturity (22.27 cm), number of clusters per plant (8.73), number of pods per plant (13.53), number of pods per cluster (1.86), number of seeds per pod (2.15), number of seeds per plant (49.07), biological yield per plant (5.45 g), seed yield per plant (2.98 g), test weight (5.14 g) and harvest index (54.67 %) was observed in control (Table 1-2). The control plants were allowed to develop naturally without any exogenous hormone intervention, potentially leading to faster transition from vegetative growth to flowering, resulting in early pod formation and development, leading to early maturity, while the application of plant growth regulators sometimes delays flowering by influencing hormonal pathways that regulate this process (18-20).

The freshly harvested seeds from all treatment combinations were analysed for their impact on seed quality parameters. Irrespective of the PGRs application, the stage of spraying exerted significant results for all seed quality parameters. Significantly higher germination (86.43 %), shoot length (4.16 cm), root length (3.73 cm), seedling length (7.88 cm), seedling dry weight (284.14 mg), seedling vigour index I (681.06) and seedling vigour index II (24558.22) were observed when spraying was done at both 30 and 45 DAS spraying stages. Significantly lower germination (83.14 %), shoot length (3.70 cm), root length (3.44 cm), seedling length (7.14 cm), seedling dry weight (268.14 mg), seedling vigour index I (593.61) and seedling vigour index II

Table 1. Effect of stages of spraying, PGRs application and their interaction on days to 50 % flowering, days to maturity, plant height, number of clusters per plant, number of pods per plant and number of pods per cluster

Factors	Days to 50 % flowering	Days to maturity	Plant height (cm)	Number of clusters per plant	Number of pods per plant	Number of pods per cluster
Stages of spraying (S)						
S_1	40.76	86.86	26.86	13.37	28.90	2.19
S_2	42.24	89.05	26.38	13.15	28.67	2.16
S_3	42.48	89.86	28.01	14.20	30.96	2.27
S.E m±	0.44	0.64	0.45	0.24	0.69	0.02
CD at 5 %	1.24	1.83	1.28	0.67	1.95	0.07
Plant growth regulators (P)						
P_1	44.33	91.00	24.94	12.40	27.20	2.07
P_2	41.67	87.44	27.58	13.89	29.69	2.21
P_3	42.00	88.11	27.19	13.67	29.71	2.22
P_4	38.89	86.67	29.22	15.02	32.96	2.33
P_5	40.00	87.33	28.18	14.59	30.77	2.25
P_6	42.56	89.56	26.44	12.97	28.11	2.17
P_7	43.33	90.00	26.02	12.48	28.13	2.17
S.E m±	0.67	0.98	0.69	0.36	1.05	0.04
CD at 5 %	1.90	2.79	1.97	1.03	2.98	0.10
S × P						
S.E m±	1.17	1.74	1.21	0.64	1.84	0.07
CD at 5 %	NS	NS	NS	NS	NS	NS
Control vs rest						
Control	35.67	72.00	22.27	8.73	17.53	1.86
Rest	41.83	88.59	27.08	13.57	29.51	2.20
S.E m±	1.18	1.73	1.22	0.64	1.85	0.06
CD at 5 %	3.38	4.95	3.49	1.83	5.29	0.19
CV %	4.86	3.40	7.73	8.15	10.80	5.22

S: Stages of spraying, S_1: 30 DAS, S_2: 45 DAS, S_3: 30 and 45 DAS, P: plant growth regulators, P_1: distilled water, P_2: SA 400 ppm, P_3: SA 800 ppm, P_4: NAA 400 ppm, P_5: NAA 800 ppm, P_6: Thiourea 400 ppm and P_7: Thiourea 800 ppm, CD: Critical difference; CV: Coefficient of variance; NS: Non Significant.

Table 2. Effect of stages of spraying, PGRs application and their interaction on the number of seeds per pod, number of seeds per plant, biological yield per plant, seed yield per plant, test weight and harvest index

Factors	Number of seeds per pod	Number of seeds per plant	Biological yield per plant (g)	Seed yield per plant (g)	Test weight (g)	Harvest index (%)
Stages of spraying (S)						
S_1	2.36	58.70	6.48	3.90	7.36	60.18
S_2	2.35	58.79	6.89	3.82	7.49	55.44
S_3	2.46	61.94	7.12	4.05	8.16	56.88
S.Em ±	0.03	1.01	0.17	0.06	0.15	1.71
CD at 5 %	0.08	2.88	0.49	0.18	0.42	NS
Plant growth regulators (P)						
P_1	2.24	56.74	5.95	3.56	6.99	59.83
P_2	2.39	59.84	7.05	3.96	7.69	56.17
P_3	2.39	58.80	6.72	3.96	7.67	58.92
P_4	2.59	65.22	8.09	4.19	8.42	51.79
P_5	2.50	61.18	7.30	4.01	7.95	65.91
P_6	2.33	58.47	6.34	3.91	7.53	61.67
P_7	2.30	58.40	6.36	3.86	7.44	60.69
S.E m±	0.05	1.55	0.26	0.10	0.23	2.61
CD at 5 %	0.13	4.41	0.75	0.28	0.64	NS
S × P						
S.E m±	0.07	2.58	0.46	0.17	0.39	4.52
CD at 5 %	NS	NS	NS	NS	NS	NS
Control vs rest						
Control	2.15	49.07	5.45	2.98	5.14	55.42
Rest	2.39	59.81	6.83	3.92	7.67	58.14
S.E m±	0.08	2.73	0.46	0.17	0.40	4.52
CD at 5 %	0.23	7.81	1.33	0.49	1.14	13.76
CV %	5.14	7.48	11.70	7.39	8.85	14.07

S: Stages of spraying, S_1: 30 DAS, S_2: 45 DAS, S_3: 30 and 45 DAS, P: plant growth regulators, P_1: distilled water, P_2: SA 400 ppm, P_3: SA 800 ppm, P_4: NAA 400 ppm, P_5: NAA 800 ppm, P_6: Thiourea 400 ppm and P_7: Thiourea 800 ppm, CD: Critical difference; CV: Coefficient of variance.

(22347.20) were observed at the stage of spraying at 45 DAS.

Spraying plant growth regulators at both 30 and 45 days after sowing (DAS) proved more effective than spraying at 30 DAS or 45 DAS. The first spray at 30 DAS coincided with the late vegetative phase, when plants were actively producing leaves and building their photosynthetic capacity. The second spray at 45 DAS matched the early reproductive phase, when flowering and initial pod setting occur. Applying PGRs at both of these critical growth stages ensured that plants received physiological support during both source development (vegetative growth) and sink establishment (reproductive growth). As a result, the split application produced better seed filling, higher 100-seed weight, improved germination percentage and greater seedling vigour compared to single sprays at either 30 or 45 DAS. This demonstrates that targeting both vegetative and reproductive stages is essential for improving seed quality in off-season soybean.

Irrespective of the stages of spraying, PGRs application exerted significant results for all seed quality parameters. Significantly higher germination (92.08 %), shoot length (4.70 cm), root length (4.14 cm), seedling length (8.84 cm), seedling dry weight (318.17 mg), seedling vigour index I (813.98) and seedling vigour index II (29297.09) were observed with the application of NAA 400 ppm. Significantly lower germination (77.00 %), shoot length (3.25 cm), root length (2.80 cm), seedling length (6.05 cm), seedling dry weight (226.08 mg), seedling vigour index I (465.85) and seedling vigour index II (17408.16) were observed in distilled water spray.

The quality of soybean seeds was significantly affected by the timing of plant growth regulator application. This auxin-mediated enhancement of sink strength promotes higher accumulation of proteins and oils, contributing to better physiological quality, as indicated by higher germination percentage and vigour index. NAA applied at the optimal reproductive stage significantly enhances seed quality traits, especially when seed filling processes are active. Research has demonstrated similar findings in garden pea, soybean, sponge gourd, ridge gourd and forage cowpea (14, 16, 21-23). The interaction effect of stages of spraying and PGRs application (S × P) showed a non-significant difference for all seed quality parameters. This indicates that the effect of spraying stages on the studied traits is independent of PGR application and likewise, the influence of PGR application is not affected by the spraying stages.

The analysis of control vs. all the rest of the treatments showed a significant difference for all the seed quality parameters studied. Absolute control recorded the lowest values for all the seed quality parameters compared to the average of all the treatments. The absolute control was also evaluated in comparison with the other treatments under laboratory conditions. Significantly lower germination (72.25 %), shoot length (2.76 cm), root length (2.44 cm), seedling length (5.20 cm), seedling dry weight (212.50 mg), seedling vigour index I (375.70) and seedling vigour index II (15353.12) were observed in the control (Table 3). Research has demonstrated similar observations in soybean, okra, pigeon pea and mungbean (24-27).

Conclusion

The current research demonstrates that applying plant growth regulators to the leaves has a significant impact on increasing both the yield and quality of off-season soybeans. Spraying NAA at 400 ppm twice at 30 and 45 DAS was found most effective, resulting in higher seed yield, improved seed quality and better physiological vigour. For farmers, this practice not only ensures higher productivity per unit area but also provides quality seed material for subsequent sowing, reducing dependency on external seed sources. The economic advantage lies in increased returns through higher

Table 3. Effect of stages of spraying, PGRs application and their interaction on germination, shoot length, root length, seedling length, seedling dry weight, seedling vigour index I and seedling vigour index II

Factors	Germination (%)	Shoot length (cm)	Root length (cm)	Seedling length (cm)	Seedling dry weight (mg)	Seedling vigour index I	Seedling vigour index II
Stages of spraying (S)							
S_1	84.32	3.98	3.59	7.57	275.64	638.30	23241.96
S_2	83.14	3.70	3.44	7.14	268.79	593.61	22347.20
S_3	86.43	4.16	3.73	7.88	284.14	681.06	24558.22
SE m±	0.51	0.04	0.03	0.05	2.38	5.31	209.49
CD at 5 %	1.43	0.10	0.09	0.13	6.71	14.84	591.500
Plant growth regulators (P)							
P_1	77.00	3.25	2.80	6.05	226.08	465.85	17408.16
P_2	86.00	4.06	3.76	7.82	291.50	672.52	25069.00
P_3	84.58	3.84	3.64	7.48	285.08	632.65	24112.06
P_4	92.08	4.70	4.14	8.84	318.17	813.98	29297.09
P_5	89.33	4.44	4.01	8.45	306.92	754.83	27417.16
P_6	82.17	3.72	3.41	7.14	255.00	586.69	20953.35
P_7	81.25	3.60	3.33	6.93	250.58	563.06	20359.62
S.E m±	0.77	0.05	0.05	0.08	3.63	8.11	320.00
CD at 5 %	2.18	0.15	0.14	0.21	10.25	22.88	903.53
S × P							
S.E m±	1.36	0.10	0.09	0.13	6.43	14.28	566.13
CD at 5 %	NS	NS	NS	NS	NS	NS	NS
Control vs rest							
Control	72.25	2.76	2.44	5.20	212.50	375.70	15353.12
Rest	84.63	3.94	3.59	7.53	276.19	637.26	23373.95
S.E m±	1.37	0.09	0.09	0.13	6.44	14.37	567.29
CD at 5 %	3.87	0.27	0.25	0.37	18.18	40.57	1601.79
CV %	3.21	4.82	4.77	3.51	4.66	4.46	4.78

S: Stages of spraying, S_1: 30 DAS, S_2: 45 DAS, S_3: 30 and 45 DAS, P: plant growth regulators, P_1: distilled water, P_2: SA 400 ppm, P_3: SA 800 ppm, P_4: NAA 400 ppm, P_5: NAA 800 ppm, P_6: Thiourea 400 ppm and P_7: Thiourea 800 ppm, CD: Critical difference; CV: Coefficient of variance, DAS: Days after sowing.

marketable yield and improved crop establishment in the next season. In the long term, adoption of such practices can contribute to sustainable soybean cultivation by improving seed health, enhancing resource use efficiency and ensuring better adaptability of the crop under varying environments. Future research can focus on optimising PGR combinations, doses and application timings across different soybean varieties and agro-climatic zones, as well as understanding their mechanistic effects on stress tolerance and nutrient use efficiency.

Acknowledgements

The authors are thankful to Junagadh Agricultural University, College of Agriculture, for providing the necessary infrastructure and resources.

Authors' contributions

PCB was involved in the research activities, field establishment and writing of the research article. JBP and RBM corrected and proofread the research article. DBK, JRS and SD were involved in statistical analysis work of the data collected during the research and participated in the sequence alignment. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Kumar AS, Lal GM, Mishra PK. Genetic variability and character association for yield and its components in soybean. Ann Plant Soil Res. 2014;16(1):48–52.
2. Gopalan C, Rama Sastri BV, Balasubramanian SC. Nutritive value of Indian foods. Hyderabad: National Institute of Nutrition, Indian Council of Medical Research; 1971. p. 151–77.
3. Caldwell BE. Soybeans: improvement, production and uses. Madison (WI): American Society of Agronomy, Inc.; 1973.
4. Andersen OM, Markham KR. Flavonoids: chemistry, biochemistry and applications. Boca Raton: CRC Press; 2005. https://doi.org/10.1201/9781420039443
5. Poudel S, Magar LP, Khatri D, Manish Pandit M, Chiluwal A. Identifying the most sensitive growth stages of soybean to defoliation. Sci Rep. 2025;15(1):28268. https://doi.org/10.1038/s41598-025-12590-7
6. Calvino PA, Sadras VO andrade FH. Quantification of environmental and management effects on the yield of late-sown soybean. Field Crops Res. 2003;83(1):67–77. https://doi.org/10.1016/S0378-4290(03)00062-5
7. Makadia MB. Efficacy of thiourea application on biochemical changes in chickpea under water stress condition [master thesis]. Junagadh: Junagadh Agricultural University; 2018. http://krishikosh.egranth.ac.in/handle/1/5810064644
8. Raskin I. Role of salicylic acid in plants. Annu Rev Plant Biol. 1992;43(1):439–63. https://doi.org/10.1146/annurev.pp.43.060192.002255
9. Cochran WG, Cox GM. Experimental Designs. 2nd ed. New York: Wiley; 1957. p. 615. https://doi.org/10.1097/00010694-195008000-00014
10. Devi KN, Vyas AK, Singh MS, Singh NG. Effect of bioregulators on growth, yield and chemical constituents of soybean (*Glycine max* L.). J Agric Sci. 2011;3(4):151. https://doi.org/10.5539/jas.v3n4p151
11. Sharma N, Magray MM, Narayan S, Bhat SA. Effect of foliar application of varying doses of salicylic acid at different growth

stages on growth, quality and nutrient uptake efficiency of French bean (*Phaseolus vulgaris* L.). J Pharm Innov. 2023;12(2):1582–89. https://doi.org/10.22271/tpi.2023.v12.i2s.18618

12. Saini C, Jain NK, Mathukia RK. Effect of sulphur and plant-growth regulators on growth, yield and economics of summer groundnut (*Arachis hypogaea* L.). Indian J Agron. 2016;61(1):115–18. https://doi.org/10.59797/ija.v61i1.4335
13. Solaimalai A, Sivakumar C, Anbumani S, Suresh T, Arulmurugan K. Role of plant growth regulators in rice production—a review. Agric Rev. 2001;22(1):33–40.
14. Hilli JS, Vyakarnahal BS, Patil SS. Influence of growth regulators and stages of spray on sex expression of ridge gourd (*Luffa acutangula* L. Roxb). Karnataka J Agric Sci. 2008;21(2):191–97.
15. El-Shafey AI. Response of soybean to water stress conditions and foliar application with salicylic and ascorbic acids. Zagazig J Agric Res. 2017;44(1):1–22. https://doi.org/10.21608/zjar.2017053922
16. Patil PM, Thombre PR, Thombre AB, Deosarkar DB, Gore VB. Effect of spraying NAA on soybean (*Glycine max* L. Merrill.) var. MAUS 71 growth, yield and seed quality. J Pharm Innov. 2023;12(12):1037–45.
17. Meena DK, Kumar A, Bhatnagar A, Sharma RK, Yogi AK, Reddy KS, et al. Enhancing soybean performance with foliar application of thiourea: a study on yield, quality and economics. Biol Forum. 2023;15(2):843–51.
18. Chovatia RS, Ahlawat TR, Mepa SV, Jat G. Response of cowpea (*Vigna unguiculata* L.) cv. Guj-4 to the foliar application of plant growth regulating chemicals. Veg Sci. 2010;37(2):196–97.
19. Chatterjee R, Choudhuri P. Influence of foliar application of plant growth promoters on growth and yield of vegetable cow pea (*Vigna unguiculata* L.). J Crop Weed. 2012;8(1):158–59.
20. Basuchaudhuri P. Influences of plant growth regulators on yield of soybean. Indian J Plant Sci. 2016;5(4):25–38. https://doi.org/10.13140/RG.2.2.27224.80641
21. Singh SK, Tomar BS, Anand A, Kumari S, Prakash K. Effect of growth regulators on growth, seed yield and quality attributes in garden pea (*Pisum sativum* var Hortense) cv. Pusa Pragati. Indian J Agric Sci. 2018;88(11):1730–34. https://doi.org/10.56093/ijas.v88i11.84914
22. Jeevitha S, Vasudevan SN. Effect of Boron and plant growth regulators on hybrid seed yield and quality of sponge gourd (*Luffa cylindrica* L.) Hyb. Haritha under protected condition. Mysore J Agric Sci. 2019;53(3):71–75.
23. Kumar B, Sarlach RS. Forage cowpea (*Vigna unguiculata*) seed yield and seed quality response to foliar application of bio-regulators. Int J Agric Sci. 2015;8(4):891–98. https://doi.org/10.5958/2230-732X.2015.00101.1
24. Borkar DH, Matte AD, Bhelkar MV, Kene DR, Bagde TR. Effect of seed treatment with different plant growth regulators on growth and yield of cowpea (*Vigna sinensis* Savi). J Soils Crops. 1991;1(2):165–8.
25. Khan SH, Chattoo MA, Mufti S. Effect of plant bioregulators on seed yield, germination and vigour in okra (*Abelmoschus esculentus* L. Moench). Prog Hortic. 2013;45(2):345–46.
26. Sharvani K, Naik V, Vidyapeeth MK, Deshmukh IJ, Kalyankar SV, Deshmukh JD. Effect of foliar spray of NAA (Naphthalene acetic acid) on flower drop and seed yield of pigeonpea (*Cajanus cajan* (L.) Millsp.). J Pharm Innov. 2022;11(1):1172–75.
27. Bhaskar R, Verma O, Shukla D, Singh V, Guru S. Effect of foliar sprays with nutrients and growth regulators on seeding vigour and enzyme activity in mungbean. Seed Res. 2019;47(1):65–71. https://doi.org/10.56093/sr.v47i1.157495

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.