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Impact of Foliar Application of Plant Growth Regulators in Soybean [*Glycine max* (L.) Merill)] on Seed Quality and Seedling Establishment

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In recent years, climatic adversities such as drought and flooding have severely impacted soybean production, productivity, and seed quality, especially during the *Kharif* season. Identifying the most favorable off-season sowing window is important for optimizing the efficient capture of radiation and partitioning of assimilates targeted for optimum seed yield and seed quality. Experiments were

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conducted during the *Rabi* to *Rabi*-summer seasons at the Experimental Research Farm, Seed Technology Research Unit, JNKVV, Jabalpur (M.P.) during 2021/2022 and 2022/2023, in a split-split plot design. The 28 treatments combinations comparing two dates of sowing with two spray schedules of seven PGRs treatments (T1Control (no spray), T2 (SA) @ 250 ppm, T3 (SA) @ 500 ppm, T4 (TU) @ 500 ppm, T5 (TU) @ 1000 ppm, T6 (CCC) @ 100 ppm, T7 (IBA) @ 200 ppm) were tested in soybean (JS 20-98) in a spilt-split plot design with three replications. The results revealed significant differences in germination percentage, seedling length, vigor index I, and vigor index II across different sowing dates. The *Rabi*-summer (D2) exhibited a superior germination percentage of 9.60%, seedling length of 2.81%, vigor index I of 12.64%, and vigor index II of 11.31% over the *Rabi* season (D1). The application of SA at 500 ppm (T3) increased the germination percentage by 1.48%, seedling length by 6.49%, and vigor index I by 9.70% compared to the control (no spray). The results showed that delaying the sowing date doesn't affect the seed quality of soybean, and the foliar application of salicylic acid at 500 ppm enhanced the germination percentage, seedling length, and seed vigor index I and IBA at 200 ppm enhanced the seed vigour index II by 4.66% as compared to the control (no spray). These findings provide promising strategies for improving soybean production under various environmental stress conditions.

Keywords: Germination rate; plant growth regulator; salicylic acid; Thiourea; IBA; CCC; seed quality; soybean.

1. INTRODUCTION

India is the fifth-largest soybean-growing country in the world [1]. Soybean, often referred to as "golden bean, miracle bean", is a major oilseed crop cultivated extensively in India. It contributes 25% of global edible oil and provides about two-thirds of the world's protein concentrate for livestock feeding [2]. Therefore, it is unsurprising that there has been a substantial surge in the global demand for soybeans [3,4]. The distinctive chemical composition of soybean seeds, which comprises around 20% oil and 40% protein, along with several nutraceutical compounds such as isoflavones, tocopherol, and lecithin, has established it as one of the most valuable crops in global agriculture [5].

In the past two decades, soybean productivity has been on a downward trend due to various adverse weather conditions, such as extreme temperatures and water scarcity or excess, which have led to a significant decline in soybean seed yield, estimated at around 30% according to Staniak et al. [6]. Environmental variables like changes in day length also contribute to this reduction in soybean yield. Excessive rainfall during the *Kharif* season adversely affects soybean cultivation, leading to nutrient deficiency and reduced seed quality. Waterlogging limits oxygenation to roots, and nutrient absorption, while heavy rains cause nutrient leaching and soil erosion. Soil compaction reduces root growth, and wet conditions encourage diseases and pests, further reducing yield. Delayed development and poor pollination worsen pod and seed formation, diminishing overall yield and quality. These circumstances might have a negative impact on seed yield for certain soybean cultivars. Pre-harvest exposure to field weathering may lead to a decline in seed quality for soybeans, which are very susceptible to such conditions. This present challenge in achieving the minimum germination threshold of 70% for the subsequent season [7]. Sowing soybeans during the *Rabi* season, between November and December, might result in the production of superior seeds that have enhanced germination and vigor [8]. Therefore, to achieve optimal seed yield and quality, we hypothesized to identify a suitable sowing window to mitigate the adverse effects of stresses faced during off-season cultivation and to identify a suitable plant growth regulator for enhancing the seed quality during off-season cultivation.

2. MATERIALS AND METHODS

The field experiment was conducted during the *Rabi* to *Rabi* summer 2021/2022 and 2022/2023 at the Experimental Farm, Seed Technology Research Unit, Jawaharlal Nehru Krishi Viswa Vidyalaya, Jabalpur, Madhya Pradesh. The experimental area is situated at a latitude of 23°12' N and a longitude of 79°56' E. At the duration of experiment temperature ranged from 17.2°C to 43.4 °C in 2021-2022 and 16.2 °C to 41.6 °C in 2022-2023. Both year at the vegetative duration of crop favorable climate occurred and at flowering to physiological maturity temperature rises. Therefore we conduct the seed quality parameter analysis and identifying suitable treatment.

We selected the soybean variety JS 20-98 for sowing during the Rabi and Rabi-summer seasons due to its high yielding potential under both normal and adverse conditions. We conducted the sowing in the first week of January (D1) and the final week of January (D2) consecutively. Because environmental variables like changes in day length also contribute to this reduction in soybean yield and seed quality, excessive rainfall and drought spells during the Kharif season adversely affect soybean cultivation, leading to nutrient deficiency and reduced seed quality. We sprayed plant growth regulators foliarly at two distinct stages: the vegetative stage (S1) and the flowering stage (S2). The plant growth regulators used were detailed as follows:

T1	**: Control (No spray)**
T2	: Salicylic acid (SA) at 250 ppm
T3	: Salicylic acid (SA) at 500 ppm
T4	: Thiourea (TU) at 500 ppm
T5	: Thiourea (TU) at 1000 ppm
T6	: Cycocel (CCC) at 100 ppm
T7	: Indole-3-butyric acid (IBA) at 200 ppm

The laboratory analytical work was conducted at the Department of Plant Physiology and, Seed Technology Research Centre, College of Agriculture, JNKVV, Jabalpur. After the crop's harvest, we prepared the seeds for germination testing using the paper towel method, in accordance with the 2006 International Seed Testing Association (ISTA) protocol [9]. The Vigour Index (I) and Index (II) was calculated using the method provided by Abdul-Baki and Anderson [10].

To perform the statistical analysis, we used R version 4.2.2 statistical software. We conducted a two-way analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) at a significance level of 5%. We reported the findings as the average of three replications.

3. RESULTS AND DISCUSSION

3.1 Influence of Different Treatments on Germination (%) rate and Seedling Length

The analysis of variance carried out on the data from two consecutive years (2021-2022 and 2022-2023), and pooled data, showed a significant variation in germination %, seedling length, vigour index I, and vigour index II in different dates of sowing (Tables 1 and 2).

Seed quality is affected by several factors, including environmental conditions, genetic traits, soil moisture and fertility levels [11]. The high temperature during the seed-filling stage reduces the germination percentage [12]. High temperatures during seed filling often lead to abnormal, shriveled, and lower-quality seeds [13]. Heat stress, before seeds reach physiological maturity, can prevent the plant from providing the necessary nutrients for storage compounds, causing physiological damage that inhibits germination [14,15].

The results from the pooled analysis of two consecutive years (Tables 1 and 3) indicated that the germination percentage ranged from 79.17% to 91.00%. There was a significant difference in germination percentage regarding the date of sowing, with D2 (89.52%) having higher germination and D1 (81.68%) having lower germination (Fig. 1). We found that *Rabi*-summer sown seeds resulted in higher seed vigor, whereas *Rabi*-sown seeds had lower seed vigor. Our findings are similar to those of Shaheb et al. [16], who reported that a significant difference was observed due to different sowing dates in the germination percentage of wheat seeds.

On the other hand, the spray schedule also showed a significant difference, with S1 (85.99%) having a higher germination percentage than S2 (85.21%). While our studies have shown that foliar spray of plant growth regulators at the vegetative stage increased the germination percentage, there is limited research on observing the germination percentage of foliar spray of plant growth regulators at the vegetative stage.

Foliar spray showed a non-significant difference, but numerically, T3 (SA at 500ppm) (86.79%) increased germination percentage as compared to other treatments. Our findings are similar to those of Jadhav et al. [17], who reported that the application of salicylic acid at different concentrations increased the germination percentage in groundnut cultivars.

The results from the pooled analysis of two consecutive years (Tables 1 and 3) indicated that the seedling length (cm) ranged from 25.29 cm to 29.68 cm. With respect to the date of sowing, a significant difference was observed for seedling length, with D2 (28.15 cm) having the highest seedling length, followed by D1 (27.38cm). Among the spray schedules, the numerically highest seedling length was found in S2 (28.00 cm), followed by S1 (27.53 cm). Our studies have shown that foliar spray of plant growth regulators at the flowering stage increased seedling length. However, there is limited research on observing seedling length on foliar spray of plant growth regulators at the flowering stage of soybean.

Table 1. Effect of sowing dates, spray scheduled and PGRs foliar spray on seed germination percentage and seedling length of soybean

Treatments	Germination percentage			Seedling length (cm)		
	2022	2023	Pooled	2022	2023	Pooled
Main plot: Date of Sowing (D)						
D1	81.43^{b}	81.93^{b}	81.68^{b}	27.07^{a}	27.68^{a}	27.38^{b}
D2	91.02^{a}	88.02^{a}	89.52^{a}	27.72^{a}	28.59^{a}	28.15^{a}
Subplot: Spray Schedule (S)						
S1	86.57^{a}	85.40^{a}	85.99^{a}	26.94^{a}	28.13^{a}	27.53^{a}
S2	85.88^{a}	84.55^{b}	85.21^{b}	27.85^{a}	28.15^{a}	28.00^{a}
Sub-sub plot: Foliar spray (T)						
T1	84.17^{a}	84.50^{a}	84.33^{a}	26.48^{a}	27.19^{a}	26.83^{a}
T2	85.83^{a}	84.83^{a}	85.33^{a}	27.81^{a}	28.16^{a}	27.98^{a}
T3	87.83^{a}	85.75^{a}	86.79^{a}	28.62^{a}	28.51^{a}	28.57^{a}
T4	87.00^{a}	84.50^{a}	85.75^{a}	28.56^{a}	28.16^{a}	28.36^{a}
T5	86.17^{a}	85.08^{a}	85.62^{a}	27.60^{a}	28.35^{a}	27.97^{a}
T6	85.92^{a}	85.33^{a}	85.62^{a}	25.58^{a}	27.62^{a}	26.60^{a}
T7	86.67^{a}	84.83^{a}	85.75^{a}	27.11^{a}	28.99^{a}	28.05^{a}
Interaction – Date of Sowing x Spray Schedule (D x S)						
D1S1	82.38^{b}	82.19^{c}	82.29^{b}	26.37^{a}	27.74^{ab}	27.06^{b}
D1S2	80.48^{c}	81.67^{c}	81.07^{c}	27.78^{a}	27.63^{b}	27.70^{ab}
D2S1	90.76^{a}	88.62^{a}	89.69^{a}	27.51^{a}	28.51^{ab}	28.01^{ab}
D2S2	91.29^{a}	87.43^{b}	89.36^{a}	27.92^{a}	28.67^{a}	28.30^{a}
Interaction – Date of Sowing x Treatments (D x T)						
D1T1	79.33^{c}	81.17^{b}	80.25^{b}	26.13^{a}	27.16^{a}	26.65^{a}
D1T2	80.33^{c}	82.17^{b}	81.25^{b}	27.00^{a}	27.41^{a}	27.21^{a}
D1T3	83.67^{bc}	82.83^{b}	83.25^{b}	28.23^{a}	27.98^{a}	28.11^{a}
D1T4	83.00^{bc}	81.67^{b}	82.33^{b}	29.72^{a}	27.76^{a}	28.74^{a}
D1T5	81.00^{c}	82.17^{b}	81.58^{b}	27.35^{a}	27.99^{a}	27.67^{a}
D1T6	80.83^{c}	81.67^{b}	81.25^{b}	24.95^{a}	27.06^{a}	26.01^{a}
D1T7	81.83^{c}	81.83^{b}	81.83^{b}	26.13^{a}	28.43^{a}	27.28^{a}
D2T1	89.00^{ab}	87.83^{a}	88.42^{a}	26.83^{a}	27.21^{a}	27.02^{a}
D2T2	91.33^{a}	87.50^{a}	89.42^{a}	28.62^{a}	28.91^{a}	28.76^{a}
D2T3	92.00^{a}	88.67^{a}	90.33^{a}	29.02^{a}	29.03^{a}	29.03^{a}
D2T4	91.00^{a}	87.33^{a}	89.17^{a}	27.40^{a}	28.56^{a}	27.98^{a}
D2T5	91.33^{a}	88.00^{a}	89.67^{a}	27.85^{a}	28.71^{a}	28.28^{a}
D2T6	91.00^{a}	89.00^{a}	90.00^{a}	26.22^{a}	28.17^{a}	27.20^{a}
D2T7	91.50^{a}	87.83^{a}	89.67^{a}	28.08^{a}	29.54^{a}	28.81^{a}
Interaction – Spray Schedule x Treatments (S x T)						
S1T1	84.50^{a}	84.67^{a}	84.58^{a}	25.38^{a}	26.81^{a}	26.10^{a}
S1T2	86.50^{a}	84.83^{a}	85.67^{a}	28.07^{a}	28.36^{a}	28.21^{a}
S1T3	88.67^{a}	86.17^{a}	87.42^{a}	27.88^{a}	28.58^{a}	28.23^{a}
S1T4	87.33^{a}	85.00^{a}	86.17^{a}	28.45^{a}	28.22^{a}	28.33^{a}
S1T5	86.67^{a}	85.83^{a}	86.25^{a}	27.23^{a}	28.25^{a}	27.74^{a}
S1T6	86.00^{a}	86.50^{a}	86.25^{a}	25.60^{a}	27.90^{a}	26.75^{a}
S1T7	86.33^{a}	84.83^{a}	85.58^{a}	25.97^{a}	28.77^{a}	27.37^{a}
S2T1	83.83^{a}	84.33^{a}	84.08^{a}	27.58^{a}	27.56^{a}	27.57^{a}

Treatments	Germination percentage			Seedling length (cm)		
	2022	2023	Pooled	2022	2023	Pooled
S2T2	85.17^{a}	84.83^{a}	85.00^{a}	27.55^{a}	27.96^{a}	27.76^{a}
S2T3	87.00^{a}	85.33^{a}	86.17^{a}	29.37^{a}	28.43^{a}	28.90^{a}
S2T4	86.67^{a}	84.00^{a}	85.33^{a}	28.67^{a}	28.10^{a}	28.38^{a}
S2T5	85.67^{a}	84.33^{a}	85.00^{a}	27.97^{a}	28.45^{a}	28.21^{a}
S2T6	85.83^{a}	84.17^{a}	85.00^{a}	25.57^{a}	27.34^{a}	26.45^{a}
S2T7	87.00^{a}	84.83^{a}	85.92^{a}	28.25^{a}	29.20^{a}	28.73^{a}

The values with identical letters are not significantly different at the p<0.05 level
Whereas: D1: Rabi sown; D2: Rabi-summer; vegetative stage (S1); flowering stage (S2); T1: Control (no spray); T2: Salicylic acid (SA) at 250 ppm; T3: Salicylic acid (SA) at 500 ppm; T4: Thiourea (TU) at 500 ppm; T5: Thiourea (TU) at 1000 ppm; T6: Cycocel (CCC) at 100 ppm; and T7: Indole-3-butyric acid (IBA) at 200 ppm

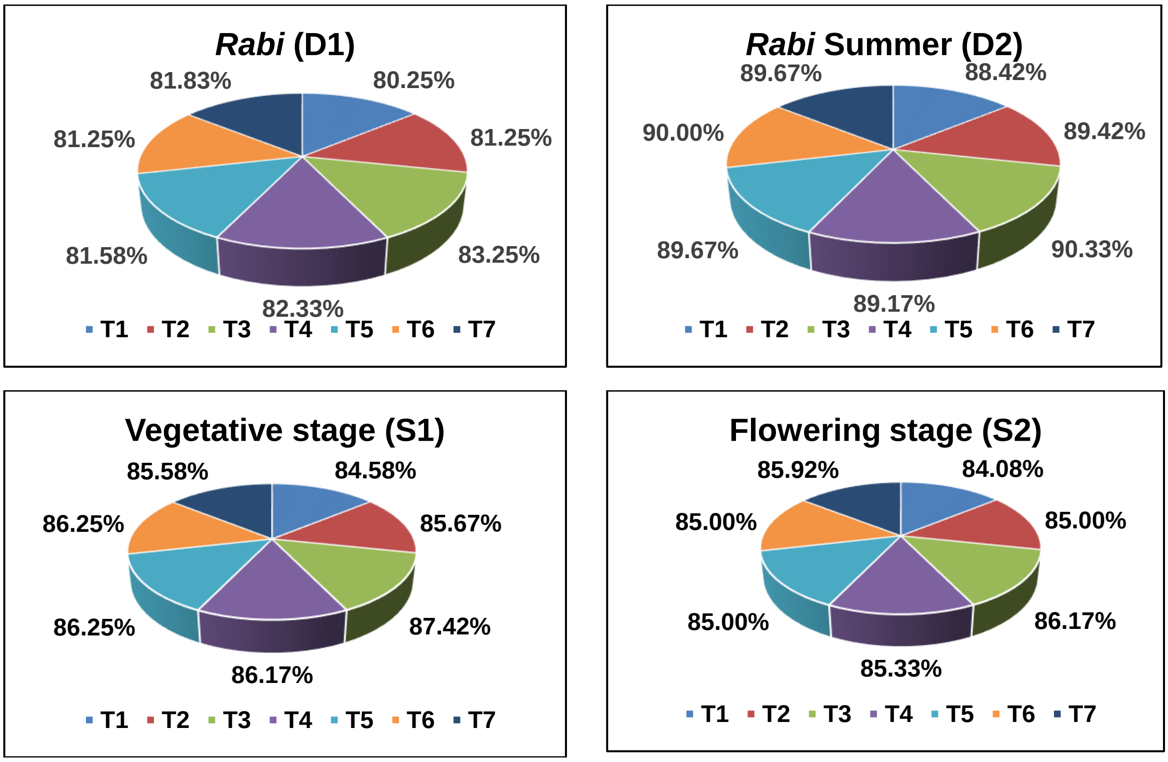

Fig. 1. Effect of foliar sprays of plant growth regulators on the seed germination percentage of soybean

Among the foliar applications of plant growth regulators, the numerically maximum seedling length (28.57 cm) was observed for treatment T3 (SA at 500 ppm), which is on par with all other treatments, whereas the minimum seedling length (26.60 cm) was observed for T6 (CCC at100ppm). Our findings are similar to those of Shaheb et al. [16], who reported that a significant difference was observed due to different sowing dates on the seedling length of wheat seeds.

3.2 Influence of Different Treatments on Seed Vigour Index I and II

The seed vigor index measures overall seed performance, including the rate and uniformity of seedling growth, emergence in unfavorable conditions, and post-storage viability. High temperatures during seed development and maturation can greatly reduce seed vigor, resulting in lower seed quality [18]. High temperatures can cause significant physiological damage to seeds, resulting in reduced seed vigor. This damage is particularly critical during the seed-filling stage, when seeds are highly susceptible to temperature stress [19].

The results from the pooled analysis of two consecutive years (Tables 2 and 3) indicated the range of seed vigour index I was found to be 2055.25 to 2581.13. Seed vigour index I varied significantly, with the highest (2520.36) in D2, followed by D1 (2237.53). With respect to the spray schedule, seed vigour index I was found to be numerically higher (2387.77) in S2, followed by 2370.12 in S1. With respect to the foliar application of plant growth regulators, the numerically highest (2482.08) seed vigour index I was found to be in treatment T3 (SA at 500 ppm) which is on par with all other treatments, and seed vigour index I was found to be the lowest (2262.70) in control T1.

Table 2. Effect of sowing dates, spray scheduled and PGRs foliar spray on vigour index I and vigour index II of soybean seeds

Treatments	Vigour Index-I			Vigour Index-II		
	2022	2023	Pooled	2022	2023	Pooled
Main plot: Date of Sowing (D)						
D1	2207.36[b]	2267.70[b]	2237.53[b]	46.58[b]	47.48[a]	47.03[b]
D2	2524.00[a]	2516.71[a]	2520.36[a]	53.48[a]	51.23[a]	52.35[a]
Subplot: Spray Schedule (S)						
S1	2337.62[a]	2402.62[a]	2370.12[a]	49.15[a]	48.31[a]	48.73[a]
S2	2393.74[a]	2381.79[a]	2387.77[a]	50.91[a]	50.40[a]	50.65[a]
Sub-sub plot: Foliar spray (T)						
T1	2228.10[a]	2297.31[a]	2262.70[a]	48.96[a]	47.58[a]	48.27[a]
T2	2393.06[a]	2389.45[a]	2391.26[a]	47.94[a]	48.22[a]	48.08[a]
T3	2518.78[a]	2445.39[a]	2482.08[a]	51.50[a]	48.49[a]	50.00[a]
T4	2482.86[a]	2380.86[a]	2431.86[a]	51.03[a]	49.25[a]	50.14[a]
T5	2380.43[a]	2412.89[a]	2396.66[a]	49.48[a]	51.25[a]	50.36[a]
T6	2201.94[a]	2359.64[a]	2280.79[a]	50.47[a]	50.50[a]	50.49[a]
T7	2354.61[a]	2459.91[a]	2407.26[a]	50.82[a]	50.22[a]	50.52[a]
Interaction – Date of Sowing x Spray Schedule (D x S)						
D1S1	2176.73[b]	2279.09[b]	2227.91[b]	45.63[b]	46.97[b]	46.30[c]
D1S2	2237.99[b]	2256.31[b]	2247.15[b]	47.53[b]	48.00[b]	47.77[bc]
D2S1	2498.50[a]	2526.15[a]	2512.33[a]	52.67[a]	49.66[ab]	51.16[ab]
D2S2	2549.50[a]	2507.28[a]	2528.39[a]	54.28[a]	52.80[a]	53.54[a]
Interaction – Date of Sowing x Treatments (D x T)						
D1T1	2065.77[a]	2203.92[e]	2134.84[b]	45.72[ab]	44.65[a]	45.18[c]
D1T2	2172.87[a]	2250.88[de]	2211.87[ab]	42.98[b]	47.70[a]	45.34[bc]
D1T3	2367.22[a]	2316.86[bcde]	2342.04[ab]	48.43[ab]	47.37[a]	47.90[abc]
D1T4	2470.27[a]	2267.20[cde]	2368.73[ab]	47.88[ab]	47.25[a]	47.56[abc]
D1T5	2216.88[a]	2298.54[cde]	2257.71[ab]	45.37[ab]	49.02[a]	47.19[abc]
D1T6	2016.30[a]	2210.77[e]	2113.54[b]	48.79[ab]	47.64[a]	48.22[abc]
D1T7	2142.22[a]	2325.72[abcde]	2233.97[ab]	46.89[ab]	48.76[a]	47.82[abc]
D2T1	2390.43[a]	2390.70[abcde]	2390.57[ab]	52.21[ab]	50.51[a]	51.36[abc]
D2T2	2613.25[a]	2528.03[abc]	2570.64[a]	52.90[a]	48.73[a]	50.81[abc]
D2T3	2670.33[a]	2573.91[ab]	2622.12[a]	54.58[a]	49.61[a]	52.09[abc]
D2T4	2495.45[a]	2494.53[abcd]	2494.99[ab]	54.18[a]	51.25[a]	52.71[ab]
D2T5	2543.97[a]	2527.24[abc]	2535.60[ab]	53.59[a]	53.47[a]	53.53[a]
D2T6	2387.58[a]	2508.50[abcd]	2448.04[ab]	52.15[ab]	53.36[a]	52.76[ab]
D2T7	2567.00[a]	2594.10[a]	2580.55[a]	54.74[a]	51.68[a]	53.21[a]
Interaction – Spray Schedule x Treatments (S x T)						
S1T1	2148.98[a]	2269.80[a]	2209.39[a]	48.57[a]	46.08[a]	47.32[a]
S1T2	2431.57[a]	2403.52[a]	2417.54[a]	46.92[a]	46.69[a]	46.80[a]
S1T3	2476.17[a]	2463.08[a]	2469.62[a]	50.01[a]	46.30[a]	48.16[a]
S1T4	2486.02[a]	2400.21[a]	2443.11[a]	50.62[a]	49.43[a]	50.02[a]
S1T5	2367.53[a]	2425.69[a]	2396.61[a]	48.16[a]	50.20[a]	49.18[a]
S1T6	2204.35[a]	2413.97[a]	2309.16[a]	50.54[a]	49.95[a]	50.24[a]
S1T7	2248.72[a]	2442.08[a]	2345.40[a]	49.25[a]	49.53[a]	49.39[a]
S2T1	2307.22[a]	2324.82[a]	2316.02[a]	49.36[a]	49.08[a]	49.22[a]
S2T2	2354.55[a]	2375.39[a]	2364.97[a]	48.96[a]	49.74[a]	49.35[a]
S2T3	2561.38[a]	2427.70[a]	2494.54[a]	52.99[a]	50.67[a]	51.83[a]
S2T4	2479.70[a]	2361.52[a]	2420.61[a]	51.44[a]	49.07[a]	50.25[a]
S2T5	2393.32[a]	2400.08[a]	2396.70[a]	50.80[a]	52.30[a]	51.55[a]
S2T6	2199.53[a]	2305.30[a]	2252.41[a]	50.41[a]	51.05[a]	50.73[a]
S2T7	2460.50[a]	2477.74[a]	2469.12[a]	52.38[a]	50.91[a]	51.64[a]

The values with identical letters are not significantly different at p<0.05 level

Table 3. Results of the two-way ANOVA and Duncan's multiple range tests for the comparative effects of plant growth regulators on seed quality attributes of soybean under different dates of sowing and foliar application of plant growth regulators

Treatments	Germination %			Seedling length (cm)			Vigour Index I			Vigour Index II		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Main plot: Date of Sowing (D)												
SEm±	0.23	0.29	0.19	0.22	0.24	0.05	18.55	18.76	12.99	0.45	1.27	0.82
SD	0.33	0.42	0.27	0.31	0.34	0.07	26.24	26.54	18.36	0.63	1.79	1.16
CD(P≤5%)	1.42**	1.79**	1.16**	1.35	1.45	0.32**	112.89**	114.18*	79.02**	2.71**	7.71	4.97*
Subplot: Spray Schedule (S)												
SEm±	0.28	0.12	0.16	0.33	0.17	0.19	28.43	15.74	19.19	0.70	0.70	0.62
SD	0.39	0.17	0.23	0.47	0.24	0.27	40.20	22.27	27.14	0.99	0.99	0.88
CD(P≤5%)	1.09	0.47**	0.64*	1.30	0.66	0.76	111.62	61.82	75.37	2.74	2.74	2.43
Sub-sub plot: Foliar spray (T)												
SEm±	0.92	0.63	0.67	0.98	0.43	0.63	95.01	38.10	59.89	1.36	1.26	1.05
SD	1.30	0.89	0.95	1.38	0.60	0.89	134.36	53.89	84.70	1.92	1.78	1.49
CD(P≤5%)	2.62	1.80	1.91	2.77	1.21	1.78	270.16	108.34	170.29	3.86	3.59	2.99
Interaction – Date of Sowing x Spray Schedule (D x S)												
SEm±	0.36	0.32	0.25	0.40	0.29	0.20	33.95	24.49	23.17	0.83	1.45	1.03
SD	0.51	0.45	0.35	0.56	0.41	0.28	48.01	34.64	32.77	1.17	2.05	1.45
CD(P≤5%)	1.54*	0.66	0.90	1.83	0.93	1.07	157.85	87.43	106.58	3.88	3.88	3.44
Interaction – Date of Sowing x Treatments (D x T)												
SEm±	1.23	0.88	0.90	1.30	0.61	0.82	125.77	53.30	79.48	1.83	2.08	1.60
SD	1.74	1.24	1.27	1.83	0.86	1.16	177.87	75.38	112.40	2.59	2.94	2.26
CD(P≤5%)	3.70	2.54	2.70	3.92	1.72	2.52	382.06	153.22	240.83	5.46	5.07	4.23
Interaction – Spray Schedule x Treatments (S x T)												
SEm±	1.24	0.84	0.90	1.32	0.58	0.84	127.60	52.31	80.73	1.91	1.79	1.51
SD	1.75	1.18	1.27	1.86	0.83	1.19	180.46	73.98	114.17	2.70	2.54	2.14
CD(P≤5%)	3.70	2.54	2.70	3.92	1.72	2.52	382.06	153.22	240.83	5.46	5.07	4.23

*a F-values. ns: not significant F ratio (p < 0.05); SEm± - Standard error mean, SD – Standard deviation; CD – Critical difference; *, ** and ** indicate significance at P < 0.05, 0.01 and 0.001, respectively.*

The results from the pooled analysis of two consecutive years (Tables 2 and 3) indicated that the range of seed vigour index II was found to be 44.73 to 54.36. Regarding the date of sowing, seed vigour index II was found to be significant. The highest (52.35) seed vigour index II was found in D2, followed by 47.03 in D1. Among the spray schedules, S2 recorded the numerically highest (50.65) seed vigour index II followed by 48.73 in S1. Among the foliar sprays of plant growth regulators, it was observed that foliar application of IBA @ 200 ppm (T7) resulted in the numerically highest seed vigour index II (50.52), which is on par with T3 (50.00), T4 (50.14), T5 (5036), and T6 (50.49). In contrast, the SA at 250ppm (T2) recorded the lowest seed vigour index II (48.08), which is on par with treatment control T1 (48.27). Our results align with Sharma et al. [19], who found that germination percentages were statistically similar across different sowing dates as temperatures increased. Elevated temperatures can reduce seed vigor by limiting the supply of photosynthetic assimilates and causing physiological damage, leading to decreased seedling growth and emergence under stressful conditions [20].

Our studies have shown that foliar sprays of plant growth regulators at the vegetative stage increased the seed vigour index I and II, there is limited research on observing the seed vigour index of foliar sprays of plant growth regulators.

4. CONCLUSION

High-temperature stress during the seed-filling stage and maturation significantly affects the germination percentage, seedling length, and seed vigor index I, and II of soybeans. Our findings indicate that foliar application of salicylic acid at 250 ppm improves the seed quality attributes of soybeans grown in the *Rabi* and

Rabi summer seasons. Additional investigation is necessary to ascertain the molecular examination of seeds for their vigor.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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