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Research Article

Integrative effect of sowing dates and row spacing on growth and yield aspects of soybean

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ABSTRACT

Temporal planting windows and plants spatial arrangements strongly modulates soybean development and productivity. A two-year field experiment was performed at the Ayub Agriculture Research Institute (AARI), Faisalabad, using soybean variety “AARI Soybean” under an RCBD spilt-plot design to examine the responses of two sowing date (15 July and 30 July) and three row spacing (30,45, and 50cm). The results showed that early sowing date (15th July) significantly improved plant height, number of pods per plant, seed per pod, 100-seed weight, and grain yield over late sowing, which expose plants to heat stress and reduced reproductive efficiency. Among row spacing, wider spacing (45-50 cm) consistently produced higher plant height, more pods per plant, better seed set, with a greater seed weight and superior grain yield due to improved light penetration reduced competition, and in hands canopy microclimate. The current study concluded that early sowing date with higher row spaces is the best option to get higher soybean yield. This research can enhance soybean adaptability under different climatic conditions.

Keywords: Legume crop; climate change; temperature; land preparation; production.

INTRODUCTION

Agriculture productivity is increasingly threatened by environmental variability, with rising temperature pose a major challenge to the sustainability and resilience of global food systems (Vos and Bellù, 2019). Soybean (*Glycine max* L.), one of the world’s most important oilseed and protein crops, is particularly sensitive to temperature fluctuations (Staniak et al., 2023). As a photoperiod sensitive crop, soybean growth, development, and yield formation depends heavily on the environmental conditions during its growing season (Yannam et al., 2024). High temperature during crop critical reproductive stages can impaired physiological functioning, accelerate phenology, reduce pollen viability and ultimately results in flower abortion, poor pod retention, and reduce seed yield and quality (Shah et al., 2024). The timing of sowing soybean is crucial because it affect the crop exposure to temperature, sunlight and weather conditions (Staniak et al., 2023). Remarkably, wrong decision of sowing may subject soybean to various abiotic stress conditions including water scarcity, heat stress, changes in rainfall, and frost, thereby reducing vegetative growth and overall plant productivity. Row spacing play a central role in determining canopy structure, plant population, and light interception efficiency. Narrow row spacing can enhance early canopy closure and suppress weeds but may

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also intensity intra-specific competition. Conversely, wider spacing can reduce canopy uniformity and limit resource use efficiency, ultimately affecting biomass production and yield (Liu et al., 2021). The interaction of plant density with row structure and climate conditions influences multiple physiological pathways, affecting carbon gain, water use dynamics, mineral uptake and assimilate distribution (V’kovski et al., 2021). Optimizing population density and spatial arrangement is therefore, essential for ensuring effective canopy development and maximum yield potential (Chen et al., 2025). However, the combined effects of sowing planting time and row spacing on soybean morphophysiological, and yield performance across multiple seasons remain insufficiently understood, particularly under changing climatic conditions (Dave et al., 2024). Through identifying this research gap, the current study aimed to access the solo and interactive effects of different sowing dates and row spaces on growth and yield performance of soybean over two years. These findings will provide evidence-based recommendations for farmers, agronomists, and policymakers to improve crop improve crop management strategies. By identifying optimal sowing dates and row configurations, research contributes to enhancing soybean productivity, stability, and resilience in diverse climatic environments.

MATERIALS AND METHODS

This two-year standard field experiment was carried out at the Ayub Agriculture Research Institute (AARI) Faisalabad, Pakistan. This study was designed to investigate the impact of planting time and inter-row spacing on soybean development and productivity. The soybean variety “AARI Soybean” was sown in the sandy loam soil. This trail was implemented following a randomized complete block design (RCBD) in a split plot configuration following three biological replications for statistical reliability. The sowing dates (15 July and 30 July) were assigned to main plots and row spacing (30 cm, 45 cm, and 50 cm) to subplots. All plots were prepared following standard agronomic practices, including land preparation, seed bed formation, fertilizer application according to recommended doses, and timely irrigation. Weeds, pests, and diseases were managed uniformly across all plots to avoid confounding affects. Experiment was performed till ripening and proper growth and yield parameters were taken as given below.

Growth and yield aspects

Plant height was measured at physiological maturity using a measuring scale from the base of the stem to the tip of the main shoot. The number of pods per plant and seeds per pod were measured by selecting ten representative flowers from each plot and manually counting pods and seeds. 100-seed weight was taken by weighing a random sample of 100 dried and cleaned seeds using and analytical balance. Grain yield was measured by harvesting each plot, threshing manually, and converting the plot yield to kg ha-1 on a dry-weight basis. All recorded data where statistically analyzed using appropriate ANOVA procedures for split-plot design, and treatment means where separated using suitable post-hoc tests.

RESULTS AND DISCUSSION

Plant height

The results showed that sowing date and row spacing markedly influenced plant height of soybean ($p < 0.05$). In the first year (2023-24), under 15th July sowing date, highest plant height (67.2 cm) was recorded with 50 cm row spacing, which was statistically significant relative to former row spacing (30 cm: 58.5 cm; 45 cm: 62.1 cm). Under 30th July sowing date, the highest plant height (65.5 cm) was documented with 50 cm row spacing, was statistically significant over other row spacing (30 cm: 55.2 cm; 45 cm: 60.8 cm). In the second year (2024-2025), under 15th July sowing date, the highest plant height (68.5 cm) was observed with 50 cm row spacing, which was statistically significant relative to other row spacing (30 cm: 59.2 cm; 45 cm: 63.5 cm). Under 30th July sowing date, the highest plant height (66.8 cm) was noted with 50 cm row spacing, which was statistically significant relative to other row spacing (30 cm: 56.5 cm; 45 cm: 61.5 cm) as shown in Figure (1).

Number of pods per plant

In the first year (2023-2024), under 15th July sowing date, the highest number of pods per plant (44) recorded with 50 cm row spacing (RS50), which was statistically significant over RS30 (34 pods) and RS45 (40 pods) as shown in Figure (2). Under 30th July sowing date, highest number of pods per plant (38) was measured with RS50, which was statistically significant relative to RS30 (32 pods) and RS45 (36 pods). In the second year (2024-25), under 15th July sowing date, highest number of pods per plant (62) was noted with RS50, which was statistically significant over RS30 (46 pods), and lower for RS50 (50 pods).

Number of Seeds per pod

In the first year (2023-24), under 15th July sowing date, the highest number of seeds per pod (4.2) was determined

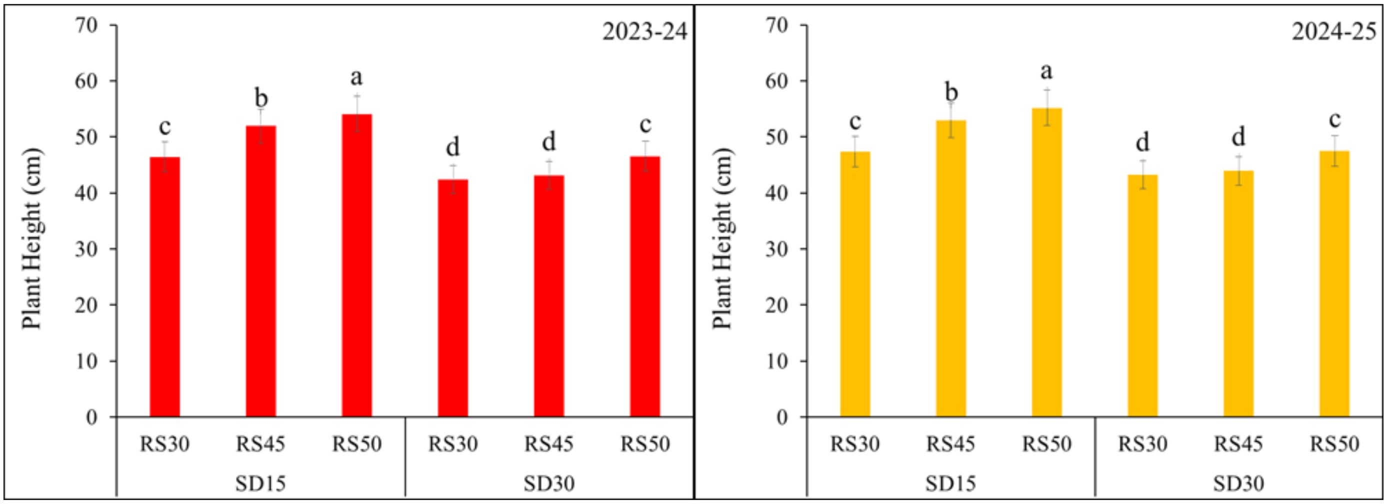

Figure 1. Effect of different row spacing (RS) and sowing dates (SD) on plant height of soybean in 2023-24 and 2024-25. Data are mean of three biological replications and standard error. Common lettering on each bar showed non-significant difference while different lettering showed significant difference among means.

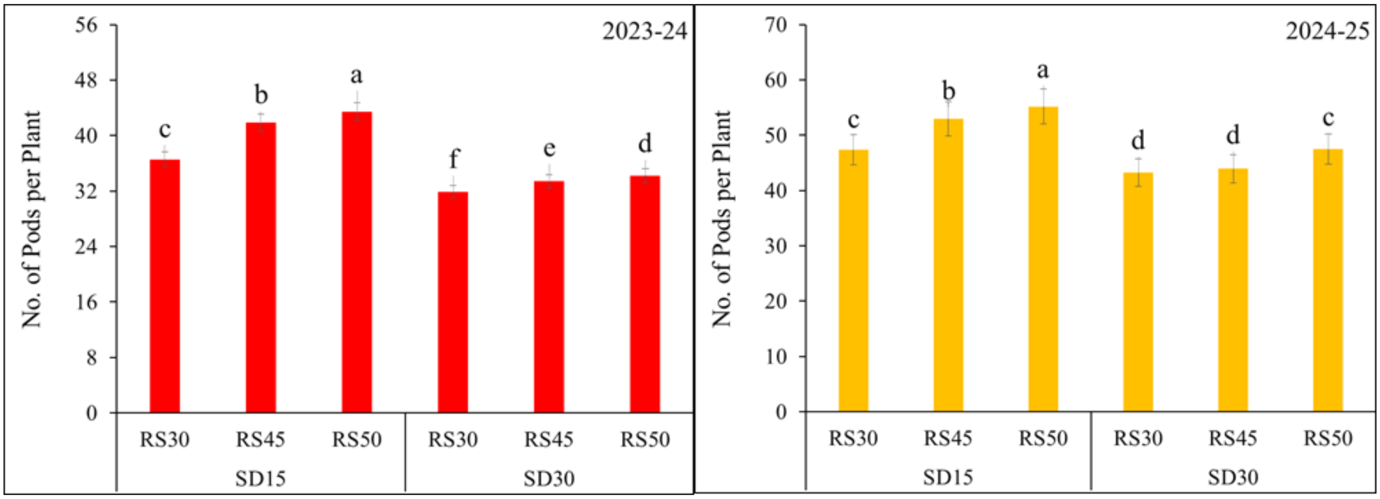

Figure 2. Effect of different row spacing (RS) and sowing dates (SD) on number of pods per plant of soybean in 2023-24 and 2024-25. Data are mean of three biological replications and standard error. Common lettering on each bar showed non-significant difference while different lettering showed significant difference among means.

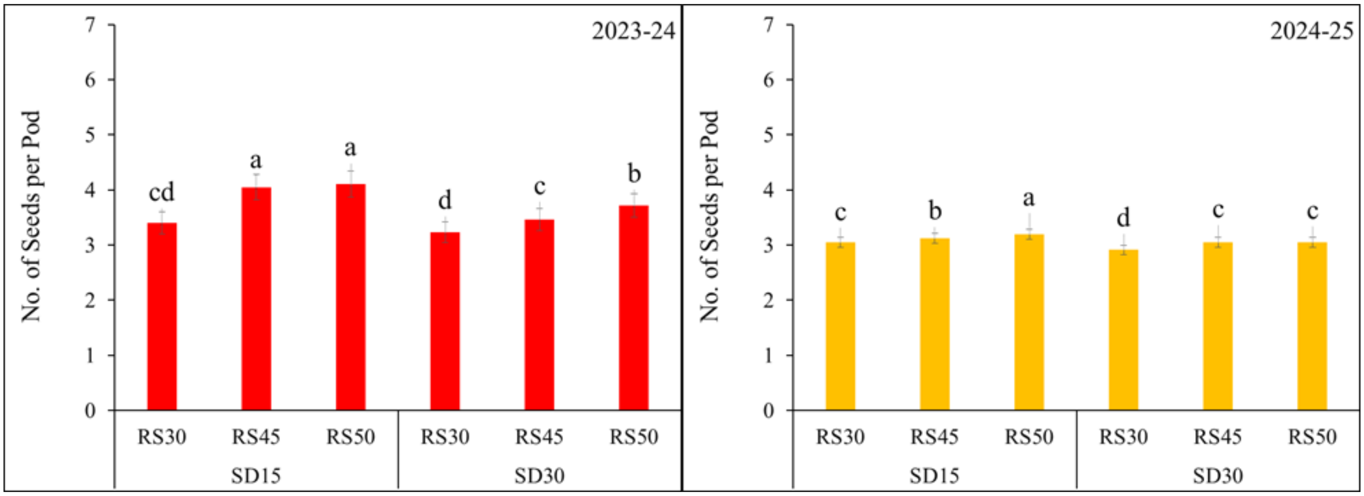

Figure 3. Effect of different row spacing (RS) and sowing dates (SD) on number of seed per pod of soybean in 2023-24 and 2024-25. Data are mean of three biological replications and standard error. Common lettering on each bar showed non-significant difference while different lettering showed significant difference among means.

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with RS45 row spacing, which was statistically similar to RS50 (4.1 seeds) as shown in Figure (3). Under 30th July sowing date, highest number of seeds per pod (3.9) was noted with RS50 row spacing, which was statistically similar to RS 45 (3.8 seeds). In the second year (2024-25), under 15th July sowing date, the highest number of seeds per pod (4.5) was measured with RS50 row spacing, which was statistically relative to RS30 (3.8 seeds) and RS45 (4.2 seeds). Under 30th July sowing date, the number of seeds per pod was statistically similar for RS45 (3.9 seeds) and RS50 (4.0 seeds), and lower for RS30 (3.5 seeds).

100 seed weight

In the first year (2023-24), under 15th July sowing date, the highest 100 seed weight (12.36 g) was recorded with 50 cm row spacing (RS50), significant over RS30 (11.20 g) and RS45 (12.20 g). Under 30th July sowing date, the highest 100 seed weight (11.76 g) was recorded with RS50, statistically significant relative to RS30 (11.01 g) and RS45 (11.40) as shown in Figure (4). In the second year (2024-25), under the July sowing date, the highest 100 seed weight (13.52 g) was recorded with RS50, which was statistically significant over RS30 (11.01 g) and RS45 (11.40). In the second year (2024-25), under 15th July sowing date, the highest 100 seed weight (13.52 g) was recorded with RS50, which was statistically significant relative to RS30 (11.54 g) and RS45 (12.81 g). Under 30th July sowing date, the 100 seed weight was statistically similar for RS30 (12.54 g), RS45 (12.15 g), and lower for RS50 (11.03 g).

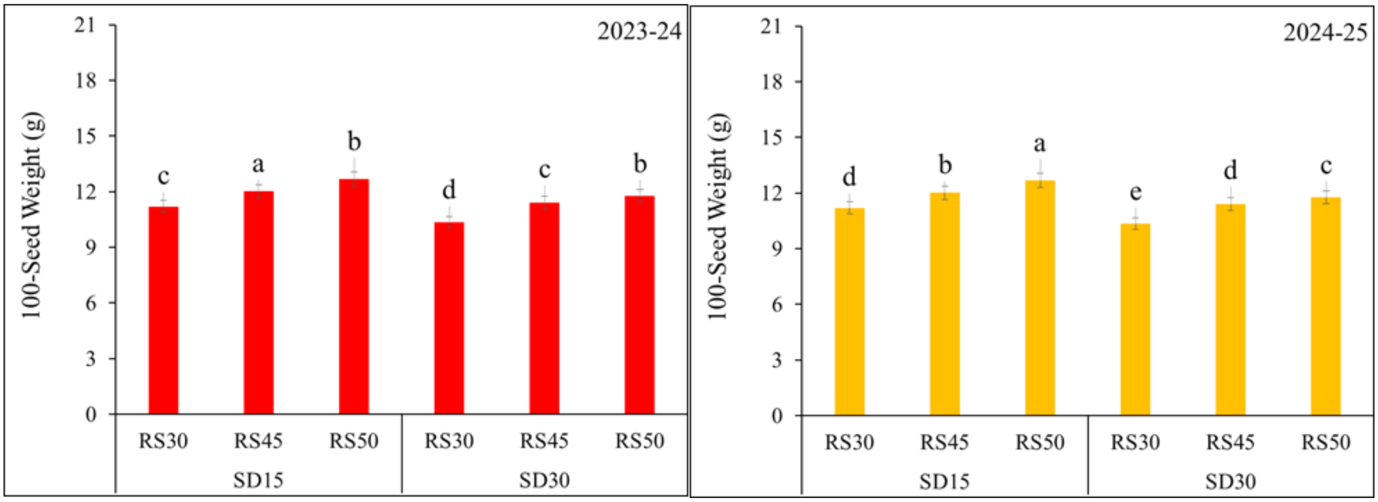

Figure 4. Effect of different row spacing (RS) and sowing dates (SD) on 100-seed weight of soybean in 2023-24 and 2024-25. Data are mean of three biological replications and standard error. Common lettering on each bar showed non-significant difference while different lettering showed significant difference among means.

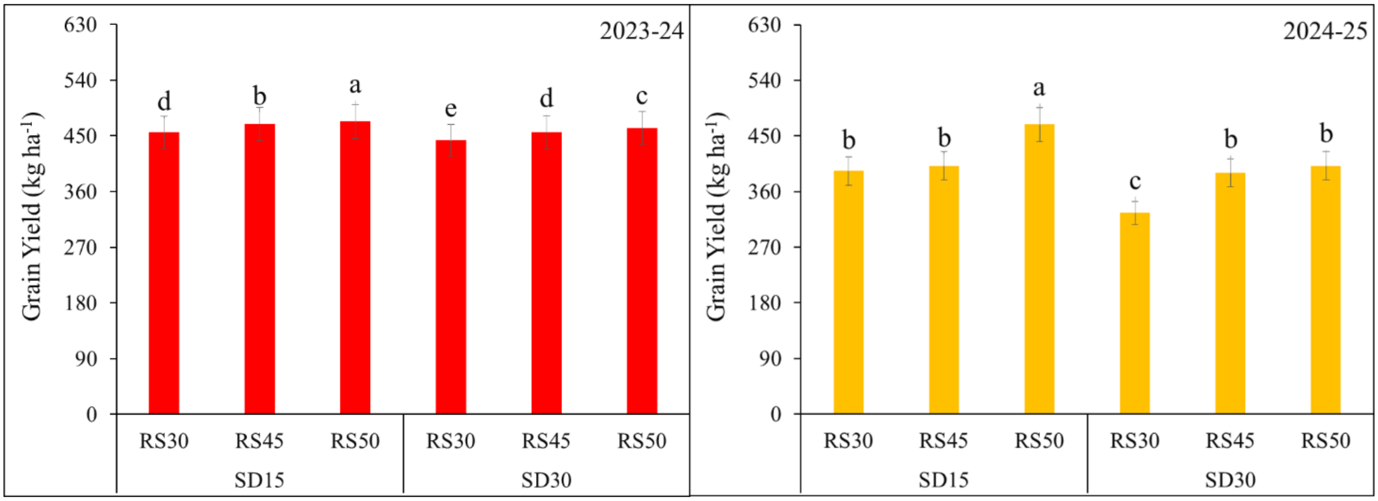

Figure 5. Effect of different row spacing (RS) and sowing dates (SD) on grain yield of soybean in 2023-24 and 2024-25. Data are mean of three biological replications and standard error. Common lettering on each bar showed non-significant difference while different lettering showed significant difference among means.

Grain yield

Analysis revealed that variation in sowing date and row spacing significantly impacted the grain yield of soybean ($p < 0.05$). In the first year (2023-24), under 15th July sowing date, the maximum grain yield (472.89 kg ha^{-1}) was found with 50 cm row spacing, which was statistically significant over other row spacing (30 cm: 455.55 kg ha^{-1}; 45 cm: 469.09 kg ha^{-1}) as shown in Figure (5). Under 30th July sowing date, the uppermost grain yield (462.99 kg ha^{-1}) was noted with 50 cm row spacing, which was statistically significant relative to other row spacing (30 cm: 442.66 kg ha^{-1}; 45 cm: 456.01 kg ha^{-1}). In the second year (2024-25), under 15th July sowing date, the optimum grain yield (468.66 kg ha^{-1}) was recorded with 50 cm row spacing, which was statistically significant over other row spacing (30 cm: 393.22 kg ha^{-1}: 45 cm: 401.01 kg ha^{-1}). Under 30th July sowing date, the optimum grain yield (401.60 kg ha^{-1}) was documented with 50 cm row spacing, statistically significant relative to other row spacing (30 cm: 389.90 kg ha^{-1}; 45 cm: 325.52 kg ha^{-1}).

In this research work, differences in plant height under varying sowing dates likely reflect temperature driven changes in cell elongation and vegetative growth duration (Dave et al., 2024). Earlier sowing exposes plants to more favorable thermal regimes, enhancing gibberellin-mediated stem elongation and sustained internal expansion (Bhattacharya et al., 2022). Conversely, exposure to late season heat stress can restrict meristematic activity, reduce leaf area development and accelerate phonological transition, limiting plant stature (Bhattacharya et al., 2022). Variation in row spacing further influence height through altered light distribution as wider spacing reduces mutual shading and supports balanced canopy development (Hota et al., 2025). Improved root growth under optimal spacing also enhanced water and nutrient uptake, supporting vertical growth (Sun et al., 2025). In the current study, pod production was strongly influenced by the thermal environment during the reproductive phase. Favorable temperatures promote successful floral initiation, pollen viability and fertilization resulting improved pod setting capacity (Hota and Chander, 2025). Late sowing often exposes plant to heat episodes that trigger floral abscission through disrupted hormonal balance particularly reduced auxin and cytokinin in developing flowers (Sun et al., 2024). Row spacing effects are likely linked to canopy micro climate where optimal spacing enhances light penetration and reduce stress induced ethylene that cause pod drop (Li et al., 2025). Enhanced assimilate supply from well-developed photosynthetic surface under optimal spacing further supports pod retention (Li et al., 2025). In this research work, the number of seeds per pod appears to be regulated by the plants ability to maintain reproductive organ functionality under varying thermal conditions. Suitable temperature favor pollen germination, ovule fertilization and embryo development ensuring higher seed formation (Mehmood et al., 2025). Heat stress from delayed sowing can impaired pollen tube growth and increase an oxidative damage in reproductive tissues, reducing seeds per pods (Li et al., 2025). Optimal row spacing improves assimilate allocation to developing pod by minimizing interplant competition and enhancing photosynthetic efficiency (Mehmood et al., 2025). Additionally, improved canopy ventilation at wider spacing helps reduce thermal load on reproductive structures (Li et al., 2025). In the current study, seed weight reflects the plant capacity to accumulate starch, protein and lipids during the seed filling duration with optimal temperature for enzymatic activities governing sucrose transport and storage compounds synthesis (Wang et al., 2023). Late season heat stress accelerates senescence and reduce photosynthetic carbon supply, and limits assimilate translocation, ultimately constraining seed mass (Mahajan et al., 2025). Row spacing influences seed weight through effects on canopy architecture where optimum spacing prevents excessive shadings and maintains higher source strength (Chizk et al., 2018). Improved root activity at wider spacing also enhances nutrient availability for seed development (Gao et al., 2021). In the current investigation, changes in grain yield likely arise from cumulative effects on vegetative growth, reproductive success and seed filling under different sowing conditions.

Furthermore, early sowing date strongly improves canopy development due to efficient RUE and continuous photosynthesis leading to enhanced total biomass production and its translocation to seed yield (Sahoo et al., 2025). In contrast, late sowing caused high temperature which disrupts carbon allocation, elevates respiration which in turn reduces reproductive process particularly grain yield (Ferguson et al., 2021). Wider rows modulate plant competition by intercepting light and optimum climate which supports higher resource utilization (Brightwood et al., 2023). Improved root-shoot coordination under suitable spacing further facilitates assimilate supply to developing seeds.

CONCLUSION

This study showed the strong impact of variation in sowing time and row spaces on soybean phenology, and grain yield which clearly demonstrated the adaptability under changing climatic conditions. Among all sowing dates, early planting gave excellent results in improving all parameters attributed to better seed vigor, filling and stability. In addition, row spacing played key role in improving canopy structure, resource utilization under micro climatic situations. This synergy enhanced physiological processes needed to get high yield productivity of soybean. These outcomes will be helpful for better decision making in order to maximize soybean productivity under field conditions. In cement, optimizing sowing time and row configuration can significantly improve yield stability and resilience under varying field conditions.

AUTHOR'S CONTRIBUTION

Performed the experiment: Muhammad Saeed, Muhammad Zafar and Muhammad Arif, analyzed the data: Rabia Saif and Ayesha Wishal, contributed in material: Nawal Zafar and Mahmood Iqbal, designed the experiment & wrote the paper: Fahid Ihsan, Memoona Shahzadi, and Ahmad Raza.

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AVAILABILITY OF DATA AND MATERIAL

The collected and analyzed data is presented in the form of figures.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The current study was checked and approved by the relevant team.

CONSENT FOR PUBLICATION

All authors have reviewed the manuscript and approved it for publication.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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Not applicable.

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