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The influence of sowing date and biostimulants foliar spray on yield and yield components of chickpea (*Cicer arietinum* L.)

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Abstract

Chickpea (*Cicer arietinum* L.) is a key rainfed crop in western Iran, whose productivity depends heavily on optimal sowing dates and biostimulant use. This study evaluated the effects of sowing date and foliar application of biostimulants on seed yield and yield components of desi chickpea. The study employed a factorial randomized complete block design with three replications across two locations in Kermanshah Province, Iran, in 2024–2025. Treatments consisted of three sowing dates (February 19, March 5, and March 21) and four foliar biostimulants applications (control, seaweed extract, amino acid, and a growth-promoting biofertilizer). The highest number of pods per plant (33.41) and the greatest 100-seed weight (17.08 g) were obtained from the March 5 sowing date at the Kermanshah site. Foliar application of seaweed extracts increased pods per plant and 100-seed weight by 87.36% and 61.41%, respectively, compared with the control at Salas-e Babajani. The maximum seed yield (1216.67 kg ha^{-1}) and aboveground biomass (2892.33 kg ha^{-1}) were achieved with the combination of the March 5 sowing date and seaweed extract application at Kermanshah, representing 3.28- and 3.64-fold increases, respectively, relative to the late sowing (March 21) control treatment at the Salas-e Babajani site. The highest seed protein content (25.70%) resulted from amino acid application at Salas-e Babajani on February 19. Seaweed extract applied on March 5 at Kermanshah also resulted in high protein content (23.76%). Optimizing sowing dates combined with these foliar biostimulants can substantially enhance chickpea yield and seed quality under western Iran's rainfed conditions.

Plain Language Summary

Subject Overview Chickpea is a vital and nutritious food crop, especially in regions like western Iran where many farmers rely on rain-fed agriculture. This means the crops grow only with rainfall, without the use of irrigation systems. In these dryland farming systems, water availability is unpredictable, and soil nutrients are often

Abbreviations: ANOVA, analysis of variance; HI, harvest index; LSD, least significant difference.

limited, which makes it challenging to achieve high and stable yields. To overcome these challenges, farmers and scientists are exploring natural and sustainable methods to boost crop production. Two key strategies are choosing the perfect time to plant the seeds and using natural boosters, called biofertilizers, to nourish the plants. Biofertilizers, such as extracts from seaweed or mixtures of amino acids, are like health supplements for crops. They are environmentally friendly, improve soil health, and help plants better withstand stress, leading to a more abundant and higher-quality harvest. The objective of this study was to evaluate the effects of various sowing dates and foliar applications of biostimulants on the growth and yield of chickpea in western Iran. The findings can assist farmers in adopting practical, eco-friendly strategies to enhance chickpea productivity under limited and unpredictable rainfall regimes.

1 | INTRODUCTION

Chickpea (Cicer arietinum L.) is a cool-season seed legume of the Fabaceae family and is widely cultivated as an important source of plant protein and essential nutrients (Choudhury & Bordolui, 2022; Nezami et al., 2024). Of the two major market classes, desi and kabuli, desi chickpea accounts for nearly 80% of global production and trade, and desi chickpea is particularly well adapted to dry and semiarid environments (Nabati et al., 2023; Wang et al., 2019). In addition to its nutritional value, chickpea contributes to sustainable cropping systems through biological nitrogen fixation, improved soil fertility, and beneficial rotational effects, including suppression of weeds and some soil-borne diseases (Richards et al., 2022). Desi chickpea seeds are also rich in amino acids, fatty acids, minerals, vitamins, and bioactive compounds such as polyphenols, anthocyanins, carotenoids, oligosaccharides, resistant starch, and non-cellulosic polysaccharides, which enhance their nutritional and functional value (Jameel et al., 2021; Sehar et al., 2023).

Seed yield in chickpea is a complex quantitative trait influenced by environmental conditions and crop management practices, including sowing date, plant density, cultivar, water availability, and nutrient supply. Among these factors, sowing date plays a central role because it determines the temperature and moisture regimes experienced during crop establishment, flowering, and seed filling. Appropriate sowing can improve stand establishment, extend the effective growth period, and better synchronize crop development with favorable environmental conditions, whereas delayed or unsuitable sowing may shorten the crop cycle and expose reproductive stages to heat and moisture stress, thereby reducing yield (Choudhary et al., 2023; Fotiadis et al., 2019; Rabbani & Safdary, 2021). In western Iran, including Kermanshah Province, chickpea is mainly grown under rainfed conditions and is typically sown from late winter to early spring, depending on soil moisture, temperature, and field accessibility. Current agronomic recommendations generally favor earlier sowing, where conditions permit, because it improves the use of seasonal rainfall, extends the effective growth period, and reduces the likelihood that flowering and seed filling will coincide with terminal drought and heat stress. By contrast, delayed sowing may shorten the crop cycle and increase the exposure of reproductive stages to high temperature and moisture deficit, thereby reducing yield. Under suitable conditions, autumn sowing (November–December) or dormant seeding management may also be considered when cold-tolerant genotypes are available (Amiri et al., 2020; Maleki et al., 2024; Younesi et al., 2020).

The increasing demand for food has intensified the need to improve crop productivity, while the excessive use of chemical fertilizers has raised concerns about environmental pollution and human health (Alfosea-Simón et al., 2021). In this context, biostimulants and biofertilizers have received increasing attention as more sustainable complements or partial alternatives to synthetic agricultural inputs. Biostimulants are low-dose biological products that regulate plant physiological processes and enhance growth, yield, quality, nutrient uptake, and stress tolerance. They may be of microbial origin, such as mycorrhizae and rhizobacteria, or non-microbial origin, such as seaweed extracts, humic substances, amino acids, and other nitrogen-containing compounds (Li et al., 2026; Makonya et al., 2025; Ronga et al., 2019; Satriani et al., 2025). Biofertilizers, by contrast, are bio-based inputs containing living microorganisms or other biologically active substances that improve nutrient availability, root activity, soil biological functioning, and plant growth (Ronga et al., 2019). In addition to their conventional role in nutrient supply, microbial biofertilizers may also function as biostimulant treatments by enhancing nutrient uptake and improving plant tolerance to environmental stresses such as drought and salinity (Kumari et al., 2022). Among biostimulants, seaweed extracts and amino acid-based products have attracted considerable attention because of their potential to improve crop performance, especially under suboptimal growing conditions (Cozzolino et al., 2021; Shafie et al., 2021). Seaweed extracts contain a wide range of bioactive compounds, including alginates, polyphenols, mannitol, oligosaccharides, vitamins, amino compounds, trace elements, and hormone-like substances, which may stimulate root growth, nutrient uptake, photosynthetic activity, antioxidant capacity, and water-use efficiency (Li et al., 2026; Satriani et al., 2025). Similarly, amino acid-based biostimulants may support plant metabolism through their roles in protein synthesis, nitrogen assimilation, osmotic adjustment, and hormone-related processes, thereby promoting growth and productivity, particularly under environmental stress (Calero Hurtado et al., 2025; Henderson et al., 2025).

Foliar application of seaweed extracts and amino acids has been reported to improve several growth, physiological, and yield-related traits in legumes. In chickpea, these treatments have been associated with increases in plant growth, chlorophyll content, nodulation, yield components, seed yield, and seed quality under different growing conditions (Devi et al., 2024; Khalesi et al., 2023; J. Kumar & Singh, 2025; Rafique et al., 2022; Shaziya et al., 2024; Viana et al., 2025). Similar beneficial effects have also been documented in other legumes, such as common bean (Phaseolus vulgaris L.) and pea (Pisum sativum L.), including increases in plant height, branch and pod number, leaf area, chlorophyll content, 100-seed weight, seed yield, and harvest index (HI) (AlJuboori & Mohammed, 2021; El-Said & Ahmed, 2021; Naz et al., 2023; Zewail, 2014). However, yield responses to biological inputs, including biostimulants and microbial growth-promoting products, are not always consistent across crops, environments, and growing seasons. These responses may vary depending on crop genotype, product composition, soil fertility, moisture availability, application timing, developmental stage, and prevailing weather conditions (Singh et al., 2017; Souza et al., 2019). For example, Singh et al. (2017) reported that foliar application of a commercial seaweed extract improved several growth traits and some yield components in chickpea but did not significantly increase seed yield. Similarly, Han et al. (2024) found no significant effect of foliar amino acid application on soybean seed yield, and Souza et al. (2019) observed no significant effects of amino acid foliar fertilization on yield components in wheat and soybean. These findings suggest that such inputs are often more effective under stress-prone conditions, such as drought, salinity, heat stress, and nutrient-limited soils, where improvements in physiological activity, nutrient uptake, water-use efficiency, and stress tolerance are more likely to enhance crop performance (Henderson et al., 2025; Li et al., 2026; Makonya et al., 2025; Satriani et al., 2025). This issue is particularly relevant under the semiarid, rainfed conditions of western Iran, where terminal drought and heat stress frequently limit chickpea productivity. Despite the recognized importance of sowing date and biostimulant application as individual management practices, limited information is available on the interaction between sowing date and foliar biostimulant application in desi chickpea under these conditions. Therefore, this study was conducted in Kermanshah Province, Iran, to evaluate the interaction between sowing date and foliar application of biostimulant treatments, including seaweed extract and amino acid as non-microbial biostimulants and a plant growth-promoting biofertilizer used as a microbial biostimulant treatment, on the yield and yield components of desi chickpea.

2 | MATERIALS AND METHODS

2.1 | Study sites and climatic conditions

The experiment was conducted during the 2024–2025 growing season at two locations in Kermanshah Province, Iran. The first site was the experimental farm of the Campus of Agriculture and Natural Resources, Razi University, Kermanshah city (34°21′ N, 47°9′ E; altitude 1319 m above sea level; mean annual precipitation 445 mm), and the second site was located in Salas-e Babajani County (34°34′ N, 45°38′ E; altitude 1170 m above sea level; mean annual precipitation 600 mm). The geographical locations of the study sites are shown in Figure 1. According to the De Martonne climate classification, both regions have cold semiarid climatic conditions. Key climatic parameters during the experimental period are presented in Table 1.

Composite soil samples were collected from a depth of 0–30 cm at multiple points within each field prior to sowing to determine the initial physicochemical properties. Soil analyses, including texture, pH, organic matter, and nutrient content, are presented in Table 2.

2.2 | Experimental design and treatments

The experiment was conducted as a factorial trial using a randomized complete block design with three replications to evaluate the effects of sowing date and foliar biostimulant application on chickpea (*C. arietinum* L.). Sowing dates included February 19 (first), March 5 (second), and March 21 (third). Foliar treatments comprised a control (distilled water), seaweed extract (1.5 L ha^{-1}), amino acid solution (2.0 L ha^{-1}), and a growth-promoting biofertilizer (2.5 L ha^{-1}).

Foliar applications were performed individually during the late afternoon to minimize evaporation and applied at the pre-flowering stage (BBCH 59) using a calibrated 20-L handheld sprayer (5 bar pressure, flat-fan nozzle, and 80° spray angle). The seaweed extract (Esperanto Kelp,

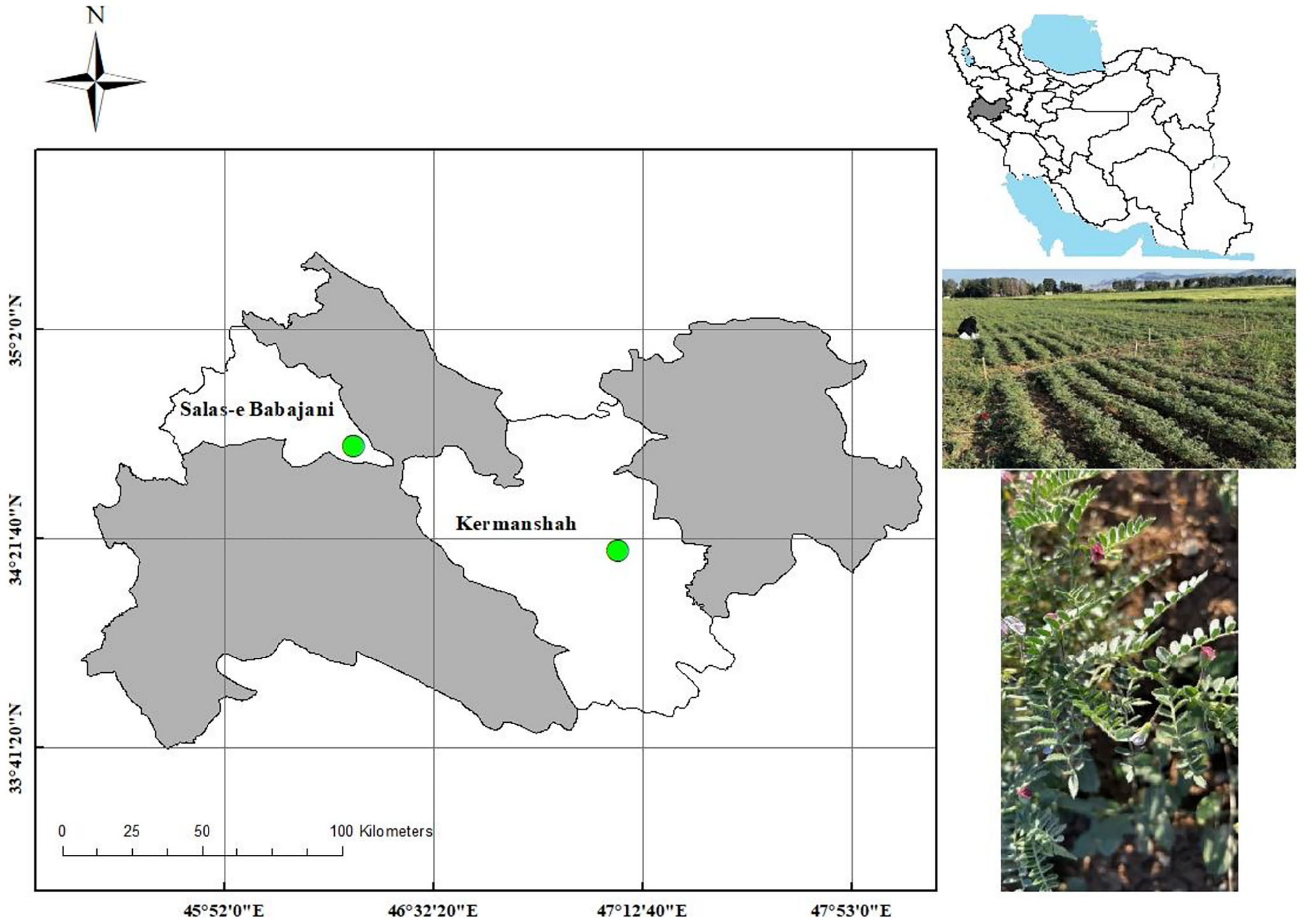

FIGURE 1 Geographical location of the experimental sites in Kermanshah Province, Iran.

TABLE 1 Monthly climatic variations during the 2024–2025 growing season at the experimental sites in Kermanshah Province, Iran.

Location	Month	Minimum temperature (˚C)	Maximum temperature (˚C)	Rainfall (mm)
Kermanshah	19 Feb.–20 Mar.	−0.1	12.6	89.8
	21 Mar.–20 Apr.	−1.3	27.2	44.9
	21 Apr.–21 May	5.1	36.2	33.9
	22 May–21 Jun.	10	39.4	0.1
Salas-e Babajani	19 Feb.–20 Mar.	2.5	13.4	86.2
	21 Mar.–20 Apr.	0	27.6	82.6
	21 Apr.–21 May	8.8	36	17.8
	22 May–21 Jun.	13.5	38.5	0

Smart Grow) contained 45% extract from *Ecklonia maxima*, *Ascophyllum nodosum*, and *Laminaria* spp., 5% soluble K_2O, 0.1% Fe, 0.1% Mn, 0.1% Zn, 4% mannitol, and 5% alginic acid. The growth-promoting biofertilizer (Makromat, Hezar Daneh Armen Technology Co.) comprised *Bacillus subtilis* at 10^7 viable cells g^{-1}. The amino acid solution (Flourish Amino Acid) contained 20 amino acids with 4% total nitrogen, 2% organic acids, and 5% total amino acids.

2.3 | Plant material, cultivation, and growing conditions

Two experimental fields were prepared by moldboard plowing during winter 2024 once soil conditions were suitable for tillage. Experimental plots measured 3 m × 2.5 m, with five planting rows per plot spaced 50 cm apart. The distance between plants within each row was 10 cm, with 50 cm separating adjacent plots and 150 cm separating blocks. The

TABLE 2 Physical and chemical properties of soils at the experimental sites.

Soil characteristics	Kermanshah	Salas-e Babajani
pH	7.41	7.1
EC (dS m^{-1})	0.41	0.22
Organic carbon (%)	1.1	0.8
Nitrogen (%)	0.14	0.19
Phosphorus (mg kg^{-1})	5.11	4.21
Potassium (mg kg^{-1})	211	156
Clay (%)	44	45
Loam (%)	46	39
Sand (%)	10	16
Soil texture	Loam-clay	Clay-loam

Abbreviation: EC, electrical conductivity.

chickpea used was a local desi-type landrace from Salas-e Babajani. Seeds were manually sown at a depth of 3 cm according to the respective sowing date treatments, targeting a plant density of 12–15 plants m^{-2} (equivalent to 45 kg ha^{-1}). Weeds were controlled through several rounds of hand weeding during the growing season to maintain weed-free plots, and no chemical fertilizers, herbicides, or pesticides were applied.

2.4 | Data collection and measurements

At physiological maturity, when plants exhibited yellowing, five plants were randomly selected from each plot to count the number of pods per plant, and the mean value was calculated for each plot. Note that 100-seed weight was determined by randomly collecting four samples of 100 seeds from each plot. Each sample was weighed using a digital balance with 0.01 g accuracy, and the average 100-seed weight was recorded.

Seed yield and total aboveground dry biomass (biological yield) were measured from a 2-m^2 area per plot after removing one border row from each side and 0.5 m from both ends to avoid edge effects. Harvested plants were air-dried to determine biological yield, after which the plants were threshed, seeds cleaned, and seed yield calculated on a per-unit-area basis at 14% seed moisture content. The HI was calculated as the ratio of seed yield to aboveground biomass for each plot (Richards et al., 2022).

Seed samples from each plot were transported to the laboratory, and seed protein content was determined using the Kjeldahl method (Pardo et al., 2000).

2.5 | Data analysis

Statistical analyses were performed after confirming the normality of all measured traits. Data were subjected to analysis of variance (ANOVA) using SAS software (version 9.1). For the combined analysis across the two locations, location and block within location were treated as random effects, whereas sowing date and biostimulant treatment were treated as fixed effects. The ANOVA model included the main effects of location, sowing date, and biostimulant treatment, as well as their interactions. Homogeneity of variances across locations was assessed using an F-test, which indicated no significant differences ($p > 0.01$) for any trait. Therefore, a combined ANOVA across both locations was carried out. Mean comparisons were conducted using the least significant difference (LSD) test at a 5% probability level. Graphs were generated and interpreted using Microsoft Excel.

3 | RESULTS

3.1 | Pods per plant and 100-seed weight

The combined ANOVA showed that location, sowing date, and biostimulant significantly ($p < 0.01$) affected both pods per plant and 100-seed weight of chickpea. Interactions of location × sowing date and location × biostimulant were also significant for both traits, while sowing date × biostimulant influenced only pods per plant (Table 3).

For the location × sowing date interaction, the lowest pod number (18.33) and 100-seed weight (11.95 g) were observed at the third sowing date (March 21) in Salas-e Babajani. In contrast, chickpeas sown at the second sowing date in Kermanshah showed the highest values, corresponding to increases of 82.3% and 42.9%, respectively (Table 4).

Regarding the location × biostimulant interaction, foliar applications improved both pods per plant and 100-seed weight across locations. Seaweed extract in Kermanshah resulted in the highest values, with pod number and 100-seed weight 87.4% and 41.6% higher than the control treatment in Salas-e Babajani, respectively. Amino acids produced the second-highest values in Salas-e Babajani, increasing pod number and 100-seed weight by 62.7% and 34.7% compared with the control treatment at the same location (Table 5).

Across the three sowing dates, foliar application of seaweed extract and amino acids increased the number of pods per plant; however, the two locations differed in which treatment produced the highest values. Based on the combined means across both locations, the greatest pod numbers were recorded on February 19 and March 5. On February 19, seaweed extract and amino acid application produced 34.16 and 33.50 pods per plant, respectively, while on March 5, the corresponding values were 33.33 and 33.00. These values represented 2.20-, 2.16-, 2.12-, and 2.12-fold increases relative to the control treatment on March 21, where the lowest pod number (15.50) was recorded (Figure 2).

TABLE 3 Combined analysis of variance of the effect of sowing date and foliar application biostimulants on the yield and yield components of desi chickpea in two locations, Salas-e Babajani and Kermanshah.

Source of variation	Df	Mean square: Number of pods per plant	100-Seed weight	Seed yield	Aboveground biomass	Harvest index	Seed protein
Location (L)	1	264.50**	11.04**	78,738.34**	760,863.92**	71.80*	12.41**
Block (location)	2	6.93^{ns}	1.44*	5300.84^{ns}	17,992.72*	33.30^{ns}	1.77*
Sowing date (S)	2	620.01**	107.92**	1,412,871.26**	3,148,390.69**	748.60**	154.60**
Biostimulants (B)	3	461.59**	49.03**	248,190.82**	1,576,110.62**	63.87*	66.70**
L × S	2	133.62**	10.89**	209,953.76**	1,446,582.54**	223.74**	42.48**
L × B	3	76.31**	6.60**	23,232.12**	156,281.43**	62.07*	9.41**
S × B	6	11.82**	0.40^{ns}	25,599.30**	159,880.54**	11.51^{ns}	0.97^{ns}
L × S × B	6	4.55^{ns}	0.48^{ns}	6461.43*	173,421.63**	61.81**	1.25*
Error	46	2.78	0.29	2545.54	4442.60	16.58	0.54
CV (%)	–	6.53	3.66	7.01	4.56	8.28	3.65

Abbreviations: CV, coefficient of variation; Df, degree of freedom.
** and * denote significance at $p < 0.01$ and at $p < 0.05$, respectively. ns; non-significant.

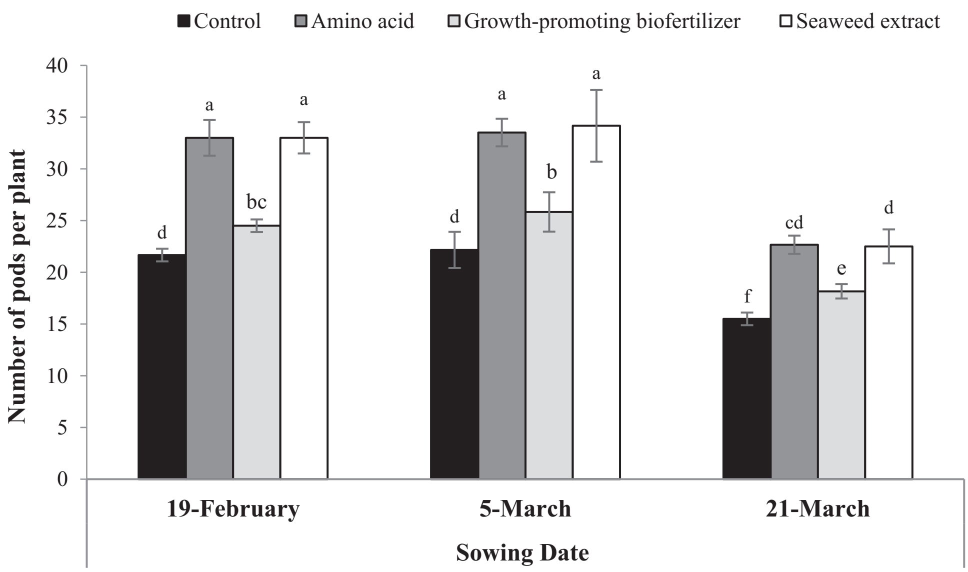

FIGURE 2 Mean comparison of the interaction effect of sowing date × foliar biostimulant application on the number of pods per plant in desi chickpea, based on the combined analysis across both experimental locations. Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

3.2 | Seed yield and aboveground biomass

The combined ANOVA showed that chickpea seed yield ($p < 0.05$) and aboveground biomass ($p < 0.01$) were significantly affected by the three-way interaction of location × sowing date × biostimulant (Table 3). In both locations, foliar application of biostimulants positively influenced seed and aboveground biomass, with the lowest values observed in control plants at the third sowing date (March 21) in Salas-e Babajani, recording 370 kg ha^{-1} for seed yield and 794.67 kg ha^{-1} for aboveground biomass. The highest seed and aboveground biomass were recorded in chickpeas sown on March 5 and treated with seaweed extract in Kermanshah, reaching 1216.67 kg ha^{-1} and 2892.33 kg ha^{-1}, respectively, corresponding to approximately 3.28- and 3.64-fold increases compared with the control at the March 21 sowing date in Salas-e Babajani. Following this treatment, chickpeas sown on February 19 and treated with amino acids in Salas-e Babajani achieved the next highest seed and aboveground biomass, showing 2.96- and 2.82-fold increases, respectively, com-

TABLE 4 Means comparison of the interaction effect of location × sowing date on some studied traits of chickpea.

Location	Sowing date	Number of pods per plant	100-Seed weight (g)
Salas-e Babajani	Feb. 19	28.16 ± 1.79b	16.23 ± 0.51b
	Mar. 5	24.41 ± 1.54c	14.91 ± 0.54d
	Mar. 21	18.33 ± 0.89e	11.95 ± 0.41f
Kermanshah	Feb. 19	27.91 ± 1.67b	15.70 ± 0.54c
	Mar. 5	33.41 ± 1.81a	17.08 ± 0.52a
	Mar. 21	21.08 ± 1.22d	12.66 ± 0.34e

Note: Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

pared with the control plants at the March 21 sowing date in the same location (Figure 3).

3.3 | Harvest index

The combined ANOVA indicated that the HI of chickpea was significantly affected ($p < 0.01$) by the three-way interaction of location × sowing date × biostimulant (Table 3). The effect of biostimulant application on HI differed between the two locations. In Salas-e Babajani, all three biostimulant treatments applied at the March 5 sowing date, as well as the growth-promoting biostimulant applied on February 19 and March 21, significantly increased HI compared with the control. In contrast, in Kermanshah, plants treated with biostimulants at all three sowing dates showed lower HI than the control. The lowest HI (34.96%) was observed in the amino acid treatment at the March 21 sowing date in Kermanshah, whereas the highest HI (61.23%) was recorded for the control treatment at the February 19 sowing date in Kermanshah, which represents a 26.27% increase compared with the amino acid treatment on March 21. Furthermore, the growth-promoting biostimulant at the February 19 sowing date in Salas-e Babajani and the control treatment at the March 5 sowing date in Kermanshah also resulted in high HI values, showing 21.70% and 20.80% higher HI, respectively, compared with the amino acid treatment on March 21 in Kermanshah (Figure 4).

3.4 | Seed protein content

Based on the combined ANOVA, the seed protein content of chickpea was significantly affected ($p < 0.05$) by the three-way interaction of location × sowing date × biostimulant (Table 3). At both experimental locations, amino acid and seaweed extract treatments consistently increased seed protein content across all three sowing dates. The highest protein content (25.70%) was recorded with amino acid application at the February 19 sowing date in Salas-e Babajani, followed by seaweed extract applied at the March 5 sowing date in Kermanshah, which had an average protein content of 23.76%.

In contrast, the lowest protein content was observed in the control treatment at the March 21 sowing date in both Salas-e Babajani (14.66%) and Kermanshah (15.23%) (Figure 5).

4 | DISCUSSION

The environment plays a central role in crop adaptation and productivity; therefore, selecting an appropriate sowing date is essential for optimizing chickpea growth, yield, and seed quality (Fotiadis et al., 2019). However, the present results show that sowing date cannot be interpreted in isolation, because its effects were strongly influenced by both biostimulant treatment and location. Thus, the main contribution of this study is to show that chickpea performance under rainfed conditions was shaped by interactions between management practices and local environmental conditions. The significant sowing date × biostimulant and location × biostimulant interactions, together with the three-way interaction for some traits, indicate that the effects of the tested foliar treatments were not uniform across sowing dates and environments. The highest seed yield, yield components, and seed quality were obtained with the March 5 sowing in Kermanshah and the February 19 sowing in Salas-e Babajani, whereas delayed sowing on March 21 generally reduced performance. These results align with the seasonal weather patterns recorded during the study, which showed that the most successful sowing dates in each location better synchronized reproductive development with periods of cooler temperatures and more favorable moisture availability. This advantage was likely associated with improved flower retention, pod set, and a longer seed-filling period compared with later sowings. Under such conditions, biostimulant treatments may have further enhanced crop performance by supporting physiological activity, nutrient uptake, and tolerance to transient stress. In the case of the microbial biostimulant treatment, these benefits may also be related to improved nutrient mobilization and root activity. By contrast, delayed sowing likely increased exposure to terminal heat and moisture stress, thereby reducing the extent to which these physiological benefits were translated into higher yield.

Previous studies likewise showed that early or optimum sowing improves chickpea productivity, whereas delayed sowing reduces reproductive success and final yield. Ali et al. (2018) reported that chickpea sown on November 20 produced higher 100-seed weight, seed yield, straw yield, and aboveground biomass than crops sown either earlier (November 5) or later (December 5 and 20 and January 4). Similarly, M. Kumar et al. (2022) found that sowing on November 10 improved pod number, seeds per plant, test weight, and

TABLE 5 Means comparison of the interaction effect of location × foliar application biostimulants on some studied traits of chickpea.

Location	Biostimulants	Number of pods per plant	100-Seed weight (g)
Salas-e Babajani	Control	18.44 ± 1.06e	12.16 ± 0.64g
	Amino acid	30 ± 2.17b	16.38 ± 0.76b
	Growth-promoting biofertilizer	20.88 ± 1.11d	13.97 ± 0.62e
	Seaweed extract	25.22 ± 1.79c	14.94 ± 0.61d
Kermanshah	Control	21.11 ± 1.51d	13.11 ± 0.59f
	Amino acid	29.44 ± 1.95b	15.72 ± 0.65c
	Growth-promoting biofertilizer	24.77 ± 1.57c	14.55 ± 0.59d
	Seaweed extract	34.55 ± 2.31a	17.22 ± 0.83a

Note: Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

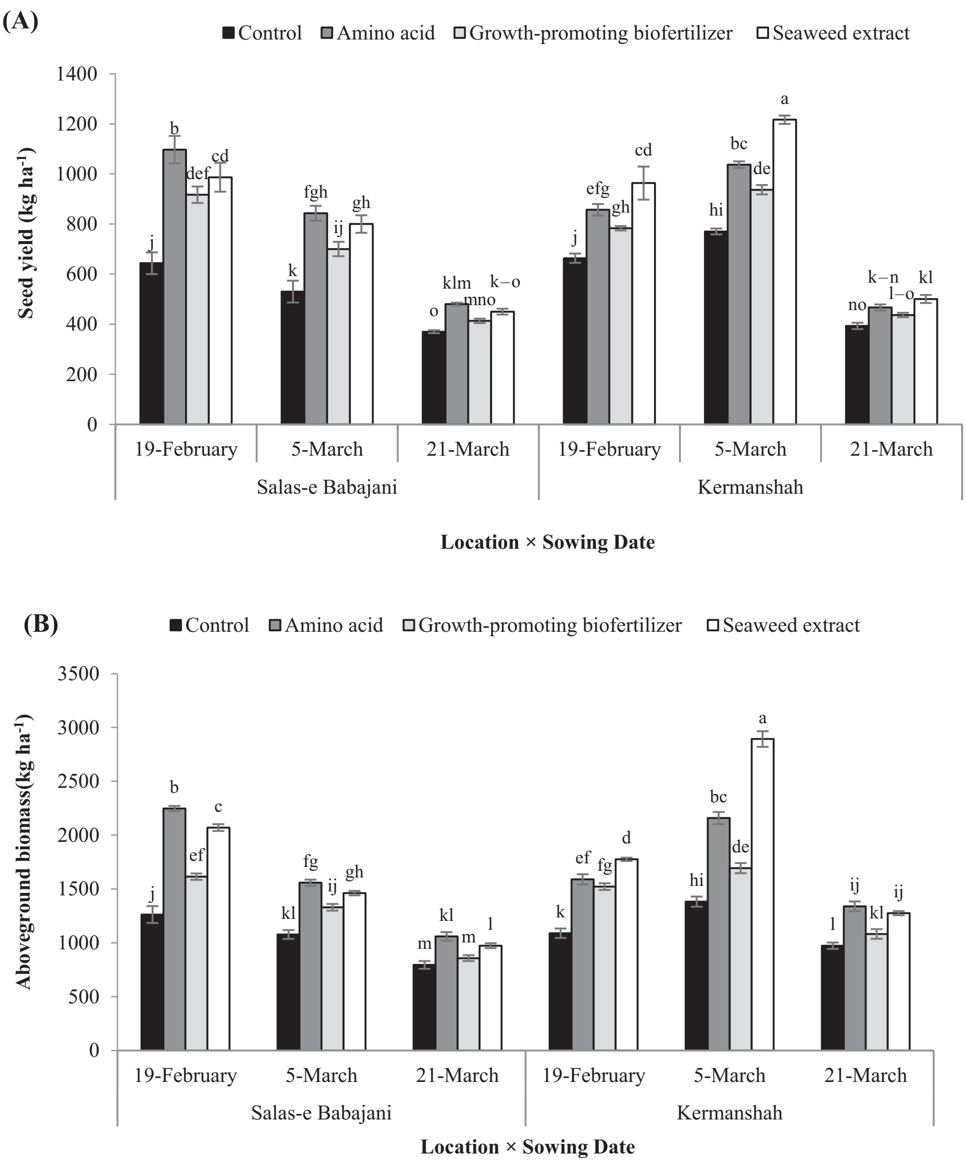

FIGURE 3 Mean comparison of the interaction of location × sowing date × foliar biostimulant application on seed yield (a) and aboveground biomass (b) of desi chickpea. Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

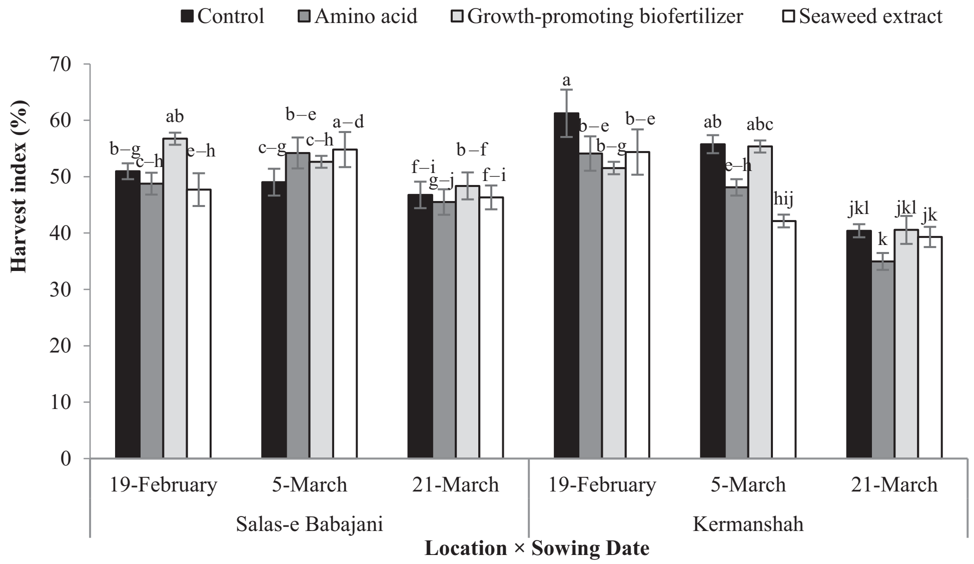

FIGURE 4 Mean comparison of the interaction of location × sowing date × foliar biostimulant application on the harvest index of desi chickpea. Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

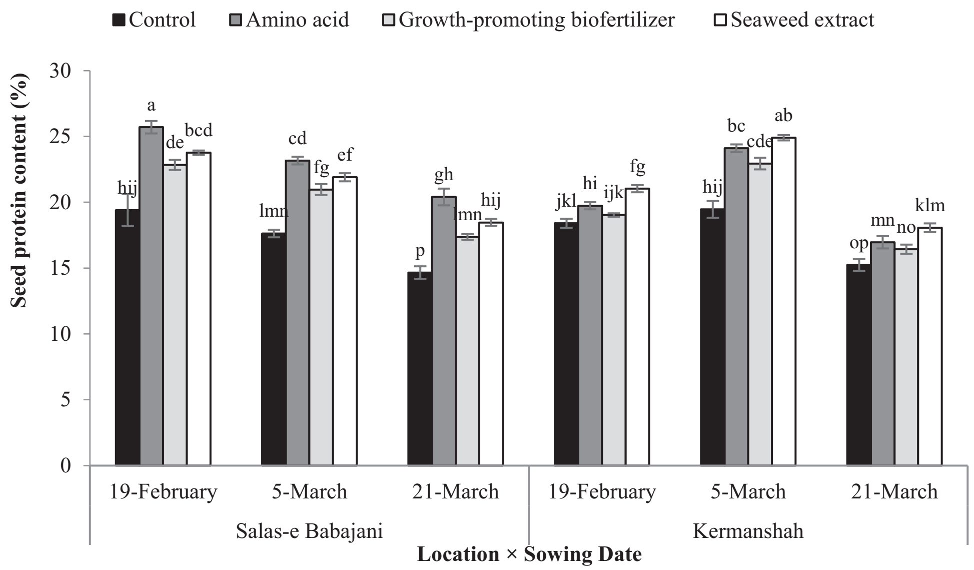

FIGURE 5 Mean comparison of the interaction of location × sowing date × foliar biostimulant application on the seed protein of desi chickpea. Different letters indicate significant differences at $p < 0.05$ according to least significant difference (LSD) test. Data are presented as means ± SE ($n = 4$).

seed yield compared with delayed sowing on November 30, while Bahalkeh et al. (2021) showed that late sowing reduced flowering and seed-filling duration, thereby limiting assimilate translocation to reproductive organs and decreasing seed number, seed weight, and total yield. In the present study, the poorer performance of the March 21 sowing was likely due to greater exposure of flowering and podding stages to high temperature and declining moisture availability, which may have increased flower and young pod abortion and shortened the seed-filling period (Ashtari et al., 2024; Elshamly, 2023). By contrast, earlier sowing under more favorable temperature and moisture conditions likely improved crop establishment, reproductive development, and the expression of yield-related traits (Mahdipour-Afra et al., 2021). Importantly, the penalty associated with delayed sowing varied across biostimulant treatments and locations, indicating that reproductive performance under terminal stress depended partly on the environmental context and the foliar input applied.

Our results further indicate that terminal stress adversely affected crop physiological efficiency. HI, defined as the ratio of seed yield to total aboveground biomass, generally tended to decline under the March 21 sowing compared with the earlier sowings, although this response was not consistent across all location × biostimulant combinations. The overlap among some mean separation groups confirms that the effect of delayed sowing on HI should be interpreted as an overall trend rather than a uniform response. Nevertheless, the lower HI observed in many late-sown treatments suggests reduced efficiency of assimilate partitioning to reproductive sinks under terminal stress. This response was likely associated with the combined effects of higher temperature, declining rainfall, and a shortened crop duration, which may have restricted photosynthate translocation to developing seeds and caused seed yield to decline more sharply than total aboveground biomass in several treatment combinations (Richards et al., 2022). Seed protein content was also reduced by delayed sowing, probably because heat and water stress impaired nitrogen uptake, nitrate reductase activity, and protein biosynthesis, while shortening the effective seed-filling period (Abaza et al., 2023; Batra et al., 2023). Importantly, these responses varied across biostimulant treatments, indicating that the tested inputs, including the microbial biostimulant, did not act uniformly across environment. Their beneficial effects were more likely expressed where they helped maintain physiological activity, nutrient acquisition, and assimilate allocation to reproductive organs under stress, thereby partly buffering the negative effects of less favorable sowing conditions on seed yield and quality.

Foliar application of the tested biostimulant products generally improved yield traits and seed protein content, but these responses were better explained by interaction effects than by simple main effects, as their magnitude varied across sowing dates and locations. Biostimulants containing seaweed extracts (Kelpak extract–Ecklonia maxima) or amino acids (Fylloton–Ascophyllum nodosum extract; Terra Sorb Complex–amino acids) have been reported to increase pod number, seed count, seed yield, and seed protein content in legumes (Kocira et al., 2020). Their beneficial effects are commonly attributed to improved nutrient uptake and nutrient-use efficiency, enhanced hormonal activity, stimulation of chlorophyll formation and photosynthesis, and better reproductive development (Huda et al., 2023; Shaziya et al., 2024). Amino acid may also promote flower and pod formation, support the synthesis of coenzymes, vitamins, purines, and pyrimidines, and enhance dry matter partitioning by improving fertilizer use efficiency and water and nutrient absorption (Ahmad et al., 2023; El-Said & Ahmed, 2021; Mohammed & Mohammed, 2023).

In the present study, the tested products appeared to act primarily as context-dependent physiological and metabolic buffers, with their benefits becoming more evident under delayed sowing and terminal stress conditions. Rather than acting simply as supplementary nutrient sources, the seaweed extract and amino acid treatments likely helped sustain reproductive performance by supporting assimilate translocation, seed development, and stress tolerance when temperature and moisture conditions became restrictive. Seaweed may have contributed through osmotic adjustment, antioxidant protection, membrane stability, and improved resource-use efficiency, whereas amino acid may have supplied readily available metabolic substrates and nitrogenous compounds that help sustain enzyme activity, protein synthesis, and seed filling under stress (Calero Hurtado et al., 2025; Li et al., 2026; Satriani et al., 2025). Likewise, the plant growth-promoting biofertilizer used as a microbial biostimulant treatment (containing B. subtilis) may have contributed through improved root activity, nutrient solubilization, nutrient uptake, phytohormone-related effects, and enhanced tolerance to abiotic stress, thereby enhancing the crop's ability to maintain flower retention, pod set, assimilate allocation, and seed filling under stressful conditions (Stępień et al., 2022). This interpretation is consistent with the significant sowing date × biostimulant interaction, indicating that the effectiveness of these inputs depended on environmental context rather than being uniform across all sowing dates and locations.

Therefore, the tested biostimulant and plant growth-promoting biofertilizer treatments should be regarded as complementary, context-dependent inputs that may improve nutrient mobilization and uptake, support physiological resilience, and help maintain reproductive performance under low-input and stress-prone rainfed conditions. In soils with limited phosphorus availability, they may enhance plant access to existing nutrient pools, while under less favorable soil or climatic conditions they may partly alleviate stress effects. However, they should not be considered stand-alone solutions for nutrient deficiency or substitutes for soil-test-based fertilization.

5 | CONCLUSION

The present study showed that delayed sowing generally reduced seed yield, yield components, and seed protein content of chickpea at both Kermanshah and Salas-e Babajani. In contrast, sowing on March 5 in Kermanshah and February 19 in Salas-e Babajani was associated with more favorable crop performance under the conditions of this study. Foliar application of biostimulants, particularly seaweed extract and amino acid treatments, was associated with improvements in pod number, 100-seed weight, seed yield, aboveground biomass, and seed protein content, although the magnitude of these responses varied with sowing date and location. Overall, these findings suggest that appropriate sowing date selection, together with complementary biostimulant inputs, may contribute to improved chickpea productivity and seed quality under rainfed and stress-prone conditions.

AUTHOR CONTRIBUTIONS

Bita Abbasi: Conceptualization; data curation; investigation; software; writing—review and editing. **Alireza Bagheri**: Conceptualization; methodology; project administration; supervision; validation; writing—review and editing. **Shahab Khoshkhooy**: Data curation; investigation. **Sadegh Jalilian**: Data curation; investigation. **Mahmood Khoramivafa**: Writing—review and editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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