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Sameer Pupneja
Research Scholar, Department of
Agronomy, Faculty of Agriculture,
Guru Kashi University, Talwandi
Sabo, Bathinda, Punjab, India

Dr. Veerpal Kaur
Assistant Professor, Department of
Agronomy, Faculty of Agriculture,
Guru Kashi University, Talwandi
Sabo, Bathinda, Punjab, India

Dr. Kanik Kumar Bansal
Assistant Professor, Department of
Agronomy, Faculty of Agriculture,
Guru Kashi University, Talwandi
Sabo, Bathinda, Punjab, India

Corresponding Author:
Sameer Pupneja
Research Scholar, Department of
Agronomy, Faculty of Agriculture,
Guru Kashi University, Talwandi
Sabo, Bathinda, Punjab, India

Response of wheat (*Triticum aestivum* L.) to high density planting & foliar application of seaweed extract and amino acid-based biostimulants

Sameer Pupneja, Veerpal Kaur and Kanik Kumar Bansal

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Abstract

This study evaluated the effects of foliar application of biostimulants and high-density planting on growth, yield, and economics of wheat (*Triticum aestivum* L.) at Guru Kashi University, Punjab during Rabi 2025-26. A Randomized Block Design with nine treatments comprising combinations of amino acid-based plant growth regulator and seaweed extract with high density planting was used. Treatments were applied under high-density planting at three growth stages. Results showed significant improvements in physiological and yield parameters due to biostimulant application. Treatment T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) recorded the highest values for tillers per plant, chlorophyll content, crop growth rate, grain weight, grain yield (52.53 q ha⁻¹), and straw yield. Harvest index and relative growth rate were also improved compared to control. Economic analysis revealed higher gross returns (₹135,790.05 ha⁻¹), net returns (₹81,890.05 ha⁻¹), and benefit-cost ratio (2.52) under T₁₀. The study concludes that combined application of foliar biostimulants with high-density planting significantly enhances wheat productivity and profitability under semi-arid conditions of Punjab, offering a sustainable strategy for improving crop performance and resource use efficiency.

Keywords: Amino acid PGR, biostimulants, chlorophyll content, grain yield, high-density planting

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and plays a significant role in ensuring food and nutritional security. In India, wheat is the second most important food grain crop after rice and contributes substantially to the agricultural economy. The crop provides carbohydrates, proteins, vitamins and minerals required for human nutrition and is widely used for preparation of flour, bread, chapatti, biscuits and other food products. In Punjab, wheat is the principal Rabi cereal crop and forms the backbone of the state's food grain production system. However, wheat productivity is often affected by improper crop management practices, nutrient imbalance and inefficient utilization of available resources. Therefore, adoption of suitable agronomic practices is necessary to sustain higher productivity and profitability.

Plant geometry and row spacing are important agronomic factors affecting growth and yield of wheat. Optimum spacing ensures proper plant distribution and efficient utilization of sunlight, soil moisture and nutrients. Appropriate row spacing promotes better tillering, root development and dry matter accumulation, whereas excessively narrow or wider spacing may adversely affect crop productivity due to increased competition or reduced plant population (Peake *et al.*, 2020) [9]. Hence, identification of suitable row spacing is essential for improving growth and yield attributes of wheat under different agro-climatic conditions.

In recent years, foliar application of bio-stimulants has gained considerable attention as an eco-friendly approach to enhance crop productivity. Bio-stimulants such as seaweed extracts, amino acids and humic substances improve nutrient uptake, photosynthetic efficiency and tolerance against abiotic stress. Foliar application at critical growth stages provides rapid absorption of growth-promoting substances and improves crop vigor and yield performance (Nardi *et al.*, 2016) [7]. Similar synergistic effects of seaweed-based biostimulants with nutrient management on wheat yield attributes were also reported by (Toppo *et al.*, 2024 and Sharma *et al.*, 2025) [18, 15]. The combined effect of optimum row spacing and foliar application of bio-stimulants may

significantly influence growth, yield and economics of wheat through efficient resource utilization and improved physiological activity. Comparable improvements in irrigated wheat productivity under seaweed extract and nutrient application were observed by Das *et al.*, (2026) ^[5]. However, limited information is available regarding their combined effect under Punjab conditions. Therefore, the present investigation was undertaken to evaluate the influence of row spacing and foliar application of bio-stimulants on growth, yield and economics of wheat (Rouphael & Colla 2024) ^[13].

2. Materials and Methods

2.1 Experimental Site and Season

The field experiment was conducted at the Agricultural

Research Farm, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India (29°57’N, 75°7’E; altitude 213 m above sea level) during the Rabi season of 2025 to study the influence of high-density planting and foliar application of bio-stimulants on growth, yield and economics of wheat (*Triticum aestivum* L.). The site has a semi-arid subtropical climate with mild winters and warm summers, from November 2025 to April 2026. Maximum temperature peaked at 38°C in April, while the minimum temperature dropped to 8°C in January. The total rainfall received during the experimental period was 58 mm, with relative humidity ranging from 24% to 49%.

Table 1: Meteorological data during the experimental period (November 2025-April 2026), Talwandi Sabo, Bathinda

Month	Min Temp (°C)	Max Temp (°C)	Relative Humidity (%)	Rainfall (mm)
November 2025	18	29	30	3
December 2025	11	23	34	4
January 2026	8	21	49	12
February 2026	12	25	42	18
March 2026	16	31	31	10
April 2026	23	38	24	11

2.2 Soil Characteristics

Prior to sowing, composite soil samples (0-15 cm in depth) were collected from five representative locations of the experimental field, air-dried, passed through a 2 mm sieve and analyzed using standard analytical procedures (Table 2). The experimental soil

was sandy loam in texture, slightly alkaline in reaction (pH 7.3), low in organic carbon (0.48%) and available nitrogen (119.2 kg ha⁻¹), medium in available phosphorus (17.95 kg P₂O₅ ha⁻¹), and medium in available potassium (173.4 kg K₂O ha⁻¹).

Table 2: Physical and chemical properties of the experimental soil (0-15 cm depth)

Property	Value	Method
pH	7.3	Glass electrode pH meter (Jackson 1967) ^[6]
EC (dS m ⁻¹)	0.81	Conductivity meter, 1:2 soil:water suspension (Jackson 1967) ^[6]
Organic carbon (%)	0.48	Walkley and Black rapid titration (Jackson 1967) ^[6]
Available N (kg ha ⁻¹)	119.2	Alkaline KMnO ₄ method (Subbiah & Asija 1956) ^[17]
Available P ₂ O ₅ (kg ha ⁻¹)	17.95	0.5 N NaHCO ₃ extractable (Olsen <i>et al.</i> , 1954) ^[8]
Available K ₂ O (kg ha ⁻¹)	173.4	1N NH ₄ OAc extractable (Jackson 1967) ^[6]

2.3 Experimental design and treatments

A Randomized Block Design (RBD) comprising nine treatments with three replications was adopted for the experiment. Each experimental plot measured 5 m × 4 m gross plot size with a net plot area of 3.8 m × 3 m. The wheat variety PBW-826, a high-yielding and heat-tolerant cultivar developed by Punjab Agricultural University (PAU), Ludhiana for timely-sown irrigated conditions, was used in the study. The variety is known for its superior grain quality, rust resistance and high yield potential, and is suitable for cultivation in the North-Western and North-Eastern Plains Zones of India (Sharma *et al.*, 2025) ^[15]. The recommended dose of fertilizer (RDF) for wheat cultivation in Punjab is 120:60:40 kg N:P:K ha⁻¹ (PAU, 2025). The treatments consisted of different concentrations of amino acid-based plant growth regulator and seaweed extract applied as foliar spray under high-density planting conditions. The treatments comprised T₁-Control (recommended density without bio-stimulant spray), T₂-High density planting + Amino Acid Based PGR @ 2 ml L⁻¹ + Seaweed Extract @ 2 ml L⁻¹, T₃-High density planting + Amino Acid Based PGR @ 2 ml L⁻¹ + Seaweed Extract @ 4 ml L⁻¹, T₄-High density planting + Amino Acid Based PGR @ 2 ml L⁻¹ + Seaweed Extract @ 6 ml L⁻¹, T₅-High density planting + Amino Acid Based PGR @ 4 ml L⁻¹ + Seaweed Extract @ 2 ml L⁻¹, T₆-High density planting + Amino Acid Based PGR @ 4 ml L⁻¹ + Seaweed Extract @ 4 ml L⁻¹, T₇-

High density planting + Amino Acid Based PGR @ 4 ml L⁻¹ + Seaweed Extract @ 6 ml L⁻¹, T₈-High density planting + Amino Acid Based PGR @ 6 ml L⁻¹ + Seaweed Extract @ 2 ml L⁻¹, T₉-High density planting + Amino Acid Based PGR @ 6 ml L⁻¹ + Seaweed Extract @ 4 ml L⁻¹ and T₁₀-High density planting + Amino Acid Based PGR @ 6 ml L⁻¹ + Seaweed Extract @ 6 ml L⁻¹. Foliar sprays were applied at 30-35, 50-55 and 70-75 days after sowing as per treatment details. Recommended agronomic practices were uniformly followed for all treatments throughout the crop growth period.

2.4 Agronomic management

The experimental field was prepared by giving pre-sowing irrigation followed by ploughing and harrowing to obtain a fine tilth. Wheat seeds with high germination percentage were sown under high-density planting using narrow row spacing to maintain a higher plant population, while the control treatment was maintained under recommended plant spacing. Phosphorus (60 kg P₂O₅ ha⁻¹ as single superphosphate) and potassium (40 kg K₂O ha⁻¹ as muriate of potash) were applied basally at the time of final land preparation. Nitrogen was applied through urea in three equal splits: one-third at sowing, one-third at crown root initiation stage, and the remaining one-third at tillering stage. The experiment comprised foliar application treatments of an amino acid-based plant growth regulator and seaweed extract at

different concentrations under high-density planting conditions. Foliar sprays were applied at 30-35, 50-55 and 70-75 days after sowing (DAS) according to the treatment schedule. The treatments included different combinations of amino acid-based PGR (2, 4 and 6 mL L⁻¹) and seaweed extract (2, 4 and 6 mL L⁻¹), along with an untreated control.

Irrigations were applied according to crop requirements with special emphasis on crown root initiation, tillering, booting, flowering and grain filling stages. Weed management was carried out through manual weeding and recommended herbicide application at appropriate stages. Plant protection measures were adopted as needed to manage insect pests and diseases during the crop season.

2.5 Observations Recorded

Growth observations were recorded at 30, 60, 90 and 120 DAS, as well as at harvest, for five randomly tagged plants from each plot. Number of tillers plant⁻¹ was counted at different growth phases and at maturity. Chlorophyll content was measured using a SPAD meter. Crop growth rate (CGR) and relative growth rate (RGR) were estimated using conventional methods.

At harvest, yield attributes including effective tillers m⁻², spikes plant⁻¹, spike length (cm), grains spike⁻¹ and test weight (1000-grain weight, g) were measured. Grain yield, straw yield and biological yield were represented in q/ha. Harvest index (HI) was determined using the following formula: HI (%) = (grain yield / biological yield) × 100.

Economic study of the treatments was carried out by calculating cost of cultivation, gross returns, net returns and benefit:cost (B:C) ratio (B:C ratio = gross return / cost of cultivation).

2.6 Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) for a randomized block design (RBD) with three replications, following the procedure described by Cochran and Cox (1967) [3] using COSTAT software. Treatment means were compared at the 5% level of significance using the critical difference (CD) test. Pearson's correlation coefficients were computed between grain yield, straw yield, and other observed parameters at different growth stages of wheat to assess the relationship among traits under varying nutrient management practices. All statistical comparisons were performed at $P = 0.05$.

3. Results and Discussion

3.1 Growth Parameters

The data presented in Table 3 indicated that foliar application treatments combined with high-density planting significantly improved the growth and physiological parameters of wheat. Among all the treatments, T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) recorded the best performance in terms of number of tillers per plant, chlorophyll content, crop growth rate (CGR), and relative growth rate (RGR), while the control treatment T₁ (recommended density without bio-stimulant spray) showed the lowest values. The maximum number of tillers per plant was observed in T₁₀ (5.5), whereas T₁ recorded only 4.2 tillers per plant. The increase in tillering under treated plots may be attributed to improved nutrient availability and the hormonal effects of seaweed extract and amino-acid-based plant growth regulators, which promoted vegetative growth and lateral shoot development. Higher tiller production contributed positively to spike formation and overall yield potential in wheat.

Similarly, chlorophyll content measured through SPAD values at harvest stage increased noticeably with foliar treatments. Treatment T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed

extract) recorded the highest SPAD value (48), while the lowest value was observed in T₁ (recommended density without bio-stimulant spray) (40). Increased chlorophyll content in treated plots suggests improved photosynthetic efficiency and delayed leaf senescence due to the beneficial effects of biostimulants and growth regulators. Better chlorophyll retention may have supported higher assimilate production and efficient grain filling during the reproductive stage.

The crop growth rate during the final growth period (90-120 DAS) was also significantly influenced by foliar nutrition and plant growth regulators. The highest CGR was recorded in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) (150 g m⁻² day⁻¹), followed by T₉ (Amino Acid Based PGR @ 6 mL L⁻¹ + Seaweed Extract @ 4 mL L⁻¹) (148 g m⁻² day⁻¹), whereas the lowest value was observed in T₁ (recommended density without bio-stimulant spray) (120 g m⁻² day⁻¹). The higher CGR under treated plots may be associated with enhanced photosynthetic activity, improved nutrient uptake, and greater dry matter accumulation. Relative growth rate gradually declined with crop maturity; however, treated plots maintained significantly higher RGR values than the control. Treatment T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) recorded the highest RGR (0.032 g g⁻¹ day⁻¹), while T₁ (recommended density without bio-stimulant spray) showed the lowest value (0.025 g g⁻¹ day⁻¹). Overall, the combined application of Seaweed extract and amino acid PGR positively influenced crop growth, physiological performance, and biomass accumulation, thereby improving wheat productivity under high-density planting conditions.

3.2 Yield Attributes and Yield

The data presented in Table 3 showed that foliar application treatments had a positive and significant effect on the yield and yield-related traits of wheat grown under high-density planting conditions. Clear differences among the treatments were observed for parameters such as 1000-grain weight, grain yield, straw yield, and harvest index, indicating the beneficial role of biostimulants and plant growth regulators in improving crop growth and productivity. Among all the treatments, T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) performed the best by recording the highest 1000-grain weight (43.87 g), grain yield (52.53 q ha⁻¹), straw yield (52.52 q ha⁻¹), and harvest index (50.0%). On the other hand, the control treatment T₁ (recommended density without bio-stimulant spray) showed the lowest values, with 38.42 g 1000-grain weight, 38.34 q ha⁻¹ grain yield, 42.37 q ha⁻¹ straw yield, and a harvest index of 47.5%.

The improvement in grain weight and grain yield under the treated plots may be due to better movement of photosynthates from leaves to grains, which helped in proper grain filling and increased accumulation of assimilates. The foliar treatments also appeared to improve tillering, chlorophyll content, and overall photosynthetic activity, resulting in greater dry matter production and better utilization of nutrients for grain development. Similarly, the higher straw yield recorded in treated plots reflected improved vegetative growth, increased plant height, and greater biomass accumulation. The higher harvest index observed in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) further indicated that the plants were more efficient in converting total biomass into economic yield, mainly through better partitioning of assimilates towards grain production rather than vegetative parts.

Overall, the combined application of Seaweed extract and amino acid PGR proved highly effective in enhancing crop growth,

grain quality, biomass production, and yield performance of wheat under high-density planting conditions. These findings highlight the importance of foliar nutrition and amino-acid-

based plant growth regulators in improving wheat productivity and supporting sustainable crop production practices.

Table 3: Effect of Various Treatments on Physiological Growth and Yield Attributes and Yield of Wheat

Treatment	No. Of Tillers Per Plant at Harvest	Chlorophyll Content (SPAD Value)	Crop Growth Rate (g/m ² /day)	Relative Growth Rate (g/g/day)	1000 Grain Weight (g)	Grain Yield (q/ha)	Straw Yield (q/ha)	Harvest Index (%)
T ₁	4.2	40	120	0.025	38.42	38.34	42.37	47.5
T ₂	4.5	42	130	0.026	39.15	42.71	45.74	48.3
T ₃	4.7	43	135	0.027	40.67	44.39	46.41	48.9
T ₄	4.9	44	140	0.028	41.22	46.82	48.86	48.9
T ₅	4.8	43	135	0.027	40.29	44.47	46.41	48.9
T ₆	5.0	45	142	0.029	41.43	47.36	49.33	48.9
T ₇	5.2	46	145	0.030	42.11	49.74	50.79	49.5
T ₈	5.1	45	142	0.029	41.57	47.41	49.46	48.9
T ₉	5.3	47	148	0.031	42.78	50.68	51.68	49.5
T ₁₀	5.5	48	150	0.032	43.87	52.53	52.52	50.0

3.3 Economic Analysis

The economic analysis revealed that the cost of cultivation increased from ₹45,600 ha⁻¹ in T₁ (recommended density without bio-stimulant spray) to ₹53,900 ha⁻¹ in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) due to higher input application, foliar sprays, and intensive crop management practices (Table 4). Despite the increased cultivation cost, treated plots recorded higher economic returns than the control. Gross return ranged from ₹99,123.90 ha⁻¹ in T₁ (recommended density without bio-stimulant spray) to ₹1,35,790.05 ha⁻¹ in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) (Table 4) calculated based on the prevailing market price of wheat at ₹2,585 q⁻¹, indicating that foliar nutrition and plant growth regulator application significantly improved crop productivity and profitability. Similarly, net return increased from ₹53,523.90 ha⁻¹ in T₁ (recommended density without bio-stimulant spray) to ₹81,890.05 ha⁻¹ in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹

seaweed extract) (Table 4), reflecting the beneficial effect of enhanced yield over additional input costs. The highest benefit-cost ratio was also observed in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) (2.52), followed by T₈ (Amino Acid Based PGR @ 6 mL L⁻¹ + Seaweed Extract @ 2 mL L⁻¹) (2.51) and T₇ (Amino Acid Based PGR @ 4 mL L⁻¹ + Seaweed Extract @ 6 mL L⁻¹) (2.50), demonstrating superior economic efficiency under these treatments (Table 4). In contrast, the control treatment recorded the lowest B:C ratio (2.17), indicating comparatively lower profitability. These findings suggest that the application of foliar sprays and growth regulators improved input-use efficiency, yield, and economic returns in wheat cultivation under high-density planting conditions. Similar results were reported by Rajala and Peltonen-Sainio (2000) [12] and Shakirova *et al.*, (2003) [14], who observed enhanced profitability and economic efficiency with improved nutrient and growth regulator management practices.

Table 4: Effect of Bio Stimulants and Row Spacing on economics of Wheat cultivation

Treatment	Total Cost (₹/ha)	Gross Return (₹/ha)	Net Return (₹/ha)	B:C Ratio (Gross/Cost)
T ₁	45,600	99,123.90	53,523.90	2.17
T ₂	46,900	110,405.35	63,505.35	2.35
T ₃	48,150	114,743.15	66,593.15	2.38
T ₄	49,230	121,029.70	71,799.70	2.46
T ₅	48,650	114,949.95	66,299.95	2.36
T ₆	50,400	122,425.60	72,025.60	2.43
T ₇	51,410	128,577.90	77,167.90	2.50
T ₈	51,700	129,554.85	77,854.85	2.51
T ₉	52,560	130,507.80	77,947.80	2.48
T ₁₀	53,900	135,790.05	81,890.05	2.52

4. Conclusion

The combined application of high-density planting with foliar sprays of Seaweed extract and amino acid PGR markedly improved wheat growth, yield and economic returns compared with all other treatments. Treatment T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract) consistently performed best, showing superior plant emergence, tillering, leaf area index, chlorophyll content, biomass accumulation, and root development, indicating enhanced nutrient uptake and photosynthetic efficiency. Yield attributes including effective tillers, spike length, grains per spike, test weight, grain, straw, and biological yield were also highest in T₁₀ (6 mL L⁻¹ amino acid PGR + 6 mL L⁻¹ seaweed extract). Post-harvest soil analysis showed slight improvements in pH, EC, organic carbon, and available NPK. Economically, T₁₀ (6 mL L⁻¹ amino acid

PGR + 6 mL L⁻¹ seaweed extract) recorded the highest gross return (₹1,35,790.05 ha⁻¹), net return (₹81,890.05 ha⁻¹), and B:C ratio (2.52). Intermediate treatments showed moderate gains, while control was lowest. Since the present findings are based on a single season of experimentation, further multi-location and multi-season trials are required to validate the consistency, reliability, and practical applicability of this integrated approach for sustainable wheat production under diverse agro-climatic conditions.

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