

RESEARCH ARTICLE

Impact of Exogenous Biostimulants on Growth Performance and Biochemical Quality Traits of French Bean (*Phaseolus vulgaris* L.)

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ABSTRACT

The growing reliance on chemical fertilizers and the associated environmental concerns have highlighted the need for sustainable, eco-friendly crop-nutrition strategies. Biostimulants and beneficial microbial formulations offer promising alternatives for enhancing crop performance while reducing chemical inputs. The experimental trial was conducted to evaluate the effects of foliar spray of bio-inputs, namely humic acid (HA), seaweed extract (SWE), and Effective Microorganisms (EM), applied individually or in combination, on the growth, yield, and quality of French bean (*Phaseolus vulgaris* L.) under sustainable crop production. The field trial was carried out at the Horticultural Research Centre, Chauras Campus, H.N.B Garhwal University, Srinagar (Garhwal), Uttarakhand. The research trial consists of eight treatments, which are arranged in a randomised block design with three replications. Foliar applications were applied at critical crop growth stages, particularly during the vegetative and flowering phases. Among the individual treatments, seaweed extract (SWE) showed the best response, significantly improving the growth, yield, and quality attributes of French bean compared with the control. Among the dual combinations, SWE + EM and HA + EM were the most effective treatments, indicating a positive synergistic interaction that enhanced nutrient availability, physiological efficiency, and yield components. However, the combined application of SWE + HA + EM (T₈) produced the maximum response, recording the highest plant height (212.13 cm), number of pods per plant (67.15), and average pod weight (9.48 g) and pod yield/plot (13.89 kg). This treatment also significantly improved quality parameters, including total carbohydrates (27.62 g/100g), protein content (20.97g/100g), and ascorbic acid (17.83 mg 100 g⁻¹). The superior performance of T₈ was attributed to the synergistic action of biostimulants and effective microorganisms.

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INTRODUCTION

Among leguminous crops, French bean has immense value as a fresh vegetable as well as a pulse crop. Among the beans, it is one of the most popular and

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widely grown crops worldwide due to its short growth cycle, high yield potential, and nutritional richness. Globally, common bean is grown on approximately 35–37 million hectares with an annual production exceeding 28 million tonnes, making it a major source of dietary protein and calories for millions of people (FAO, 2023). In India, French bean is cultivated both as a vegetable (for green pods) and as a pulse crop (for dry seeds), particularly in the states of Himachal Pradesh, Jammu & Kashmir, Uttarakhand, West Bengal, Karnataka, and Maharashtra, where it forms an important component of hill and peri-urban farming systems (ICAR, 2022). The average productivity of green pods ranges from 8 to 12 t ha⁻¹, while dry grain yields vary from 1.0 to 1.5 t ha⁻¹, depending on cultivar and management practices (FAO, 2023).

Nutritionally, French beans are valued for their high content of plant protein (18–25%), complex carbohydrates, and dietary fibre, making them an important crop for combating protein malnutrition (Gepts *et al.*, 1986). The green pods are rich in vitamin C, β -carotene, folates, and minerals such as iron, calcium, magnesium, and potassium, which contribute to immune function and metabolic health (USDA, 2022). Furthermore, French beans contain significant levels of phenolic compounds, flavonoids, and antioxidants, which are associated with a reduced risk of chronic diseases such as diabetes and cardiovascular disorders (Nzaramba *et al.*, 2021).

Despite its agronomic and nutritional importance, French bean productivity is often limited by low soil organic matter, nutrient imbalances, and excessive dependence on chemical fertilizers, which can deteriorate soil health and reduce crop quality in the long term (Rouphael & Colla, 2020). Therefore, there is a growing need for sustainable nutrient management strategies that enhance both yield and nutritional quality without causing environmental degradation.

Biostimulants are defined as substances or microorganisms that, when applied to plants or soil, stimulate natural processes to enhance nutrient uptake, nutrient efficiency, stress tolerance, and crop quality, independent of their nutrient content (Du Jardin, 2015). These biostimulants (HA, SEW and E) are of natural origin, so they are eco-friendly and play a very critical role in soil improvement and soil fertility, ultimately enhancing total plant growth. Humic acid, a major fraction of soil organic matter, plays a significant role in improving soil physical

properties, cation exchange capacity, and nutrient availability, particularly for nitrogen, phosphorus, and micronutrients (Canellas *et al.*, 2015). It has been reported to stimulate root elongation, membrane permeability, chlorophyll synthesis, and enzymatic activity, thereby improving photosynthetic efficiency and biomass accumulation (Calvo *et al.*, 2014). In legumes, humic acid application has been shown to enhance nodulation, nutrient uptake, and yield attributes by promoting better root–soil interactions (Nardi *et al.*, 2021).

Seaweed extract, derived from marine algae such as *Ascophyllum nodosum*, *Sargassum*, and *Kappaphycus*, contains bioactive compounds including auxins, cytokinins, gibberellins, amino acids, vitamins, polysaccharides, and micronutrients (Stirk *et al.*, 2014). Foliar application of seaweed extract enhances seed germination, vegetative growth, flowering, and pod formation by modulating hormonal balance and metabolic activity (Rouphael *et al.*, 2018). It also improves plant tolerance to abiotic stresses such as drought and salinity by regulating osmotic adjustment and antioxidant defence systems (Khan *et al.*, 2009).

Effective Microorganisms (EM) comprise a consortium of beneficial microbes, mainly lactic acid bacteria, photosynthetic bacteria, yeasts, and actinomycetes, that improve soil microbial diversity and nutrient cycling (Ezeagu *et al.*, 2023). EM enhances the decomposition of organic matter, the solubilization of nutrients, and the suppression of soil-borne pathogens, resulting in improved root growth and nutrient-use efficiency (Javaid & Shah, 2011). Application of EM has also been linked with increased synthesis of secondary metabolites and improved crop quality parameters such as protein and vitamin content (Nardi *et al.*, 2021).

The combined application of humic acid, seaweed extract, and Effective Microorganisms often produces synergistic effects, improving plant vigor, pod yield, and phytochemical composition more effectively than individual treatments (Rouphael & Colla, 2020). These biostimulants offer a sustainable alternative to conventional fertilizers and contribute significantly to eco-friendly French bean production systems by improving soil fertility, enhancing nutrient efficiency, and increasing the nutritional quality of produce.

MATERIALS AND METHODS

A field trial was carried out during the Kharif season 2024-25 at the Horticultural Research Centre (HRC), Chauras Campus, Department of Horticulture, Hemvati Nandan Bahuguna Garhwal University, Srinagar (Garhwal), Uttarakhand. The study assessed the impact of foliar applications of biostimulants on growth, yield, and quality parameters of French bean (*Phaseolus vulgaris* L.). The experimental site is located in a semi-arid subtropical zone and experiences hot summers (max. 35 °C), cold winters (min. ~2 °C), and annual rainfall of 500–800 mm, primarily during the monsoon.

The experimental soil was sandy loam, slightly saline (pH 7.62; EC 0.48 dS m⁻¹), low in organic carbon (0.34%), available N (134.25 kg ha⁻¹) and P (13.25 kg ha⁻¹), and medium in available K (320 kg ha⁻¹). The experiment followed a Randomized Block Design (RBD) with three replicates. Eight treatments were tested, *i.e.*, T₁ (water spray control); T₂ [seaweed extract (SWE) @ 0.2% or 2 ml L⁻¹]; T₃ [humic acid (HA) @ 0.2% or 2 g L⁻¹]; T₄ [effective microorganisms (EM) @ 0.2% or 2 ml L⁻¹]; T₅ (SWE + HA); T₆ (SWE + EM); T₇ (HA + EM); T₈ (SWE + HA + EM). Foliar sprays were applied manually at 30, 45, and 60 days after sowing. The French bean variety Local Cultivar was sown, adhering to standard agronomic protocols across treatments. Observations were recorded and analyzed using ANOVA for RBD, with significance tested at $p \leq 0.05$.

RESULTS AND DISCUSSION

The results revealed that exogenous application of biostimulants significantly influenced the vegetative growth, yield attributes, pod quality, and phytochemical quality of French bean (*Phaseolus vulgaris* L.) compared to the untreated control.

Vegetative Growth

The results indicated that the exogenous application of biostimulants significantly enhanced the vegetative growth of French bean (*Phaseolus vulgaris* L.) compared with the untreated control (Table 1). All biostimulant treatments enhanced plant height, leaf number, and chlorophyll content to varying degrees.

Among the individual treatments, seaweed extract recorded higher plant height (176.947 cm) and leaf number (12.53/plant) than humic acid (191.453 cm) and Effective Microorganisms (185.607 cm). However, the combined application of humic acid + seaweed

extract + Effective Microorganisms (T₈) produced the maximum plant height (212.137cm), number of leaves per plant (16.70), and chlorophyll content (42.370 SPAD/mg g⁻¹). The lowest values for these parameters were observed in the control treatment, which recorded a plant height of only 162.187 cm and a chlorophyll content of 35.977 SPAD/mg g⁻¹. This response may be attributed to the presence of natural growth regulators in seaweed extract (Khan *et al.*, 2009) and improved nutrient availability due to humic acid (Canellas *et al.*, 2015). A similar enhancement in the vegetative growth of French bean due to biostimulants was reported by Howida & Kader (2025) and Roupheal & Colla (2020).

The improvement in vegetative growth under biostimulant application may be attributed to the presence of natural growth regulators, such as auxins and cytokinins, in seaweed extract, which stimulate cell division and leaf addition, as well as leaf expansion. Humic acid enhances root development and nutrient absorption by improving soil structure and cation exchange capacity, while Effective Microorganisms increase microbial activity and nutrient mineralization in the rhizosphere. The synergistic action of these biostimulants under combined treatment likely enhanced photosynthetic efficiency and biomass accumulation, resulting in superior vegetative growth.

Yield and Yield Attributes

Biostimulant application significantly affected yield and yield-related traits, including the number of pods per plant, pod weight, and total pod yield (Table 1). The highest number of pods per plant (67.153) was observed under the combined treatment (T₈), which was significantly higher than the control (51.683). Similarly, the highest average pod weight (9.480g) was recorded under T₈.

Total pod yield was markedly enhanced by biostimulant application. The highest total pod yield (13.89 kg/plot) was obtained in treatment T₈ (SWE+HA+EM), followed by HA + EM (10.61 kg/plot) and SWE + HA (10.55 kg/plot), whereas the lowest total pod yield (8.53kg/plot) was observed in the control treatment. Increased yield may be associated with improved photosynthetic activity and better assimilate partitioning towards reproductive organs (Hilles *et al.*, 2026). Seaweed extract improves hormonal balance and sink–source relations (Khan *et al.*, 2009), while Effective Microorganisms enhance nutrient cycling and

reduce stress effects (Ezeagu *et al.*, 2023), thereby increasing productivity. The increase in yield may be attributed to improved vegetative growth, higher photosynthate production, and enhanced partitioning of assimilates towards reproductive organs, resulting in improved pod formation and development.

Pod Quality

Pod attributes, including pod length, pod diameter, pod texture, and dry matter content, were significantly influenced by biostimulant treatments (Table 1). The longest pods (16.083cm) were recorded under the combined treatment (T₈) (SWE+HA+EM), followed by HA + EM (15.64cm), while the shortest pods (12.410cm) were observed in the control treatment.

Pod diameter showed non-significant or marginal variation among treatments, ranging from 8.387mm to 8.867mm. Dry matter content was also enhanced under combined treatment T₈ (SWE + HA + EM), recording 7.913%, compared with 5.877% in the control. This may be due to enhanced cell division and elongation induced by growth-promoting substances in seaweed extract (Stirk *et al.*, 2014) and to improved nutrient translocation facilitated by humic acid (Canellas *et al.*, 2015). Comparable results were reported by Howida & Kader (2025) in French bean. The improvement in pod attributes may be attributed to better cell division and elongation induced by growth regulators present in the seaweed extract, and to improved nutrient uptake facilitated by humic acid and EM. Increased dry matter accumulation reflects enhanced photosynthate synthesis and translocation to pods.

Phytochemical and Quality Parameters

Significant variations were observed in quality parameters, including protein (g/100g DW) and carbohydrate (g/100g DW) content, ascorbic acid (mg/100g FW), and chlorophyll concentrations, due to different biostimulant treatments (Table 1). The highest protein content (20.97g) and total carbohydrates (27.62g) were recorded under the combined application of humic acid, seaweed extract, and Effective Microorganisms (T₈), followed by the HA + EM treatment (19.26 g protein), whereas the control treatment exhibited the lowest protein (15.783g) and carbohydrate content (22.203g). The enhancement in protein content may be attributed to improved nitrogen uptake and assimilation under biostimulant application, which stimulates enzymatic activity involved in amino acid and protein synthesis

(Calvo *et al.*, 2014; Chen & Aviad, 1990). Similarly, the increase in carbohydrate content could be associated with improved photosynthetic efficiency and the translocation of assimilates to developing pods under the influence of growth-promoting substances present in seaweed extract, and with improved nutrient availability facilitated by humic acid.

Ascorbic acid content was also significantly influenced by biostimulant application, with the maximum value (17.827 mg 100 g⁻¹) recorded in T₈ and the minimum (15.073 mg 100 g⁻¹) in the control. The increase in ascorbic acid may be attributed to enhanced metabolic activity and stimulation of antioxidant pathways under biostimulant treatments, as seaweed extract is known to promote vitamin biosynthesis and stress-related antioxidant responses (Khan *et al.*, 2009). Likewise, chlorophyll content in pods was highest under the combined treatment (44.133 mg g⁻¹) and lowest in the control (40.157 mg g⁻¹), indicating improved chlorophyll synthesis and delayed senescence due to enhanced nutrient uptake and hormonal balance under biostimulant application (Canellas *et al.*, 2015).

Fiber content showed an inverse trend, with the lowest fiber percentage (11.487g/100g) recorded under the combined treatment T₈ (SWE+HA+EM) suggesting improved pod tenderness and market quality, while the control treatment registered the highest fiber content (13.417g/100g). The reduction in fiber content may be due to improved cell wall modification and a greater allocation of assimilates to pod development rather than to structural components. Effective Microorganisms further enhance nutrient transformation and the synthesis of bioactive compounds by enhancing microbial activity in the rhizosphere (Htwe *et al.*, 2021). These results collectively indicate that the integrated application of humic acid, seaweed extract, and Effective Microorganisms exerts a synergistic effect on biochemical composition, leading to improved nutritional and market quality of French bean pods.

The enhancement in phytochemical quality under biostimulant application may be attributed to increased metabolic activity and stimulation of enzymatic processes involved in protein and carbohydrate synthesis. Seaweed extract promotes the accumulation of vitamins and sugars, humic acid facilitates nutrient absorption

Table 1. Effect of Seaweed Extract, Humic Acid, and Effective Microorganisms on Growth, Yield, and Quality Parameters of French Bean (*Phaseolus vulgaris* L.)

Sr. Treatment N.	Plant Height (cm)	No. of leaves/ Plant	Total chlorophyll (SPAD)	Pod weight / plant (g)	No. of pods/ plant	Total pod yield/ plot (kg)	Pod length (cm)	Pod diameter (mm)	Dry matter (%)	Fiber g/100g D.W.	Protein g/100g D.W.	Ascorbic acid (mg/100 g f.w.)	Total chlorophyll (mg/100 g f.w.)	Carbohydrate g/100g D.W.
1 Control	162.187	12.110	35.977	7.993	51.683	8.53	12.410	8.387	5.877	13.417	15.783	15.073	40.157	22.203
2 SWE	176.947	12.530	38.250	8.510	52.897	9.14	13.387	8.460	6.427	13.377	17.437	15.520	41.007	23.733
3 HA	191.453	15.163	39.203	8.797	56.190	10.27	14.560	8.643	6.867	12.833	18.053	16.090	41.460	24.333
4 EM	185.607	15.017	39.030	8.880	54.613	9.53	13.897	8.513	6.430	12.847	17.580	15.933	41.747	24.547
5 SWE+HA	210.160	17.683	39.327	9.420	57.047	10.55	14.580	8.737	7.160	12.337	18.543	16.760	41.913	24.887
6 SWE+EM	192.303	15.237	39.273	8.657	55.917	10.15	14.837	8.410	6.597	12.590	18.420	16.743	41.400	25.137
7 HA+EM	209.553	16.713	40.570	8.977	59.010	10.61	15.640	8.757	7.607	11.877	19.263	17.183	43.213	26.037
8 SWE+HA+EM	212.137	16.700	42.370	9.480	67.153	13.89	16.083	8.867	7.913	11.487	20.970	17.827	44.133	27.620
S.Em. +	5.240	0.544	0.417	0.247	1.120	3.663	0.261	0.120	0.201	0.265	0.306	0.109	0.209	0.265
C.D. 5%	16.049	1.665	1.278	0.757	3.429	11.218	0.799	0.628	0.614	0.810	0.936	0.335	0.640	0.813

*SWE: seaweed extract; HA: Humic acid; EM: effective microorganism; DW: dry weight; FW: fresh weight



and protein formation, while Effective Microorganisms improve nutrient cycling and synthesis of bioactive compounds. The reduction in fiber content under combined application indicates better cell wall modification and improved pod texture.

CONCLUSION

This study reveals that foliar application of biostimulants markedly enhanced vegetative growth, yield, pod characteristics, and phytochemical quality in French bean (*Phaseolus vulgaris* L.). The integrated treatment combining humic acid (HA), seaweed extract (SWE), and effective microorganisms (EM) T₈ yielded the most pronounced improvements, including superior pod metrics and elevated levels of protein, carbohydrates, ascorbic acid, and chlorophyll, as well as reduced fiber content. These improvements can likely be attributed to enhanced nutrient mobilization, heightened physiological activity, and complementary interactions among the biostimulants. Overall, the combined HA + SWE + EM approach emerges as a sustainable, environmentally sound option to boost French bean productivity and nutritional quality in field settings.

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Ethics Statement

This study complied with institutional guidelines of H.N.B. Garhwal University and national responsible conduct in plant research. No human or animal subjects were involved.

Originality and Plagiarism

This work is original, unpublished elsewhere, and not under consideration by another journal. All sources are appropriately cited to maintain academic integrity.

Consent for Publication

All authors consent to publication of this manuscript in its present form.

Competing Interests

The authors declare no competing interests.

Data Availability

All data supporting the findings are available within the article and its supplementary materials.

Author Contributions

The study was conceptualized with innovative methodology for French bean analysis. Field data was meticulously collected, rigorously analyzed, and visualized effectively. The manuscript was drafted, revised collaboratively, and approved by all authors.

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