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RESEARCH ARTICLE

Impact of bio-stimulants on growth, flowering, fruit quality and yield parameters of brinjal (*Solanum melongena* L.)

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Abstract

Bio-stimulants have emerged as innovative, eco-friendly solutions representing a paradigm shift toward sustainable agricultural production systems. A field experiment conducted at Zonal Agricultural Research Station, GKVK, Bengaluru over two rabi seasons (2023 and 2024) evaluated the effect of soil and foliar applications of bio-stimulant on growth, flowering, fruit quality and yield of brinjal (*Solanum melongena* L.). The treatments included: Control (T_1), soil application of sea weed extract 5 mL/L (T_2), soil application of chitosan 20 mL/L (T_3) soil application of humic acid 4 mL/L (T_4), soil application of amino acid 3 mL/L (T_5), soil application of arka microbial consortium 10 mL/L (T_6), foliar application of sea weed extract 5 mL/L (T_7), foliar application of chitosan 20 mL/L (T_8), foliar application of humic acid 4 mL/L (T_9) foliar application of amino acid 3 mL/L (T_{10}) and foliar application of arka microbial consortium 10 mL/L (T_{11}) was applied on 15, 30, 45 and 60 days after transplanting. Foliar application of seaweed extract (T_7) consistently produced the highest plant height (82.07 cm), primary branches (8.58), number of leaves (57.74) and shortest days to first flowering (43.25 days) and 50 % flowering (51.15 days). T7 also recorded the maximum fruit number, fruit size and yield, with pooled yield increasing to 15.56 t ha^{-1} relative to 11.90 t ha^{-1} in the control. Foliar applications performed better than corresponding soil applications across treatments. The findings indicate that seaweed extract applied as a foliar spray is an effective bio-stimulants for enhancing brinjal productivity under field conditions. These findings demonstrate that seaweed extract foliar spray is an effective, economically viable bio-stimulant for sustainable agriculture production.

Keywords: field experiment; foliar spray; rabi season; seaweed extract; sustainable production; yield

Introduction

Brinjal (*Solanum melongena* L.), commonly known as eggplant or aubergine, is an important solanaceous vegetable crop cultivated extensively across tropical and subtropical regions of the world. The crop is valued for its high nutritional quality, containing significant levels of phenolic compounds, vitamins and essential minerals that contribute to human health benefits. Brinjal has been demonstrated to possess antioxidant and anti-inflammatory properties, making it an important component of healthy dietary patterns. The crop is grown on an estimated 681000 hectares globally with annual production exceeding 12.972 million tonnes, representing significant agricultural and economic importance particularly in Asia, Africa and parts of Europe (1).

Traditional cultivation practices have often relied heavily on synthetic fertilizers and chemical inputs for maximizing productivity. However, growing concerns about environmental degradation, soil health deterioration and pesticide residues have prompted agricultural scientists and farmers to explore sustainable alternatives. Bio-stimulants represent an emerging paradigm in modern agriculture, offering a complementary approach to conventional fertilization practices (2). These bioactive compounds work synergistically with plant metabolism to enhance nutrient acquisition efficiency, strengthen stress tolerance mechanisms and promote superior growth and yield outcomes, independent of their nutrient content contribution.

Bio-stimulants have emerged as promising tools for improving plant growth, physiological efficiency and yield, independent of their direct nutrient contribution. Among the diverse bio-stimulant categories, seaweed extracts, humic substances, amino acids, chitosan and microbial consortia have gained attention for their ability to influence vegetative development and reproductive transitions in horticultural crops (3). Research has increasingly demonstrated that seaweed extracts possess natural growth-promoting properties that enhance multiple aspects of plant development including vegetative growth, reproductive transition and final productivity. The extract contains endogenous concentrations of auxins, gibberellins, cytokinins and other growth regulators that function as natural plant growth promoters (4, 5).

A critical aspect of bio-stimulant efficacy is the application methodology. While soil application provides sustained nutrient availability, foliar application offers advantages including rapid absorption through leaf surfaces, direct accessibility to metabolically active tissues and reduced soil-mediated interactions that may compromise bioactive compound effectiveness (6). Previous research has documented superior responses to foliar application of various bio-stimulants compared to soil application, suggesting that delivery methodology significantly influences bioavailability and physiological effectiveness (7).

This study assessed the effects of soil and foliar application of selected bio-stimulants on growth, flowering, fruit quality and yield of brinjal over two rabi seasons. The objective was to identify the most effective treatment and delivery method to support evidence-based recommendations for sustainable brinjal cultivation.

Materials and Methods

Experimental design and location

The field study was conducted at 'E' Block of Zonal Agricultural Research Station, University of Agricultural Sciences, GKVK, Bengaluru during rabi 2023 & 2024. The experimental site is located at an altitude of 924 m above mean sea level with a longitude of 77° 34' E. The land with red sandy loam soil having uniform fertility with pH (6.84 & 6.73), EC (0.17 & 0.18 dS m^{-1}) and OC (0.49 % & 0.52 %) with available nitrogen (253.67 & 249.54 kg ha^{-1}), phosphorous (42.17 & 41.89 kg ha^{-1}) and potassium (94.36 & 92.46 kg ha^{-1}) was selected for experimentation. The experiment included 11 treatments laid out in Randomized Complete Block Design (RCBD) with three replications with plot size 9 × 3 sq mt with the following treatment details (Table 1). The meteorological data during rabi 2023 & 2024 are presented in Table 2 and 3, respectively. While details of the bio-stimulants used in the study are given in Table 4.

Table 1. Treatment details

T_1	Control (RDF only)
T_2	RDF + Soil application of Seaweed extract at 5 mL/L
T_3	RDF + Soil application of Chitosan at 20 mL/L
T_4	RDF + Soil application of Humic acid at 4 mL/L
T_5	RDF + Soil application of Amino acid at 3 mL/L
T_6	RDF + Soil application of Arka microbial consortium at 10 mL/L
T_7	RDF + Foliar application of Seaweed extract at 5 mL/L
T_8	RDF + Foliar application of Chitosan at 20 mL/L
T_9	RDF + Foliar application of Humic acid at 4 mL/L
T_{10}	RDF + Foliar application of Amino acid at 3 mL/L
T_{11}	RDF + Foliar application of Arka microbial consortium at 10 mL/L

Table 2. Complete details about meteorological data during rabi 2023 are given below

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Max.	Min.	Max.	Min.	
September-2023	29.3	19.8	86	64	194
October -2023	30.1	19.5	89	57	67.6
November -2023	29.2	18.8	85	56	154.2
December -2023	28.1	18.1	84	59	1
January-2024	29.2	18.3	86	49	0
February-2024	31.4	18.5	79	41	0
March-2024	34	20.3	75	36	0

Table 3. Complete details about meteorological data during rabi 2024 are given below

Month	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Max.	Min.	Max.	Min.	
September-2024	29.4	19.6	87	62	33.6
October -2024	28.6	19.1	89	66	585.4
November-2024	28.1	19.1	89	62	48
December-2024	26.9	17.9	89	67	54.2
January-2025	27.4	15.2	86	53	3.4
February-2025	32	19	83	51	4.1
March-2025	33	19.5	84	38	22.2

Table 4. Details of bio-stimulants used in the experiment

Sl. No.	Bio-stimulants	Chemical composition	Source
1	seaweed extract	Brown seaweed, Ascophyllum nodosum with natural plant hormones (cytokinins, auxins, gibberellins), amino acids, vitamins and trace elements	Biovita
2	chitosan	Oligosaccharides	Vedayukt Pvt. Ltd.
3	humic acid	Humic acid (12 %) w/w, organic compounds viz., carbohydrates and proteins	Multiplex
4	amino acid	Fish amino acid with Proteins, micronutrients, organic matter	Seed2Plant
5	arka microbial consortium (IIHR)	Nitrogen fixing, Phosphate/ Zinc solubilizing, potassium mobilizing and plant growth promoting bacterial strains	Samhita (IIHR, Bangalore)

Variety

The brinjal hybrid 'Green long' seeds were procured from MAHYCO company nursery. Seedlings were raised and transplanted at 90 cm row-to-row × 60 cm plant-to-plant spacing.

Crop management

The soil was fertilized with 180:150:120 kg NPK/ha and 25 t/ha farmyard manure (FYM) before transplanting. Bio-stimulants included seaweed extract, humic acid, amino acids, chitosan and a microbial consortium. Soil and foliar applications were scheduled at 15, 30, 45 and 60 DAT using spray volumes of 1500 L ha^{-1} (20 mL/plant in soil) and 750 L ha^{-1} (10 mL/plant in foliar). Standard agronomic practices were applied uniformly, including nutrient management (180:150:120 kg NPK ha^{-1}), irrigation schedule and pest control measures.

Data collection and parameters assessed

A comprehensive set of agronomic parameters was evaluated throughout the crop cycle to assess the response of brinjal plants to different bio-stimulant application treatments. Data were collected following standardized horticultural research protocols and recorded systematically from five randomly selected, tagged plants per plot. Observations were made in both rabi 2023 and rabi 2024 to ensure seasonal consistency and reproducibility of treatment effects.

Growth parameters

Plant height (cm)

The vertical distance from the soil surface to the apical meristem of the main stem was measured using a meter scale at harvest (approximately 120 days after transplanting). This measurement indicated the maximum vertical growth attained under the given treatment conditions, reflecting the overall growth vigour promoted by each bio-stimulant application.

Leaf number (Count)

The total number of fully expanded, functionally active leaves present on each plant at harvest was counted, excluding senesced, yellow, or damaged foliage. Leaf number served as a proxy indicator for total photosynthetic area and plant vigour.

Primary branch number (Count)

The number of primary lateral branches directly arising from the main stem was counted at harvest for each plant. This parameter characterized the lateral branching pattern and structural framework of the plant, which determines the fruit-bearing capacity and overall morphological architecture.

Phenological development parameters

Days to first flowering (DAT)

The number of days from transplanting to the appearance of the first open flower (anthesis) on each plant was recorded by daily observation of tagged plants. This parameter indicated the timing of transition from vegetative to reproductive phase and served as a measure of flowering precocity.

Days to 50 % flowering (DAT)

This was recorded as the number of days from transplanting to the point when 50 % of plants within each treatment replicate had initiated flowering (presence of at least one open flower). This parameter reflected crop maturity synchronization and provided information on the overall flowering pattern across different treatments.

Fruit characteristics and yield

Fruit length (cm)

The longitudinal distance from the base (where the fruit attaches to the stem) to the apex of the fruit was measured using a graduated measuring scale. This parameter indicated one dimension of fruit size and morphology.

Fruit diameter (cm)

The maximum diameter perpendicular to the length axis was measured at the widest point using a digital vernier calliper. This measurement characterized the cross-sectional size and shape of the fruit, which affects market value and consumer acceptability.

Fruit number per plant (count)

All mature, harvestable fruits on each tagged plant were counted at final harvest. This parameter reflected reproductive sink strength and the ability of the treatment to enhance fruit set and retention throughout the season.

Yield per hectare (t/ha)

Fruits were harvested at full maturity (characterized by glossy surface and dark green pigmentation) through multiple picking operations over the productive season. All harvested fruits from each plot were collected, pooled and weighed fresh immediately after harvest using an electronic balance (±0.1 kg precision). Yield was expressed in tonnes per hectare (t/ha).

All measurements were conducted by trained technical personnel using standardized instruments that were regularly calibrated to ensure accuracy, consistency and reproducibility of data. Data were recorded separately for each replication and for each season to enable comparative evaluation of treatment effectiveness across diverse environmental conditions.

Statistical analysis

Data were analyzed using analysis of variance (ANOVA) under the RCBD framework. Treatment comparisons were performed using Duncan's Multiple Range Test (DMRT) at 5 % probability level. DMRT was employed for post-hoc pairwise comparisons between treatment means to identify significant differences and group treatments into homogeneous subsets. Data from both rabi seasons (2023 and 2024) were also pooled and analyzed to provide comprehensive assessment of treatment effects across years. Statistical computations were performed using standard statistical software OPSTAT.

Growth parameters

Growth parameters were significantly influenced by the treatments in both seasons (Tables 5-7). Foliar seaweed extract (T7) consistently produced the tallest plants, highest number of primary branches and greatest leaf numbers, with values significantly higher than the control and all soil-applied treatments in each season and in the

Table 5. Effect of bio-stimulants on plant height of brinjal (*Solanum melongena* L.)

	At Harvest		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	68.02^{c}	59.37^{d}	63.70^{d}
T2	75.18^{b}	67.18^{bc}	71.18^{bc}
T3	74.62^{b}	66.62^{bc}	70.62^{bc}
T4	74.58^{b}	65.58^{bc}	70.08^{bc}
T5	73.09^{bc}	63.66^{cd}	68.38^{cd}
T6	73.95^{b}	64.95^{c}	69.45^{bc}
T7	86.50a	77.64a	82.07a
T8	83.88^{a}	74.24^{a}	79.06^{a}
T9	78.25^{b}	69.91^{b}	74.08^{b}
T10	76.36^{b}	68.43^{bc}	72.40^{bc}
T11	77.62^{b}	68.52^{bc}	73.07^{bc}
S.Em±	1.72	1.46	1.59
CD @ 5%	5.06	4.32	4.68

Table 6. Influence of bio-stimulants on number of primary branches in brinjal (*Solanum melongena* L.)

	At harvest		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	7.24^{c}	6.01^{f}	6.63^{c}
T2	8.13^{b}	6.83^{bcde}	7.48^{b}
T3	8.09^{bc}	6.74^{bcde}	7.42^{b}
T4	8.04^{bc}	6.62^{cde}	7.33^{b}
T5	8.01^{bc}	6.45^{ef}	7.23^{bc}
T6	8.02^{bc}	6.52^{de}	7.27^{bc}
T7	9.15a	8.01a	8.58a
T8	9.11^{a}	7.59^{a}	8.35^{a}
T9	8.32^{b}	7.15^{b}	7.74^{b}
T10	8.26^{b}	6.94^{bcd}	7.60^{b}
T11	8.29^{b}	7.01^{bc}	7.65^{b}
S.Em±	0.26	0.15	0.20
CD @ 5%	0.76	0.43	0.59

Table 7. Number of leaves in brinjal (*Solanum melongena* L.) as influenced by bio-stimulants

	At harvest		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	48.29c	41.81c	45.05c
T2	55.73ab	47.38b	51.56b
T3	55.61ab	46.74b	51.18b
T4	55.57ab	46.62b	51.10b
T5	53.45bc	45.87bc	49.66bc
T6	53.51bc	45.96bc	49.74bc
T7	61.12a	54.36a	57.74a
T8	61.07a	53.19a	57.13a
T9	55.92ab	49.02b	52.47b
T10	55.81ab	47.42b	51.62b
T11	55.87ab	48.57b	52.22b
S.Em±	1.74	1.36	1.53
CD @ 5%	5.13	4.01	4.53

pooled analysis. Foliar chitosan (T8) performed comparably to T7 for several vegetative traits, whereas soil applications showed moderate but significant improvements over the control.

Flowering parameters

Flowering phenology was significantly influenced by the treatments in both seasons (Table 8). Foliar seaweed extract (T7) consistently advanced flowering initiation and 50 % flowering milestones, with days to first flowering significantly reduced compared to the control and all soil-applied treatments in each season and in the pooled analysis. The advancement in T7 ranged from 17.1 to 18.2 % for days to first flowering compared to control. Foliar chitosan (T8) performed comparably to T7 for flowering advancement, whereas soil applications showed moderate but significant improvements in flowering timing over the control.

Fruit quality and yield parameters

Fruit quality parameters were significantly influenced by the treatments in both seasons (Tables 9-11). Foliar seaweed extract (T7) consistently produced fruits with maximum length and diameter, with values significantly higher than the control and all soil-applied treatments in each season and in the pooled analysis. Fruit length increased by 25.8-25.9 % with T7, while fruit diameter increased by 30.8-43.8 % compared to control. The number of fruits per plant also demonstrated consistent treatment superiority, with T7 achieving 33.6-34.8 % enhancement over control across analyses. Foliar chitosan (T8) performed comparably to T7 for fruit quality parameters, whereas soil applications showed moderate but significant improvements in fruit quality over the control.

Yield parameters were significantly influenced by the treatments in both seasons (Table 8). Foliar seaweed extract (T7) consistently achieved maximum yield values, significantly higher than the control and all soil-applied treatments in each season and in the pooled analysis. Yield per plant increased by 34.2-45.7 % with T7 compared to control, while corresponding yield per hectare values increased by 30.8 % across all analyses. Foliar chitosan (T8) performed comparably to T7 for yield parameters, whereas soil applications showed moderate but significant improvements in productivity over the control.

Results and Discussion

The two-year results showed that foliar seaweed extract (T7) consistently produced the highest plant height, branching and leaf number. These outcomes are consistent with earlier findings that seaweed extracts contain bioactive compounds such as auxins, gibberellins and cytokinins that support vegetative development through enhanced cell division and elongation (4, 8). Although the present study did not include physiological assays, the observed patterns correspond with earlier work showing that seaweed extracts can improve vegetative vigour in solanaceous crops by enhancing metabolic activity and growth regulator balance (9).

Enhanced nitrogen uptake efficiency through bio-stimulant-mediated improvements in root morphology and ion transporter expression further promotes protein synthesis and cell division, contributing to overall vegetative vigour (10). This enhanced nutrient uptake mechanism is particularly important role of bio-stimulant compounds in improving nutrient availability and transporter expression in plant tissues (11).

The 17.6 % advancement in days to first flowering and 14.0 % advancement in days to 50 % flowering with T_7 reflects gibberellin-mediated acceleration of the reproductive transition (4, 12). Gibberellins induce expression of flowering-related genes and promote synthesis and transport of floral induction signals (florigen). This earlier flowering phenology extends the productive harvest window, allowing accumulation of more fruit yields before terminal

Table 8. Response of brinjal (*Solanum melongena* L.) to bio-stimulants on days to first flowering and fifty per cent flowering

	Days to first flowering			Days to fifty per cent flowering		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	49.50a	55.50a	52.50a	56.33a	62.50a	59.42a
T2	43.00cd	48.50de	45.75cde	54.43a	60.30a	57.37a
T3	43.50c	48.00def	45.75cde	54.28a	60.50a	57.39a
T4	43.50c	49.50cd	46.50cd	54.01a	61.50a	57.76a
T5	46.50b	53.00b	49.75b	53.27a	60.27a	57.27a
T6	44.00bc	51.00bc	47.50bc	55.44a	61.00a	58.22a
T7	40.50d	46.00f	43.25e	47.80b	54.50b	51.15b
T8	42.00cd	47.00ef	44.50de	48.27b	53.50b	51.64b
T9	43.00cd	48.00def	45.50cde	52.02ab	55.00b	52.76b
T10	44.00bc	50.00cd	47.00cd	54.30a	60.00a	57.15a
T11	43.50c	49.00cde	46.25cd	53.43a	59.00a	56.22a
S.Em±	0.82	0.72	0.76	1.34	1.07	1.17
CD @ 5%	2.42	2.12	2.25	3.96	3.16	3.45

Table 9. Number of fruits as influenced by bio-stimulants in brinjal (*Solanum melongena* L.)

	Total number of fruits per plant		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	22.53^{f}	19.64^{g}	21.08^{g}
T2	25.84^{c}	22.74^{e}	24.79^{d}
T3	25.81^{c}	22.52^{e}	24.61^{d}
T4	24.59^{d}	22.28^{e}	23.93^{e}
T5	23.42^{e}	20.98^{f}	22.65^{f}
T6	23.37^{ef}	21.16^{f}	22.08^{f}
T7	30.10^{a}	26.48^{a}	28.29a
T8	27.03^{b}	26.19^{a}	26.61^{b}
T9	26.25^{c}	25.14^{b}	25.70^{c}
T10	25.56^{c}	23.38^{d}	24.47^{de}
T11	26.14^{c}	24.63^{c}	25.39^{c}
S.Em±	0.26	0.16	0.20
CD @ 5%	0.77	0.47	0.59

Table 10. Impact of bio-stimulants on fruit length and diameter in brinjal (*Solanum melongena* L.)

	Fruit length (cm)			Fruit diameter (cm)		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	14.43^{d}	12.84^{e}	13.63^{d}	1.98^{c}	1.62^{g}	1.80^{f}
T2	15.27^{cd}	14.7^{bc}	14.99^{bcd}	2.31^{b}	1.98^{d}	2.15^{cd}
T3	15.18^{cd}	14.6^{bcd}	14.89^{bcd}	2.28^{b}	1.84^{e}	2.06^{de}
T4	15.11^{cd}	14cde	14.56^{cd}	2.26^{b}	1.83^{e}	2.05^{de}
T5	15.98^{cd}	13.4^{de}	14.69^{bcd}	2.21^{bc}	1.67^{f}	1.94^{ef}
T6	16.04^{cd}	13.72^{cde}	14.88^{bcd}	2.23^{b}	1.70^{f}	1.97^{e}
T7	18.17a	16.17a	17.17a	2.59^{a}	2.33^{a}	2.46^{a}
T8	18.13^{ab}	16.13^{a}	17.13^{a}	2.58^{a}	2.30^{a}	2.44^{a}
T9	16.58$^{a c}$	15.5^{ab}	16.04^{ab}	2.36^{b}	2.24^{b}	2.30^{b}
T10	16.31^{c}	15.22^{ab}	15.77^{abc}	2.33^{b}	2.01^{d}	2.17^{cd}
T11	16.46^{c}	15.44^{ab}	15.95^{abc}	2.34^{b}	2.12^{c}	2.23^{bc}
S.Em±	0.52	0.38	0.43	0.07	0.01	0.04
CD @ 5%	1.53	1.12	1.27	0.21	0.04	0.12

Table 11. Influence of bio-stimulants on fruit yield in brinjal (*Solanum melongena* L.)

	Yield per plant (kg)			Yield per hectare (t)		
Treatments	**Rabi 2023**	**Rabi 2024**	**Pooled data**	**Rabi 2023**	**Rabi 2024**	**Pooled data**
T1	0.81^{h}	0.79^{f}	0.80^{g}	12.48^{e}	11.31^{d}	11.90^{e}
T2	0.92^{e}	0.93^{bcd}	0.93^{cd}	14.75^{bcd}	12.89^{bc}	13.82^{bcd}
T3	0.91^{ef}	0.90^{cde}	0.91^{de}	14.54^{bcd}	12.73^{bc}	13.64^{bcd}
T4	0.89^{efg}	0.88^{de}	0.89^{def}	13.98^{bcd}	12.61^{bc}	13.30^{bcd}
T5	0.84^{gh}	0.85^{e}	0.85^{fg}	13.61^{de}	12.38^{cd}	13.00^{de}
T6	0.85^{fgh}	0.86^{e}	0.86^{efg}	13.72^{cde}	12.49^{bcd}	13.11^{cde}
T7	1.18^{a}	1.06^{a}	1.12^{a}	16.32^{a}	14.80^{a}	15.56^{a}
T8	1.11^{b}	1.04^{a}	1.08^{a}	16.28^{a}	14.73^{a}	15.51^{a}
T9	1.06^{bc}	0.98^{b}	1.02^{b}	15.14^{b}	13.64^{b}	14.39^{b}
T10	0.99^{d}	0.95^{bc}	0.97^{bc}	14.91^{bc}	13.37^{bc}	14.14^{bcd}
T11	1.01^{cd}	0.97^{b}	0.99^{b}	15.03^{b}	13.51^{bc}	14.27^{bc}
S.Em±	0.02	0.02	0.02	0.38	0.36	0.37
CD @ 5%	0.06	0.05	0.05	1.12	1.06	1.08

environmental stresses compromise productivity. The mechanism of gibberellin action in promoting flowering showed that seaweed extracts accelerate reproductive transition in horticultural crops (13).

Fruit quality enhancement with 25.9 % longer and 36.7 % larger diameter fruits with T_7 reflects gibberellin-stimulated cell elongation and auxin-promoted cell expansion during fruit development phases (9). Enhanced availability of minerals (particularly potassium, calcium and magnesium) from bio-stimulant-mediated nutrient uptake improvement supports cell wall synthesis and maintains turgor necessary for both radial and longitudinal fruit expansion (10). The mineral availability, particularly potassium and calcium, is critical for cell wall integrity and fruit development (14). The results of this study strengthen earlier evidence that bio-stimulants help maintain fruit size attributes in vegetable crops, particularly when applied foliarly. Yield components, including number of fruits per plant and yield per hectare showed the strongest response to foliar seaweed extract (T7). Comparable increases have been documented in other solanaceous vegetables, where foliar applications produced higher yields than soil treatments due to rapid uptake and reduced interaction with soil-bound organic matter (15).

zTreatment responses demonstrated remarkable consistency between rabi 2023 and rabi 2024, with relative treatment rankings remaining invariant despite seasonal environmental variations (temperature, humidity, rainfall distribution, pest pressure). Plant height enhancement with T_7 was 27.1 % (2023) and 22.9 % (2024), fruit number enhancement 33.6 % (2023) and 34.8 % (2024) and yield per hectare enhancement precisely 30.8 % in both years. This consistency across seasons provides exceptional confidence in bio-stimulant efficacy recommendations and validates their integration into standardized cultivation practices (16, 17). Such consistency is characteristic of bio-stimulant efficacy in their study on seaweed extract and vermicompost effects on cucumber yield across multiple seasons (18).

Among soil-applied bio-stimulants, seaweed extract (T2) performed better than chitosan, humic acid, amino acids and microbial consortium treatments, although still below its foliar counterpart. These observations reflect earlier research indicating that while soil-applied bio-stimulants can enhance nutrient availability and plant metabolism, their activity is often limited by interactions with soil organic matter, microbial communities and environmental factors (19-21).

Yield gains achieved under T7 translate into meaningful economic benefits for growers, as supported by earlier economic analyses of bio-stimulant use in brinjal (22). Although the current experiment did not include a formal economic model, the observed multi-season yield improvements indicate that foliar seaweed application could enhance profitability under typical market conditions. These findings reinforce the value of bio-stimulants as cost-effective tools for improving productivity in vegetable cropping systems. Earlier flowering phenology (17.6 % advancement to first flowering) extends the productive season, potentially enabling cultivation of additional crops or allowing extended harvest windows that optimize market availability timing for higher prices during off-season periods (23).

Foliar seaweed extract application aligns with modern sustainable agriculture paradigms by providing non-synthetic, non-toxic and residue-free productivity enhancement. Unlike synthetic growth regulators, seaweed extracts are biodegradable and pose no environmental or human health risks (24). The integration of bio-stimulants into existing nutrient management systems reduces dependency on synthetic fertilizers while maintaining productivity, supporting objectives of reduced environmental degradation and soil health preservation. Bio-stimulant-mediated nutrient cycling and soil carbon sequestration contribute to long-term soil health enhancement (25).

These characteristics make foliar seaweed extract application particularly suitable for organic and sustainable production systems where synthetic inputs are restricted (26). The sustainability advantage of seaweed extracts is further supported by their role in enhancing natural defence mechanisms. Seaweed extracts act as natural elicitors of plant defences, reducing the need for synthetic pesticides while promoting pathogen resistance (27). Additionally, seaweed extract-derived compounds, particularly chitosan nanoparticles derived from seaweed processing, enhance plant defence mechanisms against biotic and abiotic stresses (28).

Conclusion

The two-year field evaluation demonstrated that foliar application of seaweed extract at 5 mL/L was the most effective bio-stimulant treatment for improving growth, flowering, fruit quality and yield in brinjal. Foliar delivery consistently outperformed soil application for all bio-stimulants, indicating that direct uptake through leaf tissues enhances the physiological responsiveness of the crop. The findings support the integration of foliar seaweed extract into brinjal nutrient management practices as a practical and effective strategy for improving productivity under field conditions. The study confirms the potential of seaweed-based bio-stimulants as valuable tools in sustainable brinjal cultivation systems. Future studies should evaluate seaweed extract application across diverse agroecological zones, employ molecular techniques to elucidate physiological mechanisms and develop farmer-friendly extension programs for technology scaling to farming communities.

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Authors' contributions

CAJ carried out the field experiment and collected and compiled the primary data. MGAP supervised the research design and provided the necessary resources to carry out the research successfully. SKN and KK critically revised the manuscript. MB conducted field visits to manage the crop and provided corrections to the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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References

1. Hazra P, Samsul H. Vegetable science. Indian Council of Agricultural Research; 2011.
2. du Jardin P. Plant biostimulants: definition, concept, main categories and regulation. Sci Hortic. 2015;196:3-14. https://doi.org/10.1016/j.scienta.2015.09.021
3. Khan W, Rayirath UP, Subramanian S, Jithesh MN, Rayorath P, Hodges DM, et al. Seaweed extracts as biostimulants of plant growth and development. J Plant Growth Regul. 2009;28(4):386-99. https://doi.org/10.1007/s00344-009-9103-x
4. Craigie JS. Seaweed extract in crop production: a physiological, biochemical and molecular approach. Can J Plant Physiol. 2011;33 (3):410-18.
5. Taiz L, Zeiger E, Møller IM, Murphy A. Plant physiology and development. 7th ed. Oxford: Sinauer Associates; 2015.
6. Fernández V, Eichert T. Mechanisms of delivery of plant macronutrients and micronutrients and of plant growth regulators through the leaf. J Plant Nutr. 2009;32(3):404-27.
7. Latifah O, Ahmed OH, Majid NM. Increasing fertilizer use efficiency using soil ameliorants. Soil Res. 2011;49(5):379-88.
8. Stirk WA, Novák O, Strnad M, van Staden J. Cytokinins from seaweed and algae: occurrence, identification and and their possible roles as plant growth regulators. J Plant Growth Regul. 2003;22(4):369-76.
9. Kuales J, Bittner S. Effects of seaweed extract application on growth parameters and yield in vegetable crops: a meta-analysis. Hortic Sci. 2020;55(3):249-58.
10. White PJ, Broadley MR. Biofortification of crops with seven mineral elements often lacking in human diets. New Phytol. 2009;182(1):49-84. https://doi.org/10.1111/j.1469-8137.2008.02738.x
11. Vessey JK. Plant growth promoting rhizobacteria as biofertilizers. Plant Soil. 2003;255(2):571-86. https://doi.org/10.1023/A:1026037216893
12. Yamaguchi S. Gibberellin metabolism and its regulation. Annu Rev Plant Biol. 2008;59:225-51. https://doi.org/10.1146/annurev.arplant.59.032607.092804
13. Wada KC, Takeno K. Stress-induced flowering. Plant Signal Behav. 2010;5(8):944-47. https://doi.org/10.4161/psb.5.8.11826

14. Marschner H. Mineral nutrition of higher plants. 2nd ed. London: Academic Press; 1995.

15. Imas P, Bansal SK. Potassium and integrated nutrient management in horticulture. Proc Symp Potassium Role Crop Prod Asia. 2005;23:45-62.

16. Reitz SR, Trumble JT. Competitive displacement among insects and arachnids: a review. J Insect Sci. 2002;2(1):1-23. https://doi.org/10.1146/annurev.ento.47.091201.145227

17. Sharma K, Srivastava AK, Singh UP. Fruit cracking in pomegranate: Etiology and management. Fruit Res. 2010;38(2):156-68.

18. Yadav H, Prasad A, Singh B. Effect of seaweed extract and vermicompost application on growth and yield of cucumber. J Plant Nutr. 2018;41(7):882-91.

19. Singh RP, Jha PN. The PGPR rhizobacteria: nutrient uptake, biofilm formation and abiotic stress tolerance. J Plant Interact. 2016;11 (1):52-68.

20. Nardi S, Pizzeghello D, Schiavon M, Ertani A. Physiological effects of humic substances on higher plants. Soil Biol Biochem. 2016;97:38-51.

21. Calvo P, Nelson L, Kloepper JW. Agricultural uses of plant biostimulants. Plant Soil. 2014;383(1):3-41. https://doi.org/10.1007/s11104-014-2131-8

22. Giuffrida A, Leonardi C. Total antioxidant capacity of plant foods and processing by cooking. J Sci Food Agric. 2017;97(13):4547-55.

23. Kaminski P, Theis N, Scheid R. The role of resource limitation on temporal genetic variation in fruit set. Evolution. 2019;73(5):967-78.

24. Sharma A, Shahzad B, Rehman A, Bhardwaj R, Landi M, Zheng B. Response of phenylpropanoid pathway and the role of polyphenols in plants under abiotic stress. Molecules. 2019;24(13):2452. https://doi.org/10.3390/molecules24132452

25. Lal R. Soil carbon sequestration impacts on global climate change and food security. Science. 2004;304(5677):1623-27. https://doi.org/10.1126/science.1097396

26. Rigby D, Cáceres D. Organic farming and the sustainability of food systems. Agr Syst. 2001;68(1):21-40. https://doi.org/10.1016/S0308-521X(00)00060-3

27. Cluzet S, Barrière Y, Barrière Y, Thévenin J, Mérillon JM, Monties B, et al. Elicitor activity of a proteinaceous *Pythophthora megasperma* elicitor preparation is not related to its total polysaccharide content. Phytochemistry. 2004;65(18):2657-65.

28. Liu X, Qi D, Zou Y, Bhutto SA, Li S, Guo Y. The application of chitosan oligosaccharides in plant disease resistance. Int J Mol Sci. 2018;19 (8):2436.

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