Plant Archives Vol. 26, No. 2, 2026 pp. 2694-2699 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.no.2.369

STUDY OF BIOSTIMULANTS ON BIOMASS ACCUMULATION AND GROWTH INDICES OF GREEN CHILLI (*Capsicum annuum* L.)

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(Date of Receiving-24-07-2026; Date of Revision-22-09-2026; Date of Acceptance-04-10-2026)

ABSTRACT

A field experiment was conducted during *kharif* 2025 at the College of Agriculture, Navile, Shivamogga, Karnataka, to study the influence of biostimulants on total dry matter accumulation, growth indices and yield of green chilli. Nine treatments were evaluated in a randomized complete block design with three replications. Humic acid, amino acid and seaweed extract were applied singly and in combinations @ 0.2 per cent foliar applications along with the recommended package of practices, before flowering and at fruit development. Total dry matter, leaf area index, absolute growth rate, crop growth rate and relative growth rate were recorded at successive growth stages. The treatment comprising the package of practices + humic acid @ 0.2% + seaweed extract @ 0.2% (T_7) recorded the highest total dry matter at fruit development (62.51 g plant^{-1}) and harvest (113.39 g plant^{-1}). T_7 also recorded the highest leaf area index at fruit development (0.187) and harvest (0.165). Absolute growth rate, crop growth rate and relative growth rate were also highest in T_7. The highest green chilli yield was also recorded in T_7 (4304 kg ha^{-1}), which was statistically comparable with T_8 (4184 kg ha^{-1}) and T_9 (4124 kg ha^{-1}). The results indicated that combined application of humic acid and seaweed extract enhanced biomass accumulation, resulting in improved productivity of green chilli.

***Key words*:** Biostimulants; dry matter; growth indices; leaf area index; green chilli

Introduction

Crop yield is ultimately determined by the amount of assimilate produced and partitioned to economically important sinks. Total dry matter accumulation, leaf area index and growth rates provide quantitative measures of crop performance and help explain treatment effects that may not be evident from final yield alone. Growth analysis parameters such as absolute growth rate, crop growth rate and relative growth rate are useful for describing the temporal pattern of biomass accumulation and identifying periods of rapid crop growth. Plant biostimulants can modify nutrient acquisition, photosynthetic activity, canopy development and stress responses, thereby influencing biomass production and crop growth dynamics (Calvo *et al*., 2014; Du Jardin, 2015).

Humic substances have been described as biostimulants capable of influencing root activity, nutrient uptake, plant metabolism and overall plant growth, whereas seaweed extracts contain diverse bioactive compounds that may stimulate photosynthetic development, cell expansion, nutrient utilization and stress tolerance (Bhattacharyya *et al*., 2010; Canellas *et al*., 2015). The effectiveness of biostimulants, however, depends on the type, combination, concentration, timing

of application and crop growing environment. The interaction between humic substances and seaweed-derived biostimulants may provide complementary effects on plant growth and biomass accumulation, but information on their combined influence on dry matter production and growth dynamics of green chilli under field conditions in the Southern Transition Zone of Karnataka remains limited. Therefore, the present study was undertaken to evaluate the influence of foliar application of humic acid, amino acid and seaweed extract, applied individually and in combinations, on total dry matter accumulation, leaf area index, absolute growth rate, crop growth rate and relative growth rate of green chilli throughout the crop growth cycle.

Materials and Methods

The field experiment was conducted during the season of 2025 at College of Agriculture, Navile, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, Karnataka, India. The site lies in the Southern Transition Zone (Zone 7) of Karnataka at about 615 m above mean sea level. The soil was sandy loam, classified as Typic Haplustalf. Before transplanting, the soil had pH 6.65, electrical conductivity 0.31 dS m^{-1}, organic carbon 0.48%, available nitrogen 296.47 kg ha^{-1}, available P_2O_5 48.20 kg ha^{-1} and available K_2O 246.50 kg ha^{-1}. During July–December 2025, the crop received 504.6 mm rainfall; mean maximum and minimum temperatures were 28.7 and 18.5°C, respectively, relative humidity averaged 76.1% and bright sunshine averaged 4.8 h day^{-1}.

The experiment was laid out in a randomized complete block design with nine treatments and three replications. Each gross plot measured 6.00 × 4.05 m, with a net plot of 4.50 × 3.15 m. The F_1 hybrid Esha 4431 was used. Thirty day old healthy seedlings were transplanted at 75 × 45 cm spacing. The package of practices (POP) consisted of recommended fertilizer dose of 100:50:50 kg $N:P_2O_5:K_2O$ ha^{-1} and FYM at 25 t ha^{-1}. Biostimulants were applied as foliar sprays twice, before flowering and at fruit development.

The treatments were as follows:

T_1 :	Absolute control
T_2 :	POP
T_3 :	POP + Humic acid (@ 0.2% foliar spray, 2 times)
T_4 :	POP + Amino acid (@ 0.2% foliar spray, 2 times)
T_5 :	POP + Seaweed extract (@ 0.2% foliar spray, 2 times)
T_6 :	POP + Humic acid + Amino acid (@ 0.2% foliar spray, 2 times)
T_7 :	POP + Humic acid + Seaweed extract (@ 0.2% foliar spray, 2 times)
T_8 :	POP + Amino acid + Seaweed extract (@ 0.2% foliar spray, 2 times)
T_9 :	POP + Humic acid + Amino acid + Seaweed extract (@ 0.2% foliar spray, 2 times)

Note: POP: RDF (100:50:50 kg $N:P_2O_5:K_2O$ ha^{-1}) + FYM (25 t ha^{-1}); *Time of spraying: 1st before flowering and 2nd @ fruit development stage*

Biostimulant formulations and crop management. Humic acid was Humic power (98% water-soluble powder), amino acid formulation was Samras (20%) and seaweed extract was Kelpak, a 100% liquid concentrate derived from *Ecklonia maxima*. For 0.2% solutions, 2 g humic acid or 2 ml amino acid or 2 ml seaweed extract was diluted to 1 Liter with water. Half of the recommended fertilizer dose was applied as basal and the remaining half at 60 days after transplanting. The crop was weeded once in every 30 days; irrigation was supplied according to soil moisture and weather conditions. Necessary plant protection measures were adopted. Green fruits were harvested in successive pickings and cumulative marketable yield was recorded.

Sampling and growth analysis

Five plants were sampled for dry matter estimation at the specified growth stages like before flowering, at fruit development and at harvest.

Total dry matter accumulation (g $plant^{-1}$)

The plant samples were dried at 65 ± 5°C until constant weight. Completely dried samples were weighed and the total dry weight of plants was expressed in gram per plant

Leaf area index

Leaf area index is the ratio of leaf area to ground area occupied by the crop plant. Leaf area index (LAI) was worked out using the following formula given by Watson, (1952).

$$LAI = \frac{\text{Leaf area per plant (cm}^2\text{)}}{\text{Ground area covered by the plant (cm}^2\text{)}}$$

Absolute growth rate

Absolute growth rate (AGR) indicates the dry weight increase per unit time and expressed in g $plant^{-1}$ day^{-1}. It was calculated by using the following formula given by Radford (1967).

$$AGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,

W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.

Crop growth rate

Crop growth rate (CGR) is defined as rate of dry matter production per unit ground area per unit time (Watson, 1958). It is expressed in g m^{-2} day^{-1} and calculated by the formula.

$$CGR = \frac{W_2 - W_1}{(t_2 - t_1) \times A}$$

Where,

W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.

A = Spacing (m^2) or land area

Relative growth rate

Relative growth rate (RGR) is defined as the rate of increase in plant dry matter per unit of existing dry matter per unit time. It was calculated by using the formula suggested by Radford (1967) and expressed in g g^{-1} day^{-1}.

$$RGR = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

Where,

W_1 and W_2 are dry weight of plant at time t_1 and t_2, respectively.

ln stands for the natural logarithm

Chilli yield per plant (g $plant^{-1}$):

The weight of fruits from all the pickings was recorded from five tagged plants and the total weight of green fruits per plant was calculated and expressed in grams.

Chilli yield per plot (kg $plot^{-1}$):

The weight of fruits from all the pickings was recorded from each plot and the total weight of green fruits per plot was calculated and expressed in kg $plot^{-1}$.

Chilli yield per hectare (kg ha^{-1}):

Fresh green chilli yield per hectare was calculated from plot yield and expressed as kg ha^{-1}

Statistical analysis

Data were analyzed according to the procedure of Gomez and Gomez (1984). Treatment effects were tested at the 5% probability level. Standard error of the mean and critical difference at 5% were presented wherever appropriate; differences were considered significant when the F-test was significant.

Table 1: Total dry matter accumulation of green chilli as influenced by biostimulants at different stages.

Treatment	Total dry matter accumulation (g $plant^{-1}$)		
	Before flowering	At fruit development	At harvest
T_1	4.41	20.21	36.75
T_2	11.94	43.98	79.92
T_3	11.50	48.02	87.31
T_4	9.59	44.64	81.04
T_5	13.59	50.16	91.16
T_6	9.72	52.85	95.93
T_7	10.48	62.51	113.39
T_8	12.51	57.39	104.28
T_9	10.94	54.82	99.57
S.Em.±	0.35	3.01	2.89
CD at 5%	1.02	8.75	8.39

Results and Discussion

Total dry matter accumulation

Total dry matter accumulation was significantly influenced by biostimulant application throughout the crop growth period (Table 1). Before flowering, T_5 recorded the highest dry matter (13.59 g $plant^{-1}$), while T_7 recorded highest dry matter at fruit development and at harvest, followed by T_8, while T_1 recorded the lowest values at all stages (4.41, 20.21 and 36.75 g $plant^{-1}$, respectively). The higher dry matter accumulation in T_7 may be attributed to enhanced photosynthetic efficiency, improved nutrient uptake and greater assimilate production resulted from the synergistic action of humic acid and seaweed extract. Earlier studies by Ichwan *et al*., (2021) and Zohaib *et al*., (2024) reported that biostimulant application significantly increased dry matter accumulation in chilli.

Table 2: Leaf area index of green chilli as influenced by biostimulants at different stages.

Treatment	Leaf area index		
	Before flowering	At fruit development	At harvest
T_1	0.036	0.110	0.089
T_2	0.062	0.126	0.105
T_3	0.059	0.136	0.123
T_4	0.047	0.131	0.116
T_5	0.071	0.159	0.124
T_6	0.055	0.162	0.125
T_7	0.053	0.187	0.165
T_8	0.065	0.184	0.155
T_9	0.056	0.170	0.128
S.Em.±	0.002	0.005	0.004
CD at 5%	0.006	0.014	0.012

Table 3: Absolute growth rate, crop growth rate and relative growth rate of green chilli as influenced by biostimulants

Treatment	Flowering–Fruit development	Fruit development –Harvest	Flowering–Fruit development	Fruit development –Harvest	Flowering–Fruit development	Fruit development –Harvest
T_1	0.63	0.28	1.87	0.82	0.0609	0.009966
T_2	1.28	0.60	3.79	1.77	0.0521	0.009962
T_3	1.46	0.65	4.33	1.94	0.0572	0.009963
T_4	1.40	0.61	4.14	1.80	0.0614	0.009966
T_5	1.46	0.68	4.33	2.02	0.0522	0.009965
T_6	1.72	0.72	5.10	2.13	0.0676	0.009965
T_7	2.07	0.85	6.14	2.52	0.0713	0.009964
T_8	1.79	0.78	5.31	2.32	0.0609	0.009963
T_9	1.75	0.75	5.19	2.21	0.0644	0.009964
S.Em.±	0.044	0.028	0.130	0.062	0.002	0.0003
CD at 5%	0.128	0.083	0.378	0.180	0.005	0.0009

Leaf area index

Leaf area index increased markedly after the biostimulant sprays (Table 2). T_7 recorded the highest LAI at fruit development (0.187) and at harvest (0.165), while T_8 recorded 0.184 and 0.155. The absolute control had only 0.110 and 0.089. The greater leaf area and LAI in T_7 may be attributed to enhanced cell expansion, improved nutrient uptake and the cytokinin activity of seaweed extract, resulted in better canopy development, light interception and photosynthetic efficiency. Yuniati *et al*., (2023) also observed improved leaf area index in green chilli following biostimulant application. Comparable responses were reported Helaly *et al*., (2018) in tomato.

Absolute Growth Rate (AGR)

Absolute growth rate (AGR), which represents the increase in plant dry matter per unit time, was significantly influenced by biostimulant application during both growth intervals (Table 3). During flowering to fruit development, T_7 (POP + humic acid @ 0.2% + seaweed extract @ 0.2%) recorded the highest AGR value of 2.07 g plant^{-1} day^{-1}, followed by T_8 with 1.79 g plant^{-1} day^{-1}, while the lowest value of 0.63 g plant^{-1} day^{-1} was recorded in T_1 (absolute control). During fruit development to harvest, T_7 continued to record the highest AGR value (0.85 g plant^{-1} day^{-1}), which was on par with T_8 (0.78 g plant^{-1} day^{-1}), whereas T_1 recorded the lowest value. The higher AGR value under T_7 indicates greater accumulation of plant biomass over time, particularly during the reproductive phase. This may be attributed to improved canopy development, nutrient acquisition and photosynthetic activity resulting from the combined application of humic acid and seaweed extract. Similar improvement in growth responses following biostimulant application has been reported in chilli by Vijayakumar *et al*., (2019) and Khan *et al*., (2026).

Crop Growth Rate (CGR)

Crop growth rate (CGR), which indicates the rate of dry matter production per unit ground area, differed significantly among the biostimulant treatments (Table 3). During flowering to fruit development, the highest CGR was recorded in T_7 (6.14 g m^{-2} day^{-1}), followed by T_8 (5.31 g m^{-2} day^{-1}), whereas T_1 recorded the lowest CGR (1.87 g m^{-2} day^{-1}). A similar trend was observed during fruit development to harvest, with T_7 recording the highest CGR (2.52 g m^{-2} day^{-1}), followed by T_8 (2.32 g m^{-2} day^{-1}) and T_1 recording the lowest. The greater CGR under T_7 reflects enhanced biomass production per unit ground area and was consistent with its higher total dry matter accumulation and leaf area index. The improved growth rate may have resulted from better canopy development and sustained assimilate production during the reproductive period. Ambika and Sujatha (2017) and Vijayakumar *et al*., (2019) also reported improved growth responses with biostimulant application.

Relative Growth Rate (RGR)

Relative growth rate (RGR), which express the

Table 4: Green chilli yield as influenced by biostimulants.

Treatment	Green chilli yield plant^{-1} (g)	Green chilli yield plot^{-1} (kg)	Green chilli yield (kg ha^{-1})
T_1	53.2	1.90	1339
T_2	120.8	4.97	3506
T_3	132.4	5.27	3717
T_4	124.8	5.13	3614
T_5	143.7	5.41	3816
T_6	148.0	5.63	3969
T_7	180.6	6.10	4304
T_8	176.1	5.93	4184
T_9	163.8	5.85	4124
S.Em.±	4.30	0.15	112
CD at 5%	12.52	0.45	326

increase in dry matter relative to the existing plant biomass, was significantly influenced by biostimulant application (Table 3). During flowering to fruit development, T_7 recorded the highest RGR (0.0713 g g^{-1} day^{-1}), followed by T_6 (0.0676 g g^{-1} day^{-1}) and T_9 (0.0644 g g^{-1} day^{-1}). During fruit development to harvest, T_7 recorded RGR (0.009964 g g^{-1} day^{-1}), which was on par with other treatments. The higher RGR under T_7, particularly during flowering to fruit development, indicated a greater relative increase in plant biomass during this active growth phase. The decline in RGR during the later growth interval may be associated with the increasing size and age of the plants and the shift in assimilate allocation towards reproductive sinks. Similar enhancement in RGR and biomass accumulation following biostimulant application has been reported by Ambika and Sujatha (2017) in pigeonpea and Rizk *et al*., (2018) in potato.

Green chilli yield

Green chilli yield was significantly influenced by biostimulant application (Table 4). T_7 recorded the highest green chilli yield per hectare (4304 kg ha^{-1}), followed by T_8 (4184 kg ha^{-1}) and T_9 (4124 kg ha^{-1}), whereas T_1 recorded the lowest yield (1339 kg ha^{-1}). T_7 was statistically on par with T_8 and T_9 for green chilli yield, as the difference between their yields was smaller than the reported critical difference. Yield per plant and yield per plot also followed a similar trend, with T_7 recorded the highest values of 180.6 g $plant^{-1}$ and 6.10 kg $plot^{-1}$, respectively, followed by T_8 with 176.1 g $plant^{-1}$ and 5.93 kg $plot^{-1}$. The superior yield under T_7 may be attributed to the combined improvement in vegetative growth, canopy development and biomass accumulation. The combined application of humic acid and seaweed extract have improved nutrient acquisition and plant growth, thereby favoured fruit development and final productivity. Similar positive responses of chilli yield to humic acid and seaweed-based biostimulants have been reported by Sridhar and Rengasamy (2012), Soliman and Dakar (2025) and Wani *et al*., (2025).

Conclusion

Foliar application of humic acid @ 0.2% + seaweed extract @ 0.2% , before flowering and at fruit development stage with the recommended package of practices (T_7) produced the strongest sustained biomass accumulation and growth performance in green chilli. The treatment recorded the highest total dry matter after flowering, LAI, AGR and CGR, and the highest RGR during flowering to fruit development, with T_7 being statistically comparable with T_8 for several growth responses. T_7 also recorded the highest green chilli yield of 4304 kg ha^{-1}, which was statistically on par with T_8 (4184 kg ha^{-1}) and T_9 (4124 kg ha^{-1}), indicating that improved biomass accumulation and favourable growth dynamics were effectively translated into greater productivity. The superiority of T_7 suggested that the combined application of humic acid and seaweed extract supported sustained crop growth during the critical reproductive phase. These findings indicated that integrating complementary biostimulants with the recommended package of practices can improve biomass production, growth efficiency and yield potential of green chilli under the agro-climatic conditions of the Southern Transition Zone of Karnataka.

Acknowledgement

I sincerely acknowledge the guidance and support of the advisory members. I am also grateful to the Department of Agronomy, College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, for providing the necessary facilities and support during my research.

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