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RESEARCH ARTICLE

Effect of bio-stimulants and plant growth regulators on the growth and quality of green chilli (*Capsicum annuum* L.)

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This research was carried out on "Effect of bio-stimulants and plant growth regulators on the growth, yield and quality of green chilli (*Capsicum annuum* L.)" at the Instructional Farm, Faculty of Horticulture, UBKV, Pundibari, Coochbehar during 2022-2023. The experiment was conducted in factorial RBD with 27 different treatment combinations, in which factor A was included with 9 different doses of humic acid and seaweed extract as soil application and factor B was included with 3 different PGRs (NAA, GA3 and Triacontanol) with different concentrations as foliar spray. This study was to identify which bio-stimulants and PGRs yielded the best growth results of green chilli. Among the bio-stimulant treatments, A3 [Mobicel – H (80% Humic acid) @ 15 kg/ha] showed the maximum plant height (40.50 cm) and A5 [Biovita Granules (8% Seaweed Extract) at 8 kg/ha] resulted in an increase in the no. of primary branches (8.84) and plant spread (50.35 cm), respectively at 90 DAT. On the other hand, maximum chlorophyll-a content (243.76 mg/100 g) and total chlorophyll (a+b) content (208.90 mg/100 g) of mature leaves were found in the treatment A3 (Mobicel – H (80% Humic acid) @ 15 kg/ha) and maximum chlorophyll-a content (67.76) and ascorbic acid content (100.72 mg/100 g) were found in the treatment A5 (Biovita granules (8% Seaweed extract) @ 8 kg/ha).

Keywords: Chilli, humic acid, seaweed extract, NAA, GA3, Triacontanol, total chlorophyll, ascorbic acid.

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Introduction

The term "*Capsicum*" is derived from the Greek word "Kapsimo," which means "to burn." Chilli (*Capsicum annuum* L.) originated from South America. (Nkansah et al., 2011). Cultivated chilli, belonging to the genus *Capsicum*, is a member of the Solanaceae family and typically has a chromosome number of 2n = 24. In India, West Bengal holds the 12th position in chilli cultivation, contributing around 0.47% to the nation's total production. This accounts for approximately 8,567 tons of chillies grown across an area of 5,450 hectares (Spice Board of India, 2020-21). Humic acid, often termed the 'dark gold of agriculture,' constitutes a vital part of humic substances. Due to its diverse functional groups, humic acid plays various roles in the soil-plant relationship, influencing total carbohydrate content and the overall yield of crops (Pantoja et al., 2016; Peña et al., 2005; Canellas et al., 2010; Karakurt et al., 2009). Seaweed extract, derived from marine macroscopic algae found in relatively shallow coastal waters, is another bio-stimulant (Brownlee et al., 2012). They act as bio-stimulants primarily due to the presence of plant hormones, such as auxin, cytokinin, gibberellin, abscisic acid, and ethylene (Shinde, 2020; Lucasz Tuhy et al., 2013). Seaweed extracts hold significant importance in enhancing plant growth and yield, as well as in helping plants cope with various stresses (Jayasinghe, 2016). 1-Naphthaleneacetic acid (NAA) has been found to reduce pre-harvest fruit drop (Iqbal et al., 2009) and delay fruit ripening when applied before harvest by reducing ethylene biosynthesis (Acuña et al., 2010). Additionally, early-stage application of NAA causes the abscission of fruitlets, leading to enhanced fruit size and quality (Hield et al., 1962; Ortolá et al., 1991; Galliani et al., 1975; Agustí et al., 1999). Gibberellins (GAs) are known as growth promoters that mediate many plant responses, ranging from seed germination to senescence (Ginnakoula et al., 2012). Triacontanol (TRIA) is a substance known for promoting the growth of plants, and it has the ability to enhance the development of various crops when externally applied at relatively low levels (Naeem et al., 2012). Its exogenous application has been found to improve plant biomass, photosynthetic pigments, gas exchange parameters, mineral nutrient acquisition, and modulate antioxidant enzyme activities, leading to improved yield and quality parameters (Zaid et al., 2020; Naeem et al., 2019; Waqas et al., 2016). Although several studies have reported the beneficial effects of bio-stimulants and plant growth regulators on crop performance and information regarding their efficacy under the agro-climatic conditions of West Bengal is limited. Therefore, the present investigation was undertaken to evaluate the influence of selected bio-stimulants and plant growth regulators on the growth and quality attributes of green chilli, with the objective of identifying suitable treatments for enhancing productivity and promoting sustainable cultivation practices.

Materials and Methods

This experiment was carried out at the Instructional Field of the Department of Vegetable and Spice Crops, Faculty of Horticulture, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, during 2022-23. The Terai region of West Bengal, where the farm is situated, provides conducive conditions for agricultural and horticultural research. The experiment was laid out in a randomized block design with two factors, resulting in 27 treatment combinations replicated three times. The experiment focused on investigating the effects of nine different bio-stimulants applied as soil amendments, denoted as factor A, *viz,* A1: Mobicel – H (80% Humic acid) @ 5 kg/ha, A2: Mobicel – H (80% Humic acid) @ 10 kg/ha, A3: Mobicel – H (80% Humic acid) @ 15 kg/ha, A4: Biovita granules (8% Seaweed extract) @ 4 kg/ha, A5: Biovita granules (8% Seaweed extract) @ 8 kg/ha, A6: Mobicel – H (80% Humic acid) @ 2.5 kg/ha + Biovita granules (8% Seaweed extract) @ 2 kg/ha, A7: Mobicel – H (80% Humic acid) @ 2.5 kg/ha + Biovita granules (8% Seaweed extract) @ 4 kg/ha, A8: Mobicel – H (80% Humic acid) @ 5 kg/ha + Biovita granules (8% Seaweed extract) @ 2 kg/ha, A9: Mobicel – H (80% Humic acid) @ 5 kg/ha + Biovita granules (8% Seaweed extract) @ 4 kg/ha and factor B, i.e., 3 treatments of plant growth regulators application as foliar spray *viz,* B1: NAA @ 40 ppm, B2: GA3 @ 50, B3: Triacontanol @ 5 ppm. Healthy OP variety seeds of Chinese Bona (DEB 1304) were selected for sowing. Seedlings of chilli were transplanted in the 2.5 x 2.4 m size plot at a spacing of 50 x 40 cm. Recommended fertilizer dose of 20 ton of FYM and 120:60:60 kg of N, P and K per ha were applied through urea, single super phosphate and murate of potash, respectively. The biochemical parameters were analysed using standard methodologies. Chlorophyll content of leaves was estimated following the procedure of Sadasivam and Manickam (1996), while β -carotene content of fruits was determined according to Davies (1976). Ascorbic acid content in fresh fruits was estimated following the standard biochemical method recommended by AOAC (1990). The data thus obtained were subjected to statistical analysis in accordance with the experimental design.

Results and Discussion

Growth parameters

Plant height (cm)

Table 1 showed that at 30 DAT, bio-stimulants, plant growth regulators, and their interactions had a non-significant effect on plant height. Only bio-stimulants had a significant effect on plant height at 60 days after transplanting. At 60 days after transplanting (DAT), only bio-stimulants had a notable effect on plant height. Treatment A3 resulted in the tallest plants (46.11 cm), followed by treatments A2, A9 and A8 with heights of 45.03, 44.11 and 44.03 cm, respectively. The shortest plants were in treatment A4, i.e., 35.30 cm. At 90 days after transplanting, treatment A3 resulted in the tallest plants (59.83 cm), while the shortest plants were observed in treatment A6 (41.90 cm). Also, humic acid, particularly at A3, was the most effective treatment for increasing plant height.

These findings indicated that humic acid significantly enhanced plant height, whereas sole application of seaweed extract was less effective than its combined application with humic acid. Similar results have been reported by Meena et al. (2022), Van et al. (2022), Ali et al. (2020), Jan et al. (2020), Ameta et al. (2017), and Fathima et al. (2013) in chilli, and by Sharma et al. (2017) in French bean. The positive effect of humic acid may be attributed to its ability to improve soil fertility, enhance nutrient availability, and stimulate meristematic cell division, thereby promoting plant growth (Ameta et al., 2017). Moreover, humic acid helps alleviate abiotic stress, resulting in improved growth and yield of vegetable crops (Doran et al., 2003).

Studies by Sugandhika et al. (2021), Ozbay et al. (2019), and Vijaykumar et al. (2018) supported the efficacy of seaweed extract in plant growth. Seaweed ingredients contain vital nutrients, vitamins, amino acids, auxins, and

Table 1: Effect of bio-stimulants, plant growth regulators and their interactions on growth parameters of chilli plants at 30, 60 and 90 DAT

Treatments / Characters	*30 DAT*				*60 DAT*				*90 DAT*			
	Plant height (cm)	*Stem girth (mm)*	*No. of primary branches*	*Plant spread (cm)*	*Plant height (cm)*	*Stem girth (mm)*	*No. of primary branches*	*Plant spread (cm)*	*Plant height (cm)*	*Stem girth (mm)*	*No. of primary branches*	*Plant spread (cm)*
Factor A (Bio-stimulants)												
A1	20.80	2.74	7.26^{d}	16.65	43.42^{bc}	4.08	7.13^{c}	31.16^{d}	52.01^{c}	4.90	7.13^{d}	38.60^{e}
A2	20.52	2.47	7.36^{c}	17.31	45.03^{ab}	3.91	7.23^{c}	30.74^{d}	56.07^{b}	4.69	7.23^{d}	38.91^{de}
A3	20.65	2.45	7.36^{c}	17.30	46.11^{a}	3.84	7.39^{c}	31.10^{d}	59.83^{a}	4.61	7.39^{d}	39.39^{cde}
A4	20.42	2.60	7.20^{de}	17.05	35.30^{f}	4.05	8.27^{ab}	35.17^{bc}	45.31^{de}	4.86	8.50^{abc}	46.40^{ab}
A5	20.73	2.42	7.27^{d}	16.57	37.74^{e}	3.84	8.50^{a}	40.50^{a}	46.47^{d}	4.61	8.84^{a}	50.35^{a}
A6	20.51	2.19	7.16^{e}	16.31	40.32^{d}	3.53	7.95^{b}	33.02^{cd}	41.90^{e}	4.23	8.04^{c}	42.96^{bc}
A7	20.71	2.61	7.36^{c}	17.36	41.41^{cd}	3.83	8.26^{ab}	38.22^{ab}	43.22^{de}	4.60	8.49^{abc}	46.36^{b}
A8	20.71	2.46	7.46^{b}	17.94	44.03^{ab}	3.70	8.10^{ab}	33.08^{cd}	52.33^{c}	4.44	8.23^{bc}	42.72^{bcd}
A9	20.76	2.64	7.55^{a}	18.19	44.11^{ab}	3.75	8.36^{ab}	38.69^{a}	52.32^{c}	4.50	8.60^{ab}	46.51^{ab}
SE_m	0.14	0.12	0.03	0.81	0.80	0.12	0.18	1.12	1.25	0.14	0.19	1.40
C.D. ($p = 0.05$)	N.S.	N.S.	0.08	N.S.	2.27	N.S.	0.52	3.17	3.54	N.S.	0.53	3.98
Factor B (Plant growth regulators)												
B1	20.69	2.47	7.32	17.18	42.09	3.82	7.90	34.60	49.60	4.58	8.05	43.42
B2	20.61	2.56	7.33	17.20	41.65	3.87	7.91	34.62	50.26	4.65	8.05	43.39
B3	20.64	2.50	7.34	17.19	42.09	3.82	7.93	34.68	49.96	4.59	8.06	43.93
SE_m	0.08	0.07	0.05	0.47	0.47	0.07	0.11	0.64	0.72	0.08	0.11	0.81
C.D. ($p = 0.05$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Interaction (A X B)												
A1B1	20.93	2.75	7.25	16.59	43.29	4.08	7.11	31.22	51.17	4.90	7.11	38.33
A1B2	20.98	2.75	7.27	16.65	42.12	17	7.02	31.27	52.35	5.00	7.02	39.12
A1B3	20.49	2.73	7.26	16.71	44.86	4.00	7.25	30.98	52.50	4.80	7.25	38.34
A2B1	20.37	2.33	7.36	17.28	415	3.89	7.17	30.95	56.37	4.66	7.17	38.97
A2B2	20.27	2.50	7.38	17.32	44.92	3.92	7.22	30.26	55.61	4.70	7.22	38.62

Cont...

A2B3	20.94	2.58	7.34	17.33	46.01	3.92	7.31	31.02	56.23	4.70	7.31	39.14
A3B1	20.69	2.45	7.35	17.30	46.95	3.80	7.42	31.02	59.83	4.56	7.42	39.24
A3B2	20.69	2.42	7.36	17.32	44.28	3.75	7.36	32.21	60.01	4.50	7.36	38.33
A3B3	20.58	2.48	7.38	17.29	47.11	3.97	7.39	30.07	59.65	4.76	7.39	40.61
A4B1	20.81	2.56	7.19	17.02	35.84	4.00	8.23	34.83	45.35	4.80	8.50	46.11
A4B2	20.21	2.67	7.19	17.02	34.95	4.00	8.33	34.33	44.03	4.80	8.54	45.43
A4B3	20.25	2.58	7.23	17.12	35.11	15	8.25	36.33	46.55	4.98	8.46	47.66
A5B1	20.71	2.30	7.26	16.54	36.96	3.67	8.47	40.51	47.38	4.40	8.80	50.41
A5B2	20.63	2.63	7.30	16.55	38.01	19	8.54	41.01	45.17	5.03	8.91	50.74
A5B3	20.84	2.33	7.25	16.62	38.25	3.67	8.49	39.98	46.87	4.40	8.81	49.91
A6B1	20.57	2.25	7.18	16.33	40.22	3.58	7.96	32.95	41.20	4.30	8.07	42.63
A6B2	20.40	2.15	7.15	16.50	41.23	3.60	7.91	33.24	43.32	4.32	8.00	42.69
A6B3	20.56	2.17	7.15	16.11	39.52	3.40	7.98	32.86	41.17	4.08	8.06	43.55
A7B1	20.32	2.58	7.38	17.38	42.26	3.70	8.31	38.52	42.94	4.44	8.53	46.19
A7B2	20.90	2.67	7.36	17.36	42.12	4.05	8.21	37.12	44.96	4.86	8.46	46.42
A7B3	20.91	2.58	7.35	17.35	39.86	3.75	8.27	39.02	41.75	4.50	8.48	46.48
A8B1	20.94	2.42	7.43	17.92	415	3.82	8.09	33.14	50.87	4.58	8.21	42.83
A8B2	20.83	2.82	7.46	18.02	44.92	3.50	8.17	32.85	52.98	4.20	8.28	42.32
A8B3	20.35	2.13	7.47	17.88	43.01	3.78	8.05	33.26	53.15	4.54	8.19	43.01
A9B1	20.87	2.58	7.52	18.22	44.95	3.83	8.36	38.25	51.31	4.60	8.61	46.06
A9B2	20.57	2.47	7.54	18.05	42.28	3.67	8.39	39.26	53.92	4.40	8.62	46.82
A9B3	20.85	2.86	7.59	18.31	45.11	3.75	8.34	38.57	51.74	4.50	8.57	46.65
SEm (±)	0.25	0.21	0.05	1.40	1.38	0.20	0.32	1.93	2.16	0.25	0.32	2.42
C.D. ($p = 0.05$)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

A1: Mobicel – H (80% Humic Acid) at 5 kg/ha, A2: Mobicel – H (80% Humic Acid) at 10 kg/ha, A3: Mobicel – H (80% Humic Acid) at 15 kg/ha, A4: Biovita Granules (8% Seaweed Extract) at 4 kg/ha, A5: Biovita Granules (8% Seaweed Extract) at 8 kg/ha, A6: Mobicel – H (80% Humic Acid) at 2.5 kg/ha + Biovita Granules (8% Seaweed Extract) at 2 kg/ha, A7: Mobicel – H (80% Humic Acid) at 2.5 kg/ha + Biovita Granules (8% Seaweed Extract) at 4 kg/ha, A8: Mobicel – H (80% Humic Acid) at 5 kg/ha + Biovita Granules (8% Seaweed Extract) at 2 kg/ha, A9: Mobicel – H (80% Humic Acid) at 5 kg/ha + Biovita Granules (8% Seaweed Extract) at 4 kg/ha, B1: NAA @ 40 ppm, B2: GA3 @ 50 ppm, B3: Triacontanol @ 5 ppm. (ppm- parts per million) cytokinins, enhancing cellular metabolism and promoting growth (Crouch and van Staden, 1993; Khan et al., 2009; Craigie, 2011; Spann and Little, 2010; du Jardin, 2015). Zodape et al. (2011) noted that seaweed sap boosts tomato plant height by providing macro and micronutrients, along with growth-stimulating cytokinins.

Stem girth (mm)

In the case of the stem girth, bio-stimulants, plant growth regulators and their interactions had no significant effect, as shown in Table 1. This may be because stem girth is a comparatively less plastic growth parameter, being largely regulated by genetic factors and overall crop growth. The applied treatments possibly promoted cell elongation and branching rather than radial stem expansion, resulting in non-significant differences among treatments.

Number of primary branches

At 30 days after transplanting, the maximum no. of primary branches (7.55) was obtained by treating with treatment A9, while the minimum (7.16) was found in treatment A6. Among all the bio-stimulant treatments, treatment A5 resulted in the maximum number of primary branches (8.50), followed by A9 (8.36), A4 (8.27) and A8 (8.10) at 60 days after transplanting. Whereas the minimum number of primary branches (7.13) was found in the plot treated with treatment A1. The plants treated with treatment A5 showed the maximum number of primary branches (8.84), which was significantly at par with the treatments A9 (8.60), A4 (8.50), and A7 (8.49) at 90 days after transplanting. However, the minimum (7.13) was found in the plot treated with treatment A1.

The higher number of primary branches in A5 may be attributed to the presence of cytokinins, auxins, amino acids, vitamins, and macro- and micronutrients in seaweed extract. These constituents stimulate axillary bud growth, enhance nutrient uptake and photosynthetic activity, and promote vegetative growth, resulting in increased branching. Earlier studies by Vijaykumar et al. (2018), Manna et al. (2012), and Sridhar et al. (2012) found that seaweed extract enhances primary branch numbers in chilli plants. Ramamoorthy et al. (2007) noted that seaweed extract as a foliar spray boosts plant growth by aiding the absorption and translocation of growth-promoting substances. Rayorath et al. (2008) suggested that constituents in seaweed extracts, particularly from *Ascophyllum nodosum*, regulate auxin concentration and translocation, contributing to improved plant growth.

Similar results were found by Ameta et al., 2017; Meena et al. (2022); Jan et al. (2020) and Fathima et al. (2013) in chilli plants and Bassiony et al . (2010) in snap bean using humic acid. The introduction of humic acid positively influenced the soil's physical, chemical, and biological properties, leading to enhanced plant growth, as demonstrated by Nardi et al. (2005) and Trevisan et al. (2010).

Plant spread (cm)

Table 1 indicated that bio-stimulants alone significantly affected the plant spread at 60 and 90 days after transplanting at 60 and 90 days after transplanting. At 60 days after transplanting, the maximum plant spread (40.50 cm) was obtained by treatment A5, which was significantly at par with treatments A9 (38.69 cm) and A7 (38.22 cm). While the minimum plant spread (30.74 cm) was found by applying A2. The plants treated with A5 showed the maximum plant spread (50.35 cm), followed by A9 (46.51 cm) and A4 (46.40 cm). Whereas the minimum plant spread (38.60 cm) was found in plants treated with A1 at 90 days after transplanting.

Present findings were similar to the research work of Van et al. (2022). By enhancing plant hormone activity, humic acid functions as a bio-stimulant to encourage plant growth (Serenella et al., 2002).

Khan et al. (2011) found that Stimplex® treatment induces cytokinin-like responses in Arabidopsis thaliana, suggesting compounds in seaweed extracts may have cytokinin-like activity. Cytokinins promote cell division, root sink activity, and growth (Nelson and Van Staden, 1984). Seaweed extracts' auxins and cytokinins have been associated with increased lateral root formation, total root volume, and root length (Crouch and Staden, 1993; Stirk and van Staden, 1997; Arthur et al., 2003; Khan et al., 2011; Sarhan and Ismael, 2014; Vijayanand et al., 2014).

Quality parameters

Bio-stimulants and plant growth regulators had a significant effect on all the quality parameters (chlorophyll a, b, total chlorophyll and ascorbic acid) of green chillis, except "β-carotene of fruit", which had non-significant results. On the other hand, their interactions had the most significant impact in the case of "β-carotene of fruit" only (Table 2).

Chlorophyll A of mature leaf (mg/100 g)

Bio-stimulants and plant growth regulators had significant effects on the chlorophyll a content of leaves, while their interactions showed non-significant results. Chlorophyll A content of leaves was significantly increased (243.76 mg/100 g) by the application of treatment A3, followed by A9 and A2 where magnitude was recorded as 235.65 and 233.03 mg/100g of fresh leaf, respectively. The minimum chlorophyll a content (202.78 mg/100 g) was found in the plot treated with treatment A4.

Foliar application of treatment B1 (NAA @ 40 ppm) resulted in a notable rise in leaf chlorophyll a content (227.23 mg/100 g), while the application of treatment B2 (GA3 @ 50 ppm) led to the lowest chlorophyll a content (219.02 mg/100 g) observed in the plot.

Chlorophyll B of mature leaf (mg/100 g)

The chlorophyll B content of leaves was notably impacted by bio-stimulants and plant growth regulators, but their

Table 2: Effect of bio-stimulants, plant growth regulators and their interactions on quality parameters of chilli plants.

Characters / *Treatments*	*Chlorophyll-a of mature Leaf (mg per 100 gm)*	*Chlorophyll-b of mature leaf (mg per 100 gm)*	*Total chlorophyll of mature leaf (mg per 100 gm) (A+B)*	*β-carotene of fruit (mg per 100 gm)*	*Ascorbic acid of fruit (mg per 100 gm)*
Factor A (Bio-stimulants)					
A1	216.80^{c}	58.83^{de}	275.63^{e}	0.94	90.44^{c}
A2	233.03^{b}	61.93^{c}	294.96^{b}	0.94	90.68^{c}
A3	243.76^{a}	65.15^{b}	308.90^{a}	0.96	91.04^{c}
A4	202.78^{d}	61.75^{c}	264.54^{f}	0.95	94.02^{b}
A5	221.34^{c}	67.7^{6}a	289.11^{c}	0.94	100.72^{a}
A6	207.37^{d}	57.66^{e}	265.02^{f}	0.95	90.77^{c}
A7	216.19^{c}	59.04^{de}	275.23^{e}	0.93	92.53^{bc}
A8	222.19^{c}	59.99^{d}	282.19^{d}	0.94	91.27^{c}
A9	235.65^{b}	64.29^{b}	299.94^{b}	0.94	92.67^{bc}
SE_m (±)	2.21	0.61	1.98	0.01	0.92
C.D. ($p = 0.05$)	6.28	1.74	5.62	N.S.	2.60
Factor B (Plant growth regulators)					
B1	227.23^{a}	63.02^{a}	290.24^{a}	0.95	90.95^{b}
B2	219.02^{b}	61.14^{b}	280.15^{b}	0.94	96.00^{a}
B3	220.13^{b}	61.31^{b}	281.44^{b}	0.95	91.10^{b}
SE_m (±)	1.28	0.35	1.14	0.01	0.53
C.D. ($p = 0.05$)	3.63	1.01	3.24	N.S.	1.50
Interaction (A X B)					
A1B1	221.98	59.91	281.89	0.98^{bc}	88.35
A1B2	214.74	58.98	273.72	0.87^{hi}	93.22
A1B3	213.68	57.61	271.29	0.96^{cde}	89.76
A2B1	239.65	62.73	302.38	0.94^{cdef}	87.76
A2B2	229.11	60.86	289.97	0.91^{efgh}	94.39

Cont...

A2B3	230.34	62.19	292.53	0.97^{cd}	89.90
A3B1	248.57	65.11	313.68	0.92^{defgh}	90.15
A3B2	243.14	65.65	308.79	0.93^{cdefg}	96.06
A3B3	239.56	64.68	304.24	1.03^{ab}	86.90
A4B1	209.56	63.58	273.14	0.95^{cdef}	92.58
A4B2	196.24	60.99	257.23	0.98^{bc}	98.58
A4B3	202.55	60.69	263.24	0.93^{cdefg}	90.90
A5B1	225.15	68.79	293.94	0.94^{cdef}	98.22
A5B2	221.36	66.77	288.13	1.07^{a}	104.76
A5B3	217.52	67.73	285.25	0.82^{i}	99.17
A6B1	212.22	59.30	271.52	0.96^{cde}	89.90
A6B2	204.32	56.17	260.49	0.97^{cd}	92.39
A6B3	205.56	57.50	263.06	0.91^{efgh}	90.03
A7B1	218.11	60.89	279.00	0.95^{cdef}	90.39
A7B2	213.96	57.77	271.73	0.90^{fgh}	95.15
A7B3	216.51	58.46	274.97	0.95^{cdef}	92.06
A8B1	228.11	61.59	289.70	0.98^{bc}	90.84
A8B2	217.96	58.85	276.81	0.94^{cdef}	93.22
A8B3	220.51	59.54	280.05	0.91^{efgh}	89.76
A9B1	241.68	65.25	306.93	0.91^{efgh}	90.39
A9B2	230.34	64.19	294.53	0.88^{gh}	96.22
A9B3	234.92	63.43	298.35	1.04^{a}	91.39
SE_m (±)	3.83	1.06	3.43	0.02	1.59
C.D. ($p = 0.05$)	N.S.	N.S.	N.S.	0.05	N.S.

A1: Mobicel – H (80% Humic Acid) at 5 kg/ha, A2: Mobicel – H (80% Humic Acid) at 10 kg/ha, A3: Mobicel – H (80% Humic Acid) at 15 kg/ha, A4: Biovita Granules (8% Seaweed Extract) at 4 kg/ha, A5: Biovita Granules (8% Seaweed Extract) at 8 kg/ha, A6: Mobicel – H (80% Humic Acid) at 2.5 kg/ha + Biovita Granules (8% Seaweed Extract) at 2 kg/ha, A7: Mobicel – H (80% Humic Acid) at 2.5 kg/ha + Biovita Granules (8% Seaweed Extract) at 4 kg/ha, A8: Mobicel – H (80% Humic Acid) at 5 kg/ha + Biovita Granules (8% Seaweed Extract) at 2 kg/ha, A9: Mobicel – H (80% Humic Acid) at 5 kg/ha + Biovita Granules (8% Seaweed Extract) at 4 kg/ha, B1: NAA @ 40 ppm, B2: GA3 @ 50 ppm, B3: Triacontanol @ 5 ppm. (ppm- parts per millio).

combined effects yielding results were not statistically significant. Soil application of treatment A5 resulted in a significant increase in leaf chlorophyll b content (67.76 mg/100 g). On the other hand, the lowest chlorophyll b content (57.66 mg/100 g) was observed in the plot treated with A6. Applying treatment B1 (NAA @ 40 ppm) led to a significant increase in leaf chlorophyll b content (63.02 mg/100 g), whereas treatment B2 (GA3 @ 50 ppm) resulted in the minimum chlorophyll b content (61.14 mg/100 g) within the plot.

Total chlorophyll of mature leaf (mg/100 g)

The total chlorophyll content of leaves was noticeably influenced by bio-stimulants and plant growth regulators; however, their interaction effects did not result in statistically significant outcomes (Table 2). Among the bio-stimulants, the total chlorophyll content of the leaf experienced a significant increase (308.90 mg/100 g) due to the implementation of treatment A3, followed by A9 and A2 where magnitude was recorded as 299.94 and 294.96 mg/100 g of fresh leaf, respectively. In contrast, the lowest content (264.54 mg/100 g) was observed in the plot treated with A4. In this experiment, humic acid had a greater impact on leaf chlorophyll content compared to seaweed extract or their combination treatments. This predominant influencing attribute of humic acid also reported in earlier research works of Karakurt et al. (2009), Unlu et al. (2011) and Selim et al. (2012). Karakurat et al. (2012) also suggested that humic acid significantly increases chlorophyll content in pepper fruit with foliar and soil application. Humic acid likely contributed to improved mineral nutrient absorption by enhancing cell permeability (Valdrighi et al., 1996; Dursun et al., 2002; Zandonadi et al., 2007).

In case of plant growth regulators, the application of treatment B1 (NAA @ 40 ppm) significantly increased the total chlorophyll content of leaves (290.24 mg/100 g), while the minimum (280.15 mg/100 g) was found in the plot treated with treatment B2 (GA3 @ 50 ppm). Sarker et al. (2009), Singh et al. (2015), Jakhar et al. *(2018) and* Anabarasi et al. (2022) also demonstrated the importance of NAA in improving yield-contributing characters. Arora et al. (2014) observed maximum chlorophyll content (2.56 mg/100 g) in 60 ppm NAA as compared to the control (1.15 mg/100 g); hence, they suggested this might be due to increased synthesis of metabolites related to pigment. Additionally, regarding the significantly outstanding performance of combination treatments, plant growth hormones might have been associated with humic fractions, leading to a combined hormonal and humic influence on plant growth and development (Atiyeh et al., 2002). This notion found support in the work of Canellas et al. (2000) who demonstrated the presence of exchangeable auxin groups within the macrostructure of humic acids.

β-carotene of fruit (mg per 100 g)

Table 2 revealed that bio-stimulants and plant growth regulators individually had no significant effect on the β-carotene content of green fruits, but their interactions had a significant impact on the β-carotene content.

The significant and maximum β-carotene content (1.07 and 1.04 mg/100 g, respectively) was found by using the treatment combination A5B2 and A9B3, which were statistically *at par*, followed by the treatment A3B3 (1.03 mg/100 g). On the other hand, the lowest β-carotene content (0.82) was found in the plot treated with the treatment combination A5B3. Aminifard et al., 2012 found the similar results during their research in chilli plants by using humic acid.

Ascorbic acid of fruit (mg per 100 g)

Both bio-stimulants and plant growth regulators showed a significant effect on the ascorbic acid content of green chilli fruits, but their interaction failed to exhibit any significant influence (Table 2). In the case of bio-stimulants, the application of treatment A5 significantly increased the ascorbic acid content of green chilli fruits (100.72 mg/100 g), followed by A4, which estimated 94.44 mg/100 g. However, the lowest ascorbic acid content (90.44 mg/100 g) was found in the plot treated with treatment A1. The results clearly indicate that the current trait is significantly influenced by seaweed extract, particularly at higher doses, which was similar to the investigation of Manna et al. (2012). The current findings align with Reeta et al. (2010) report, which observed a significant increase in ascorbic acid levels in tomatoes with the use of seaweed liquid fertilizers.

Whereas, in the case of plant growth regulators plot treated with GA3 at 50 ppm resulted in significant and maximum ascorbic acid content (96.00 mg/100 g) of green chillis, while the lowest amount (90.95 mg/100 g) was found by treating with treatment B1 (NAA at 40 ppm). Such increased ascorbic acid through foliar spray of GA3 was also reported by Singh et al. (2019) and Chaudhry et al. (2006). The increase in ascorbic acid content following GA_3 application may be attributed to its ability to enhance photosynthesis and carbohydrate metabolism, thereby providing more substrates for ascorbic acid biosynthesis through the L-galactose pathway**.** In addition, GA_3 delays leaf senescence and strengthens the antioxidant defence system, promoting ascorbic acid accumulation by stimulating its biosynthesis and reducing its oxidation through lower activity of ascorbic acid oxidase**.** These outcomes correlate with the conclusions drawn by Chattopadhyay and Sen (1974) as well as Desai et al. (1993).

Conclusion

The present study demonstrated that bio-stimulants had a greater influence on the growth and quality parameters of green chilli than plant growth regulators. Among the bio-stimulants, humic acid at 15 kg ha^{-1} (A3) emerged as the overall best treatment by significantly improving plant height, chlorophyll *a*, and total chlorophyll content, indicating enhanced plant vigour and photosynthetic efficiency. Seaweed extract at 8 kg ha^{-1} (A5) was superior for increasing primary branches, plant spread, chlorophyll *b*, and ascorbic acid content. Among the plant growth regulators, NAA at 40 ppm (B1) was the most effective in improving chlorophyll content, whereas GA_3 at 50 ppm (B2) enhanced ascorbic acid content. Therefore, soil application of humic acid at 15 kg ha^{-1} along with foliar application of NAA at 40 ppm is recommended for improving the overall growth and physiological quality of green chilli under the Terai region of West Bengal.

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सारांश

यह शोध कार्य "हरित मिर्च की वृद्धि, उपज एवं गुणवत्ता पर जैव उत्तेजकों तथा पादप वृद्धि नियामकों के प्रभाव" विषय पर वर्ष २०२२–२०२३ के दौरान उत्तर बंग कृषि विश्वविद्यालय, पुंडीबाड़ी, कूचबिहार के बागवानी संकाय के शिक्षण एवं अनुसंधान फार्म में किया गया। प्रयोग को फैक्टोरियल रैंडमाइज्ड ब्लॉक डिज़ाइन (Factorial RBD) में २७ विभिन्न उपचार संयोजनों के साथ संपन्न किया गया। इसमें फैक्टर A के अंतर्गत ह्यूमिक एसिड तथा समुद्री शैवाल का सत्त की ९ विभिन्न मात्राओं का मृदा अनुप्रयोग किया गया, जबकि फैक्टर B के अंतर्गत ३ विभिन्न पादप वृद्धि नियामकों (NAA, GA_3 तथा ट्रायकोंटानॉल) को विभिन्न सांद्रताओं में पर्णीय छिड़काव के रूप में प्रयोग किया गया। इस अध्ययन का उद्देश्य यह निर्धारित करना था कि कौन-सा जैव उत्तेजक तथा पादप वृद्धि नियामक का संयोजन हरित मिर्च की सर्वोत्तम वृद्धि प्रदान करता है। जैव उत्तेजक उपचारों में A3 [मोबीसेल-एच (८०% ह्यूमिक एसिड) @ १५ किग्रा./हेक्टेयर] उपचार में अधिकतम पौध ऊँचाई (४०.५० सेमी) दर्ज की गई। वहीं A5 [बायोविटा ग्रैन्यूल्स (८% समुद्री शैवाल का सत्त) @ ८ किग्रा./हेक्टेयर] उपचार में ९० DAT (रोपण के ९० दिन बाद) प्राथमिक शाखाओं की अधिकतम संख्या (८.८४) तथा पौधे का अधिकतम फैलाव (५०.३५ सेमी) प्राप्त हुआ। दूसरी ओर, परिपक्व पत्तियों में अधिकतम क्लोरोफिल-a (२४३.७६ मि.ग्रा./१०० ग्राम) तथा कुल क्लोरोफिल (a+b) (२०८.९० मि.ग्रा./१०० ग्राम) की मात्रा A3 [मोबीसेल-एच (८०% ह्यूमिक एसिड) @ १५ किग्रा./हेक्टेयर] उपचार में पाई गई। जबकि A5 [बायोविटा ग्रैन्यूल्स (८% समुद्री शैवाल का सत्त) @ ८ किग्रा./हेक्टेयर] उपचार में अधिकतम क्लोरोफिल-b (६७.७६ मि.ग्रा./१०० ग्राम) तथा एस्कॉर्बिक एसिड (विटामिन C) की मात्रा (१००.७२ मि.ग्रा./१०० ग्राम) दर्ज की गई।