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GC Vinay
M.Sc., Department of Horticulture Vegetable Science, CoA, IGKV, Raipur, Chhattisgarh, India

Rajshree Gayen
Senior Scientist, Department of Vegetable Science, CoA, IGKV, Raipur, Chhattisgarh, India

Kavita Kandpal
Professor, Department of Horticulture, UAS, GKVK, Bangalore, Karnataka, India

Corresponding Author:
GC Vinay
M.Sc., Department of Horticulture Vegetable Science, CoA, IGKV, Raipur, Chhattisgarh, India

Effect of foliar application of bio-stimulants on growth and yield of tomato (*Solanum lycopersicum*)

GC Vinay, Rajshree Gayen and Kavita Kandpal

Abstract
The experiment was conducted with the title of "Effect of foliar application of bio-stimulants on growth, yield and quality of tomato (*Solanum lycopersicum*)". The bio-stimulants used are Seaweed extract (*Ascophyllum* sp. and *Sargassum* sp.) and Humic acid. The twelve treatments include control (untreated plants); only RDF; RDF + FYM; *Asophyllum* sp. (1, 1.5 and 2 ml/L); *Sargassum* sp. (1, 1.5 and 2 ml/L); Humic acid (1.5, 3 and 4.5 ml/L). the foliar spray of these bio-stimulants taken during 20, 40 and 60 days after transplanting Experimental findings revealed that the foliar application of Humic acid at 3 ml/L recorded lesser days to the opening of the first flower (20 days), 50% flowering (22 days), first fruiting (29.33 days) and recorded higher plant height (122.73 cm), leaf chlorophyll content (55.82 (SPAD reading)), Leaf area per plant (2396.34 cm^2), root weight (146.80 gm), root length (31.40 cm), shoot weight (1736.45 gm), yield parameters like fruit yield per plant (6.57), number of fruits per plant (69.57), number of fruits per cluster (6.3), average fruit diameter (Equatorial (6.64 cm) and Polar (6.67 cm)), average fruit weight of ten fruits (924.1 gm) and average fruit length (6.10 cm).

Keywords: tomato, bio-stimulants, growth, yield and quality

Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important and most widely consumed vegetable crop in the world. Tomato is a member of the Solanaceae (Night shade) family, which includes many commercially important plants like potatoes, eggplants, tobacco, petunias, peppers (Capsicum) and *Physalis.* In India, tomato is grown throughout the country with an area of 852,000 ha and production of 21003, 000 MT (Anon., 2020). The leading tomato growing states are Andhra Pradesh, Madya Pradesh and Karnataka

Biofertilizers are helpful microorganisms that may transform nutritionally significant components from non-usable to usable forms through biological processes. It has shown to boost production in a variety of plants while also saving inorganic fertilizers (Olsen *et al.*, 1996) [12]. Direct effects of biostimulant substances and compounds comprise the stimulation of enzyme activities involved in glycolysis, Krebs cycle and nitrate absorption, as well as hormone activities. These natural compounds have been shown to boost nutrition absorption and utilisation efficiency for both macro and micro elements (Battacharyya *et al.*, 2015) [2]. The biostimulant mediated positive effects on plant nutrition, photosynthesis and secondary metabolism can enhance vegetable quality (Colla *et al.*, 2015) [4].

Seaweeds are a known source of plant growth regulators (Jameson, 1993), organic osmolites (e.g., betaines), amino acids, mineral nutrients, vitamins, and vitamin precursors (Berlyn and Russo, 1990) [3]. This bio-stimulant delivers a consistent and balanced formulation containing kahydrin, alginic acid and betaine, all of which contribute synergistically to the product's effectiveness (Vernieri *et al.*, 2006) [16].

Humic substances (HS) consist of several components, namely, humic acid (HA) fraction soluble in water at high pH, fulvic acid (FA) soluble in water at all pH, and a fraction, humin, not soluble in water at any pH. In addition, humic substances promote the conversion of a number of mineral elements into forms available to plants. The HS presence in soil may exert several effects on plant functions and some of these may result, directly or indirectly, in a modulation of ion uptake (Nardi *et al.*, 2002) [11].

Material and Methods

The experimental material for this study consisted of twelve treatments *viz.*, T1: Absolute Control (No fertilizers), T2: 100%RDF, T3: 100%RDF + FYM (38t/ha), T4: 100% RDF + FYM (38t/ha) + SWEA @ 1ml/litre, T5: 100% RDF + FYM (38t/ha) + SWEA @ 1.5ml/litre, T6: 100% RDF + FYM (38t/ha) + SWEA @ 2ml/litre, T7: 100%RDF + FYM (38t/ha) + SWES @ 1ml/litre, T8: 100%RDF + FYM (38t/ha) + SWES @ 1.5ml/litre, T9: 100%RDF + FYM (38t/ha) + SWES @ 2ml/litre, T10: 100%RDF + FYM (38t/ha) + Humic acid @ 1.5ml/litre, T11: 100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre, T12: 100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre. The foliar application of bio – stimulants was taken 20, 40, 60 days after transplanting

Observations was taken in five randomly selected plants in each treatment of plant growth and yield attributes viz. plant height **(**cm), Leaf chlorophyll content (SPAD), Leaf area per plant (cm^2), Root length(cm), Root weight (gm), Shoot weight (gm), Days to first flowering, Days to 50% flowering, Days to first fruiting, Average fruit weight (gm), Average fruit length (cm), Average fruit diameter (cm) (equatorial and polar), Number of fruits per cluster, Number of fruits per plant, Fruit yield per plant (kg). The recommended spacing (100 cm × 60 cm), plot size (42.5 m × 12 m) and followed package of practices. This experiment designed with RCBD. The observations was recorded in 30, 60 and 90 days.

Result and Discussion

The Plant height was recoreded in all the three stages (30, 60 and 90 DAT) of observations, all the treatments recorded significant differences in plant height (Table. 1) The treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) recorded significantly taller plants and recorded 64.8 cm, 114.45cm and 122.73 cm of plant height on 30, 60 and 90 days after transplanting respectively followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) which recorded 62.25 cm, 110.92 cm and 119.6 cm respectively. The lowest plant height was recorded in T1 (Absolute Control) with 51.83 cm, 92.40 cm and 99.20 cm respectively at 30, 60, 90 DAT, respectively. The growth stimulation by humic acid might be due to its effect on prolonged cell elongation. In general, cell elongation is ceased by a rapid increase in wall bound hydroxyproline. This mechanism reported by Vaughan (1974) would apply to the effect of humic acid on increased plant height.

The observation of root length was taken after the final harvest. The data showed significant differences in the mean root length among the treatments (Table 2). The mean root length varied from 17.60 cm in T_1 (Absolute Control) to 31.40 cm in T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by 29.70 cm in T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) and 26.80 cm in T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5 ml/litre). The plant's ability to forage from deeper layers is determined by the length of its root. A well-developed root system facilitates in the effective uptake of nutrients, resulting in a healthy plant. The results were similar to the earlier findings of Sladky (1969) [14] who reported that humic acid enhanced cell elongation by as much as 60 percent in the root tips of tomato.

The observation of root weight was taken after the final harvest. The data showed significant differences in the mean root weight among treatments (Table 2). The mean root weight varied from 53.90 gm to 146.80 gm. T_{11} (100% RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) showed highest root weight (146.80 gm) followed by 136.80 gm in T_{12} (100% RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) and 130.30 gm in T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5 ml/litre). The treatment T_1 (Absolute control) recorded the lowest root weight (53.90 gm). It might due to the phytohormone auxin which is present in humic acid to regulate the initiation and emergence phases of lateral root development. It has been reported that auxin can induce *de novo* synthesis of the PM H^+ -ATPase in plant tissues (Hager *et al.* 1991) [9]. and Simlar observation was recorded maize where the the major isoform (MHA2) expressed in maize was induced by humic substances (Quaggiotti *et al.* 2004).

The observation on shoot weight was taken at the time of the final harvesting. This showed differences in the mean shoot weight among various treatments (Table 2). The mean shoot weight varied from 517.60 gm in T_1 (Absolute Control) to 1736.45 gm in T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by 1653.62 gm in T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) and 1596.72 gm in T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5 ml/litre). It might be due to effect of application of balanced nutrition and timely availability of nutrients from humic acid spray which increases the cell elongation and division results rapid growth of vegetative characters which increases the plant shoot weight. Similar findings are reported in radish (EL-Sayed *et al*., 2014) [7].

The plant cholrophyll content (Table 3). The treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) recorded significantly highest reading 59.34, 56.18 and 55.82 of plant chlorophyll content at30, 60 and 90 days after transplanting, respectively followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) which was recorded 55.72, 53.12 and 52.16 respectively. The lowest plant chlorophyll content was recorded in T_1 (Absolute Control) with 45.08, 43.48 and 41.20 SPAD reading, at all the growth stages (30, 60 and 90 DAT), respectively. The leaf chlorophyll content is the key factor determining the rate of photosynthesis. It is also considered as an index of metabolic efficiency of the plant to utilize the absorbed nutrients. Chen *et al*. (2001) reported that photosynthetic rate of cucumber was highly correlated with chlorophyll content.

The observation on leaf area were recorded at the time after the final harvest. Significant differences in the mean leaf area between treatment (Table 7). The mean leaf area varied from 1931.84 cm^2 in T_1 (Absolute Control) to 2396.34 cm^2 in T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by 2234.15 cm^2 in T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre). Plants ultimately depend on green leaf surface for dry matter accumulation as the leaves intercept solar radiation and produce photosynthates through photosynthesis. The production, expansion and survival of green leaf area are the important determinants of crop productivity.

No significant difference with region to days taken for first flowering was recorded for various treatments (Table 5) Earliest flowering was recorded in the treatment T_{11} (100% RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) was 20 days which was on par with the treatment T_3 (100%RDF + FYM (38t/ha)), T_5 (100% RDF + FYM (38t/ha) + SWEA @ 1.5ml/litre), T_7 (100%RDF + FYM (38t/ha) + SWES @ 1ml/litre), and T_{12} (100% RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) was recorded (20 days). The treatment T_1 (Absolute Control) had taken the longest duration for bud opening (21 days).

Significant differences were noted with regard to days taken for 50% flowering (Table 5) in the all treatments. The treatment T_8 (100%RDF + FYM (38t/ha) + SWES @ 1.5ml/litre) and T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) both recorded earliest flower opening (22 days). Which is on par with T_2 (100%RDF + FYM (38t/ha) and T_{12} (100% RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) was recorded 22.33 days. The treatment T_1 (Absolute Control) had taken the longest duration (24 days). This might due to rapid translocation of photosynthesis and it accelerated towards initiation of flower buds which leads to earliness in flower initiation.

Significant differences were noted with regard to days taken for 1st fruiting (Table 5) in all the treatments. The treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) recorded earliest fruiting (29.33) days followed by the treatment T_9 (100%RDF + FYM (38t/ha) + SWES @ 2ml/litre) and T_{12} (100%RDF + FYM (38t/ha) + Humic acid@ 4.5ml/litre) both recorded (29.67days). The treatment T_1 (Absolute Control) had taken the longest duration for 50 % flowering (30.67 DAT).

Statistical analysis showed that there were significant differences in the average fruit weight (Table 6) among different treatments. The observations recorded on average fruit weight are given. The range for average fruit weight varied from 734.3 gm to 924.1 gm. Maximum average fruit weight was observed in treatments T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) (924.1 gm) followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid@ 4.5ml/litre) (916.5 gm). whereas, the minimum average fruit (734.3 gm) weight was noticed in T_1 (Absolute control). Similar finding were reported in tomato by (Feleafel and Mirdad, (2014) [8].

The maximum fruit length (6.10 cm) (Table 6) was recorded in treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) (6.03 cm) and minimum average fruit length (5.78 cm) was recorded in T_1 (Absolute Control).

The observation recorded on average fruit diameter is presented in Table 7. The equatorial fruit diameter (6.64) was statistically significant to reveal the effect of treatments and the maximum equatorial fruit diameter was observed in treatment T_{11} (100% RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by 6.53 cm in T_{12} (100% RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) and T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5ml/litre) whereas, treatment T_1 (Absolute Control) exhibited the minimum average fruit equatorial fruit diameter (5.96 cm).

The data recorded on polar fruit diameter revealed that the average polar fruit diameter was significantly affected by various treatments (Table 6). The maximum polar fruit diameter (6.67 cm) was recorded in treatment T_{11} (100% RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) i.e. 6.40 cm and minimum fruit polar diameter (5.73 cm) was recorded in T_1 (Absolute Control). Similar findings were reported in kiwifruit **(**Mahmoudi *et al*., 2014) [10] and tomato (Feleafel and Mirdad, 2014) [8].

The observation recorded on number of fruits per cluster is presented in Table 7. The trait was statistically significant to reveal the effect of treatments and the maximum number of fruits per cluster was observed in treatment T_{11} (100% RDF + FYM(38t/ha) + Humic acid @ 3ml/litre) (6.3 fruits per cluster) followed by 6.2 and 6.1 fruits per cluster in T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5ml/litre and T_{12} (100%RDF + FYM (38t/ha)+ Humic acid @ 4.5ml/litre), respectively. whereas, treatment T_1 Absolute control exhibited the minimum number of fruits per cluster (4.5). The increase in fruit setting can again be explained by the presence of adequate level of auxin. Inhibition of peroxidase activity by humic acid (Muscolo *et al*., 1993) [11] led to reduction in the auxin breakdown and promoted fruit setting. Similar findings were reported by Feleafel and Mirdad, (2014) [8].

A significant effect of the treatments on number of fruits per plant was noticed and the data related to it is given in table 7. Among the treatments, T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) exhibited the maximum number of fruits per plant (69.57) followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) is 63.23 and T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5ml) is 58.67. While, the minimum number of fruits per plant was recorded in T_1 (Absolute control) is 23.0. The range of number of fruits per plant varied between 23.0 to 69.57. The beneficial effect of humic acid as antioxidant on photosynthesis pigments may be due to decreasing the role of photochemical reactions, chloroplast structure, photosynthetic electron transfer as well as photosynthesis. And also due to application of balanced nutrition and timely availability of nutrients from foliar spray may increases numper of fruits per plant and yield Similar finding are reported in tomato (Feleafel and Mirdad, 2014) [8], El-Hamied (2014) [6] for valancia orange.

The fruit yield per plant increased significantly with application of various biostimulants. The data with regards to fruit yield per plant is presented in Table 7. Among the treatments the maximum fruit yield per plant (6.57 kg) was exhibited by treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) followed by T_{12} (100%RDF + FYM (38t/ha) + Humic acid @ 4.5ml/litre) is 5.87 kg/plant and T_{10} (100%RDF + FYM (38t/ha) + Humic acid @ 1.5ml) (5.63 kg/plant), whereas, the minimum number of fruits per plant was recorded in T_1 (Absolute control) (2.10 kg). These results coincide with the findings of Saruhan *et al.* (2011) and Hafez and Soubei (2012). Humic acid increases the yield attributes by activating hormones like auxin and cytokinin and by increasing the cell division and enlargement. Similar results were also found by Bakry *et al.* (2013) for wheat, Mahmoudi *et al*. (2014) [10] for *Actindia deliciosa*, El-Hamied (2014) [6] for Valancia orange, EL-Sayed *et al.* (2014) [7] for radish and Feleafel and Mirdad (2014) [8] for tomato.

Tables 1: Effect of bio-stimulants on plant height (cm) of tomato

Treatments	Plant height(cm)		
	30DAT	60DAT	90DAT
T_1	51.83	92.40	99.20
T_2	59.32	101.20	104.23
T_3	60.32	103.12	106.57
T_4	61.75	105.92	111.60
T_5	60.63	104.80	110.70
T_6	60.54	103.71	109.60
T_7	61.67	105.41	110.60
T_8	61.8	106.42	112.60
T_9	60.31	106.13	108.60
T_{10}	61.92	109.12	115.10
T_{11}	64.8	114.5	122.73
T_{12}	62.25	110.92	119.60
S.Em±	0.820	1.063	0.749
CD (5%)	2.406	3.118	2.198

Table 2: Effect of bio-stimulants on shoot weight, root length and root weight

Treatments	Shoot weight(gm)	Root weight(gm)	Root length(cm)
T_1	517.60	53.90	17.60
T_2	985.59	66.20	20.30
T_3	1037.29	109.30	23.20
T_4	1456.75	121.40	15.50
T_5	1432.46	115.60	24.60
T_6	1235.36	112.40	25.30
T_7	1336.56	119.50	23.90
T_8	1517.32	128.90	25.90
T_9	1357.32	120.70	22.60
T_{10}	1596.72	130.30	26.80
T_{11}	1736.45	146.80	31.40
T_{12}	1653.62	136.80	29.70
S.Em±	7.090	0.566	0.095
CD (5%)	20.794	1.660	0.279

Table 3: Effect of bio-stimulants on leaf chlorophyll content (SPAD)

Treatments	Leaf chlorophyll content (SPAD)		
	30DAT	60DAT	90DAT
T_1	45.08	43.48	41.20
T_2	50.72	50.34	49.32
T_3	51.35	52.06	51.32
T_4	53.83	51.83	50.61
T_5	53.15	51.14	50.12
T_6	52.42	50.35	51.36
T_7	52.62	51.46	48.32
T_8	54.68	52.28	47.36
T_9	52.44	50.44	51.16
T_{10}	54.55	52.92	51.32
T_{11}	56.49	56.18	55.82
T_{12}	55.72	53.12	52.16
S.Em±	0.0.64	0.061	0.072
CD (5%)	0.188	0.180	0.212

Table 4: Effect of bio-stimulants on leaf area per plant and average fruit weight

Treatments	leaf area per plant (cm^2)	Average fruit weight (gm)
T_1	1931.84	734.3
T_2	1946.35	740.5
T_3	2015.46	816.1
T_4	2153.45	915.4
T_5	2093.64	897.4
T_6	2135.65	842.7
T_7	2017.54	907.2
T_8	2196.32	868.06
T_9	2113.52	845.4
T_{10}	2205.54	916.3
T_{11}	2396.34	924.1
T_{12}	2234.15	916.5
S.Em±	2.747	1.40
CD (5%)	8.058	4.106

Table 5: Effect of bio-stimulants on flowering parameters

Treatments	Days to first flowering (DAT)	Days to 50% flowering (DAT)	Days to 1st fruiting
T_1	21.00	24.00	30.67
T_2	20.67	22.57	31.00
T_3	20.00	22.67	30.00
T_4	21.00	22.67	30.33
T_5	20.00	22.67	30.33
T_6	20.33	22.67	31.33
T_7	20.00	22.67	30.33
T_8	20.67	22.00	30.00
T_9	21.00	22.67	29.67
T_{10}	20.33	22.67	30.67
T_{11}	20.00	22.00	29.33
T_{12}	20.00	22.33	29.67
S.Em±	0.407	0.223	0.385
CD (5%)	1.194	0.654	1.129

Table 6: Effect of bio-stimulants on fruit length and fruit diameter

Treatments	Average Fruit length (cm)	Fruit diameter(cm)	
		Equatorial (cm)	Polar(cm)
T_1	5.78	5.96	5.73
T_2	5.87	6.04	5.86
T_3	5.56	6.20	6.04
T_4	6.01	6.36	6.23
T_5	6.09	6.46	6.08
T_6	6.00	6.5	6.23
T_7	5.91	6.37	6.28
T_8	5.87	6.23	6.29
T_9	5.91	6.4	6.20
T_{10}	5.93	6.53	6.36
T_{11}	6.10	6.64	6.67
T_{12}	6.03	6.53	6.4
S.Em±	0.003	0.004	0.005
CD (5%)	0.009	0.013	0.015

Table 7: Effect of bio-stimulants on yield attributes.

Treatments	Number of fruits per plant	Yield per plant (Kg)	Fruits per cluster
T_1	23.00	2.10	4.5
T_2	43.33	4.13	5.0
T_3	51.32	4.93	5.3
T_4	54.14	5.29	5.6
T_5	52.15	5.20	5.7
T_6	51.13	5.07	5.4
T_7	53.34	5.21	5.6
T_8	55.33	5.37	5.9
T_9	50.65	5.28	5.4
T_{10}	58.67	5.63	6.2
T_{11}	69.57	6.57	6.3
T_{12}	63.23	5.87	6.1
S.Em±	0.748	0.023	0.01
CD (5%)	2.193	0.067	0.032

Conclusion

A field experiment was conducted at the Department of Horticulture, University of Agricultural Sciences, GKVK campus, Bengaluru-65 during *rabi* season in year of 2021-2022 to investigate the "Effect of foliar application of bio-stimulants on growth, yield and quality of tomato (*Solanum lycopersicum*)" The experiment consisted of twelve treatments laid out in Randomised Complete Block Design with three replications. The treatment T_{11} (100%RDF + FYM (38t/ha) + Humic acid @ 3ml/litre) has shown best result.

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