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Abhishek D
M.Sc. Scholar, Department of Agronomy, College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSN UAHS), Shivamogga, Karnataka, India

Basavaraj Naik T
Associate Professor and Senior Farm Superintendent, Zonal Agricultural, and Horticultural Research, Station, Navile, KSN UAHS, Shivamogga, Karnataka, India

Veeranna HK
Professor, Department of Agronomy, KSN UAHS, Shivamogga, Karnataka, India

Thippesha D
Professor and Head, Department of Horticulture, KSN UAHS, Shivamogga, Karnataka, India

Dhananjaya BC
Professor and Head, Department of Soil Science, KSN UAHS, Shivamogga, Karnataka, India

Corresponding Author:
Abhishek D
M.Sc. Scholar, Department of Agronomy, College of Agriculture, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences (KSN UAHS), Shivamogga, Karnataka, India

Effect of biostimulant on growth, yield and nutrient uptake of tomato (*Lycopersicon esculentum* L.) under southern transition zone of Karnataka

Abhishek D, Basavaraj Naik T, Veeranna HK, Thippesha D and Dhananjaya BC

Abstract
A field experiment was carried out at ZAHRS, Navile, KSN University of Agricultural and Horticultural Sciences, Shivamogga, India, during *Rabi* 2022, to study the effect of biostimulant on growth, yield and nutrient uptake of tomato (*Lycopersicon esculentum* L.) under southern transition zone of Karnataka (zone 7). The experiment was laid out in Randomised Block Design with eleven treatments and replicated thrice. The treatments include *viz.*, standard check (only package of practice) (T_1), foliar application of biostimulant @ 1 ml l^{-1} (T_2), 2 ml l^{-1} (T_3), 2.5 ml l^{-1} (T_4), 3 ml l^{-1} (T_5) and 4 ml l^{-1} (T_6) each at pre-flowering, flowering and fruit development stages and soil application of biostimulant @ 10 kg ha^{-1} (T_7), 15 kg ha^{-1} (T_8), 17.5 kg ha^{-1} (T_9), 20 kg ha^{-1} (T_{10}) and 25 kg ha^{-1} (T_{11}) each at transplanting and pre-flowering stage. The results revealed, significantly higher plant height (103.75 cm), number of branches per plant (30.93), leaf area index (1.77) and total dry matter (282.32 g $plant^{-1}$) at grand growth stage were recorded in foliar application of biostimulant @ 4 ml l^{-1} (T_6) followed by soil application of biostimulant @ 25 kg ha^{-1} (T_{11}). The yield traits of tomato *viz*., No. of fruits $plant^{-1}$ (43.62), mean fruit weight (125.16 g), fruit diameter (5.85 cm) and fruit yield per plant (4.37 kg) were higher in foliar application @ 4 ml l^{-1} followed by soil application @ 25 kg ha^{-1}. Significant improvement in tomato fruit yield (71.76 t ha^{-1}) was recorded, which was 20.97 percent higher in T_6 over standard check. The uptake of nutrients also follows a similar trend. Foliar application @ 4 ml l^{-1} recorded significantly higher total uptake of nitrogen (161.26 kg ha^{-1}), phosphorus (27.94 kg ha^{-1}) and potassium (235.10 kg ha^{-1}) at harvest.

Keywords: Tomato, biostimulant, foliar & soil application, growth & yield, nutrient uptake

Introduction
Tomato (*Lycopersicon esculentum* L.) is one of the most important solanaceous vegetable crops grown all over the world throughout the year due to its wider adaptability under various agro-climatic conditions, high-yielding potential and suitability for a variety of uses in both fresh and processed food industries. It is a tropical day-neutral plant. Tomato is also known as "protective food" due to its unique nutritional value. Tomatoes are a significant source of antioxidants in the diet, including phenolics, carotenoids (especially lycopene and beta-carotene), vitamin C (ascorbic acid) and trace amounts of vitamin E (Rai *et al*., 2012) [25]. In the world, tomato ranks second in importance after potato and is the most important vegetable for processing. India ranks second in the area and production of tomato in the world after China. In India, it has been cultivated at an area of 8.40 lakh hectares with a production of 203.31 lakh million tonnes (MT) and productivity of 24.20 MT ha^{-1} (indiastat.com) [1]. However, the productivity of tomato is very low compared to advanced countries due to poor nutrient management practices and low nutrient availability to crop during pre-flowering, flowering and fruit development stages.

Several efforts have been made to increase tomato productivity by developing a large number of high yielding, quality and disease resistant varieties and hybrids, improved production and protection management practices. However, it has become intangible to increase the yield. After the green revolution, the use of chemical fertilizers and pesticides in plant production posed a serious threat to ecology and the environment. Problems like leaching, volatilization, denitrification of nitrogen and deposition of non-available phosphorus in the soil also result from the heavy use of chemical fertilizers (Maurya and Beniwal, 2003) [21]. The current global scenario firmly emphasizes the need to adopt eco-friendly agricultural practices for sustainable production.

To cope with all these problems, a cheaper, better and safer way to improve soil cope with all these problems, a cheaper, better and safer way to improve soil fertility status and maximize productivity with minimum eco hazards is necessary. In this context, the use of biostimulants, which has no residual effect, appears to be the most important new tool in increasing the yield of vegetables, especially tomato crop.

The biostimulants have evolved as a supplement to mineral fertilizers and hold a promise to enhance the quality and yield of crops. Among various categories of biostimulants, humic substances (HS) are one such biostimulant that promotes crop growth and development, thereby increasing crop productivity. Humic substances (HS) are the innate components of the soil organic matter, which is not only the consequence of the degradation of plant, animal and residue of microorganisms but also the metabolic products of soil micro-organisms utilizing such degraded components. HS consists of two main fractions based on their atomic mass and solubility: Humic Acid (HA) and Fulvic Acid (FA). HA is a dark brown to black substance insoluble in water at acidic pH, while FA is a yellow to brown substance soluble in water at all pH values. HA and FA can act as biostimulants by chelating metal ions, enhancing soil fertility, stimulating root growth, increasing nutrient availability and uptake, modulating plant hormone levels, activating enzymatic systems, inducing antioxidant responses and improving plant resistance to abiotic and biotic stresses. HS affect the physical, physicochemical, chemical and biological properties of soil and plays a vital role in improving soil fertility (Bhupenchandra *et al.*, 2020) [7]. The objective is to find out whether tomato growth, yield and nutrient uptake is influenced by biostimulant application.

Materials and Methods

Description of the site and treatment setup

A field experiment was carried out during the *Rabi* season of 2022 at Zonal Agricultural and Horticultural Research Station, Navile, KSNUAHS, Shivamogga, situated at 13° 58' to 14° 1' North latitude and 75° 34' to 75° 42' East longitude with an altitude of 650 m above the mean sea level. The investigation site had soil in sandy loam in texture, slightly acidic and non-saline (pH: 6.26, EC: 0.22 dS m^{-1}), low in organic carbon (3.62 g kg^{-1}) (Walkley and Black, 1934) [36], low in available nitrogen (258.26 kg ha^{-1}) (Subbiah and Asija, 1956) [32], medium in available phosphorus (33.49 kg ha^{-1}) (Jackson, 1973) [16] and medium in available potassium (154.68 kg ha^{-1}) (Jackson, 1973) [16]. The experimental site falls under the Southern Transition Zone of Karnataka. The mean temperatures during the experiment were 28-31 °C in the day time and 15-21 °C at night. The relative humidity was 70-90%. Total rainfall received during the study period was 246.6 mm. The experiment was conducted in a randomized block design, replicated thrice consisting of 11 treatments *viz.*, standard check (only package of practice) (T_1), foliar application of biostimulant @ 1 ml l^{-1} (T_2), 2 ml l^{-1} (T_3), 2.5 ml l^{-1} (T_4), 3 ml l^{-1} (T_5) and 4 ml l^{-1} (T_6) each at pre-flowering, flowering and fruit development stages and soil application of biostimulant @ 10 kg ha^{-1} (T_7), 15 kg ha^{-1} (T_8), 17.5 kg ha^{-1} (T_9), 20 kg ha^{-1} (T_{10}) and 25 kg ha^{-1} (T_{11}) each at transplanting and pre-flowering stage. A common package of practices (PoP), *i.e.*, 250:250:250 kg NPK ha^{-1} and 25 t ha^{-1} FYM, followed for all the treatments. The biostimulant used in the experiment contains both humic acid and fulvic acid (humic substances). The tomato seedlings of *Arka Abhed* hybrid were transplanted in field at 25 days after sowing at a spacing of 90 × 45 cm with a depth of 3-5 cm. The prescribed fertilizer dosage was administered in two separate doses. Biostimulant was applied as a soil application at transplanting and pre-flowering stage and as a foliar application at pre-flowering, flowering and fruit development stages. Plant protection chemicals, irrigation, staking and weed management were taken accordance with a standard package of practices.

Data collection

Observations were recorded on various phenological growth stages *viz.*, plant height (cm), number of branches $plant^{-1}$, leaf area and leaf area index. Destructive samples were collected for dry matter estimation (dried in a hot air oven at 65-70 °C) from the gross plot area. The leaves from five representative plants were fed to leaf area meter (Model LI-COR 3100) and leaf area index was calculated by dividing total leaf area by total ground area. The geometric mean diameter of tomato fruits was calculated using the equation given by Mohsenin (1986) [24], *i.e.*, $D_g = (LD^2)^{1/3}$, where 'Dg' is the geometric mean (cm), 'L' is the longitudinal diameter (cm) and 'D' is the equatorial diameter (cm). The tomato is harvested at the edible fruit maturity stage through hand picking treatment wise separately, the yield from net plot area is converted into tonnes per hectare (t ha^{-1}) and considered as final yield. The plant and fruit samples were collected at the final harvest. Samples were dried to facilitate fine grinding. The uprooted finely grounded samples were analyzed for total nitrogen (Jackson, 1973) [16], phosphorous (Jackson, 1973) [16] and potassium (Jackson, 1973) [16]. Nitrogen, phosphorus and potassium uptake was calculated for plant, fruit and total uptake for each treatment separately using the formula given below and expressed in kg ha^{-1}.

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)}}{100} \times \text{Dry matter (kg ha}^{-1}\text{)}$$

Statistical analysis

Data were statistically analysed using the analysis of variance (ANOVA) technique applicable to the randomized block design. The significance of the treatment effect was determined using F-test; the means of the treatments are tested using the critical differences (CD) at the 5% probability level. Wherever the 'F' ratio was found non-significant, the critical difference has not been mentioned but indicated as 'NS'.

Results and Discussion

The growth, yield and nutrient uptake of tomato were significantly influenced by biostimulant application and experimental results in detail were discussed in the following paragraphs and represented in Tables 1, 2, 3 and 4.

Growth and growth attributes of tomato

The results obtained in experiment varied significantly (p=0.05) due to biostimulant application at 30, 60 and 90 DAT. Significantly higher plant height was recorded with T_6 treatment *i.e.*, foliar application of biostimulant @ 4 ml l^{-1} (40.05, 103.75 and 124.67 cm) and was statistically on par with T_{11} *i.e.*, soil application of biostimulant @ 25 kg ha^{-1} (40.10, 102.31 and 122.86 cm), respectively (Table 1). The standard check treatment (no biostimulant application) produced shorter plants at all stages (38.73, 95.21 and 113.88 cm) (T_1). Plant height as the dominant growth attribute linearly influences other attributes of the crop, thus accommodating higher branches. Significantly, higher number of branches were found in T_{11} (8.73) and lowest in T_1 (7.40) at 30 DAT. Foliar application of biostimulant @ 4 ml l^{-1} (T_6) recorded significantly higher number of branches (30.93 and 34.86) at 60 and 90 DAT, respectively and was on par with soil application of biostimulant @ 25 kg ha^{-1} (30.49 and 33.93). The least number of branches $plant^{-1}$ (26.85 and 29.91) was recorded with the standard check treatment.

Similarly, significantly higher leaf area and LAI was registered in the foliar application of biostimulant @ 4 ml l^{-1} (T_6) and was on par with soil application of biostimulant @ 25 kg ha^{-1} (T_{11}) at 30, 60 and 90 DAT, respectively, and least was found in standard check (Table 2). Significantly higher leaf area (7.23, 71.50 and 45.86 dm^2 $plant^{-1}$ at 30, 60 and 90 DAT, respectively) was registered with T_6 and was on par with T_{11} (7.21, 70.35 and 44.79 dm^2 $plant^{-1}$ at 30, 60 and 90 DAT, respectively). Significantly, a lower leaf area was recorded with the standard check treatment (6.31, 59.23 and 35.94 dm^2 $plant^{-1}$ at 30, 60 and 90 DAT, respectively). The LAI reached maximum at grand growth stage (60 DAT) and declined at the maturity (90 DAT). The highest LAI in our experiment was registered in T_6 (foliar application of biostimulant @ 4 ml l^{-1}) (0.18, 1.77 and 1.13) followed by T_{11} (0.18, 1.74 and 1.11) at 30, 60 and 90 DAT, respectively. The least LAI was recorded with the standard check treatment (0.16, 1.46 and 0.89 at 30, 60 and 90 DAT, respectively). Dry matter production (DMP) at grand growth stage significantly varied due to different levels and methods of biostimulant application. Significantly, higher dry matter production (128.46, 153.86 and 282.32 g $plant^{-1}$ of plant, fruit and total dry matter, respectively) at the grand growth stage was registered with T_6 (foliar application of biostimulant @ 4 ml l^{-1}). The subsequent best treatment was T_{11} with dry matter production (126.99, 149.50 and 276.49 g $plant^{-1}$ of plant, fruit and total dry matter, respectively) and was on par with T_6. Standard check treatment recorded significantly lowest plant, fruit and total dry matter production (114.87, 120.45 and 235.32 g $plant^{-1}$).

Table 1: Plant height and number of branches of tomato as influenced by different levels and methods of biostimulant application

Treatments	Plant height (cm)			Number of branches $plant^{-1}$		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
T_1: Standard check	38.73	95.21	113.88	7.40	26.85	29.91
T_2: Foliar application of biostimulant @ 1 ml l^{-1}	38.98	96.88	115.25	7.67	27.66	30.78
T_3: Foliar application of biostimulant @ 2 ml l^{-1}	39.36	97.68	116.78	8.07	28.29	31.27
T_4: Foliar application of biostimulant @ 2.5 ml l^{-1}	39.43	98.46	118.36	8.30	29.04	32.21
T_5: Foliar application of biostimulant @ 3 ml l^{-1}	39.62	100.31	121.33	8.47	29.80	33.18
T_6: Foliar application of biostimulant @ 4 ml l^{-1}	40.05	103.75	124.67	8.53	30.93	34.86
T_7: Soil application of biostimulant @ 10 kg ha^{-1}	39.35	96.36	114.89	7.93	27.53	30.32
T_8: Soil application of biostimulant @ 15 kg ha^{-1}	39.42	97.11	116.13	8.53	28.07	31.01
T_9: Soil application of biostimulant @ 17.5 kg ha^{-1}	39.49	98.29	117.51	8.60	28.47	31.99
T_{10}: Soil application of biostimulant @ 20 kg ha^{-1}	39.94	99.12	119.54	8.67	29.33	32.66
T_{11}: Soil application of biostimulant @ 25 kg ha^{-1}	40.10	102.31	122.86	8.73	30.49	33.93
S.Em. ±	0.68	1.55	1.73	0.37	0.53	0.75
CD (p=0.05)	NS	4.58	5.11	NS	1.57	2.21

Note

a. Recommended dose of fertilizers (250:250:250 kg N: P: K ha^{-1}) and FYM (25 t ha^{-1}) are commonly applied to all treatments
b. Foliar application was done each at the pre-flowering, flowering and fruit development stages
c. Soil application was done each at the transplanting and pre-flowering stage
d. Biostimulant contains both humic acid and fulvic acid

Table 2: Leaf area, leaf area index (LAI) and dry matter production (at grand growth stage) of tomato as influenced by different levels and methods of biostimulant application

Treatments	Leaf area (dm^2 $plant^{-1}$)			Leaf area index			Dry matter production (g $plant^{-1}$)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	Plant	Fruit	Total
T_1: Standard check	6.31	59.23	35.94	0.16	1.46	0.89	114.87	120.45	235.32
T_2: Foliar application of biostimulant @ 1 ml l^{-1}	6.63	62.19	37.42	0.16	1.54	0.92	117.87	129.03	246.90
T_3: Foliar application of biostimulant @ 2 ml l^{-1}	6.95	64.44	39.56	0.17	1.59	0.98	120.70	133.03	253.73
T_4: Foliar application of biostimulant @ 2.5 ml l^{-1}	7.03	66.54	41.29	0.17	1.64	1.02	121.50	137.42	258.92
T_5: Foliar application of biostimulant @ 3 ml l^{-1}	7.16	68.51	44.24	0.18	1.69	1.09	125.71	143.26	268.97
T_6: Foliar application of biostimulant @ 4 ml l^{-1}	7.23	71.50	45.86	0.18	1.77	1.13	128.46	153.86	282.32
T_7: Soil application of biostimulant @ 10 kg ha^{-1}	6.52	61.61	37.13	0.16	1.52	0.92	118.28	130.62	248.90
T_8: Soil application of biostimulant @ 15 kg ha^{-1}	6.81	63.58	39.42	0.17	1.57	0.97	120.53	133.73	254.26
T_9: Soil application of biostimulant @ 17.5 kg ha^{-1}	6.96	66.26	40.06	0.17	1.64	0.99	121.21	136.91	258.12
T_{10}: Soil application of biostimulant @ 20 kg ha^{-1}	7.08	67.87	42.32	0.17	1.68	1.04	124.46	141.83	266.29
T_{11}: Soil application of biostimulant @ 25 kg ha^{-1}	7.21	70.35	44.79	0.18	1.74	1.11	126.99	149.50	276.49
S.Em. ±	0.40	1.63	1.12	0.01	0.04	0.03	2.35	3.94	5.30
CD (p=0.05)	NS	4.80	3.31	NS	0.12	0.08	6.92	11.62	15.63

The increased plant growth of tomato with biostimulant application at higher levels (T_6 and T_{11}) was attributed to the stimulatory effect of HS on plant growth and enzymatic activities. Taller plants and more branches recorded with treatments T_6 and T_{11} were attributed to the role of HS in stimulating meristematic growth through its effect on the synthesis of growth hormones and its positive impact on chlorophyll content, thereby accumulating more photosynthates in plant tissue. Humic acid helps promote growth by decreasing IAA oxidase activity and boosting metabolic activities, which increases plant height. The higher number of branches is due to better nutrient uptake and translocation. Applying biostimulant at higher levels along with RDF will balance growth hormones like auxin and gibberellins that improve the side branches proportionally to height. The increase in number of branches with increased levels of biostimulant might be due to increased physiological processes by better utilization of applied NPK fertilizers and by maintaining balance in enzymatic, stomatal activity (water use), transport of nutrients and photosynthates. The results are in line with the findings of Bama *et al*. (2004) [4], Sangeetha and Singaram (2007) [28] and Ulukan (2008) [34], who got taller plants in wheat for humic acid application, while Meganid *et al*. (2015) [23] in common bean seen the same effect.

Improvement in growth parameters of tomato in biostimulant applied plot is attributed to high photosynthetic potential development like leaf area, LAI, leaf area duration (LAD) and chlorophyll content. Plant canopies intercept light with varying degrees of efficiency associated chiefly with their leaf area index and its functionality. The efficiency of interception of incident light, combined with the efficiency of the leaves' photochemical reactions, determine the canopy's efficiency in utilizing radiant energy per unit of land area. Higher leaf area is due to the higher number of leaves and branches. HS can promote LAI in plants by affecting various physiological and biochemical processes related to plant growth and productivity in leaves and roots. Some of these processes include chlorophyll synthesis and photosynthesis, root development and nutrient uptake, hormone production and stress responses (Canellas and Olivares, 2014; Shah *et al*., 2018) [8, 30]. The higher photosynthetic potential in plots that received humic substances is also due to the biostimulatory/growth regulator effect on growth, which measures total dry matter/biomass development of photosynthetic apparatus, *i.e.*, leaf area, leaf area index and leaf area duration. Delfine *et al*. (2005) [11] also opined that the hormonal effect of humic acid on plant growth and transitional production of plant dry mass was due to the foliar application of humic acid in corn.

To get higher yields in any crop, the plant needs to produce more total dry matter and distribute it to different plant parts. It also needs to move more photosynthates to the sink. The amount of total dry matter that goes to each plant part depends on how the environment affects the growth. For example, the amount of light the plant can use for photosynthesis, the temperature of air and leaf, relative humidity, CO_2 level and soil moisture. Higher total dry matter in tomato crops is mainly due to its higher plant (leaf + stem) dry weight and fruit dry weight. Higher total dry matter in the treatments that received humic substances both through foliar and soil might be due to the balanced availability of macro and micronutrients at all stages by preventing their fixation and precipitation, thereby improving nutrient use efficiency and better availability of nutrients in the soil. The magnitude of dry matter can be more meaningfully interpreted in terms of leaf number, leaf area, LAI and LAD. All these put together can be referred to as photosynthetic apparatus. These results are in line with Gulser *et al.* (2010) [14] in pepper, Cavalcante *et al*. (2011) [9] in papaya and Mayi *et al.* (2014) [22] in olive.

Yields attributes and tomato yield

The response of yield attributes of tomato significantly influenced by different levels and methods of biostimulant application (Table 3). The maximum number of fruits per plant (43.62) was recorded with foliar application of biostimulant @ 4 ml l^{-1} (T_6), which was statistically on par with soil application of biostimulant @ 25 kg ha^{-1} (T_6) (41.46). Mean individual fruit weight and fruit diameter registered the highest values of 125.16 g and 5.85 cm, respectively, with T_6 and on par with T_{11} (122.94 g and 5.62 cm). Significantly, the least number of fruits $plant^{-1}$ (33.87), mean fruit weight (111.29) and fruit diameter (4.76 cm) was recorded with the standard check treatment. Significantly, higher fruit yield (4.37 kg $plant^{-1}$ and 71.76 t ha^{-1}) of tomato was registered with T_6 (foliar application of biostimulant @ 4 ml l^{-1}) which was statistically at par with T_{11} (4.32 kg $plant^{-1}$ and 70.61 t ha^{-1}). Significantly, the lowest fruit yield (3.61 kg $plant^{-1}$ and 59.32 t ha^{-1}) was recorded with the standard check treatment. Treatment T_6 resulted in 20.97 percent improvement in fruit yield over standard check treatment, which was closely followed by treatment T_{11} with 19.03 percent yield improvement.

Combined effect of growth as well as yield attributing characters reflected on fruit yield of tomato. There was a strong correlation between yield components yield $plant^{-1}$, number of fruits $plant^{-1}$, mean fruit weight (g) and fruit diameter was obtained. Biostimulant might be associated with an increased number of branches, improved leaf area, enhanced chlorophyll content and higher dry matter accumulation obtained through the usage of biostimulant can be attributed to these enhanced yield attributes. These are in line with the findings of Russo *et al*. (1993) [26], Kumar *et al*. (2000) [20] and Gore *et al*. (2007) [13] in marigold, bell pepper and chilli, respectively.

Table 3: Yield attributes and yield of tomato as influenced by different levels and methods of biostimulant application

Treatments	Number of fruits $plant^{-1}$	Mean fruit weight (g)	Fruit diameter (cm)	Yield (kg $plant^{-1}$)	Yield (t ha^{-1})
T_1: Standard check	33.87	111.29	4.76	3.61	59.32
T_2: Foliar application of biostimulant @ 1 ml l^{-1}	35.64	113.11	4.88	3.69	62.37
T_3: Foliar application of biostimulant @ 2 ml l^{-1}	36.82	114.58	5.00	3.76	64.19
T_4: Foliar application of biostimulant @ 2.5 ml l^{-1}	37.19	116.07	5.23	3.93	65.87
T_5: Foliar application of biostimulant @ 3 ml l^{-1}	39.23	120.42	5.44	4.19	68.51
T_6: Foliar application of biostimulant @ 4 ml l^{-1}	43.62	125.16	5.85	4.37	71.76

T_7: Soil application of biostimulant @ 10 kg ha^{-1}	35.32	112.63	4.82	3.64	61.38
T_8: Soil application of biostimulant @ 15 kg ha^{-1}	36.27	113.95	4.95	3.72	63.43
T_9: Soil application of biostimulant @ 17.5 kg ha^{-1}	36.98	115.32	5.19	3.82	65.16
T_{10}: Soil application of biostimulant @ 20 kg ha^{-1}	38.89	118.22	5.38	4.08	66.45
T_{11}: Soil application of biostimulant @ 25 kg ha^{-1}	41.46	122.94	5.62	4.32	70.61
S.Em. ±	1.56	2.34	0.27	0.09	1.93
CD (p=0.05)	4.59	6.90	0.80	0.27	5.71

Higher fruit yield of tomato due to foliar (T_6) and soil (T_{11}) application of biostimulant at higher levels was attributed to betterment in yield parameters and their differential contribution as well as the cumulative effect in making up final yield (Table 3). The extent of yield improvement in T_6 and T_{11} treatments was 20.97 and 19.03 percent, respectively, over standard check treatment (Fig. 1). Increased nutrient uptake, especially N, due to the presence of humic acid in biostimulant (Aya and Gulser, 2005) [3] and improved metabolic activities of the plants (Vikas *et al.*, 2015) [35] could also have aided in increased yield as the higher quantum of carbohydrates and phytohormones are required for fruit development and higher fruit yield (Sahu *et al.*, 2015) [27]. Further, the application of humic substances may improve the soil's physical, chemical and biological properties, which can enhance fruit production. It may also facilitate the movement of photosynthates from the source to the sink, such as the fruit and indirectly affect the yield through other yield components. Similar results were also reported by Khungar and Manoharan (2000) [19], where humic acid application @ 10 kg ha^{-1} to green gram and soybean resulted in a yield increase of 80.65 and 71.07 percent over control, respectively. While Asri *et al.* (2015) [2] in tomato, Bashir *et al.* (2016) [5] in gladiolus and Khan *et al.* (2019) [18] in apple have reported better growth parameters, yield attributes and yield due to application of humic acid.

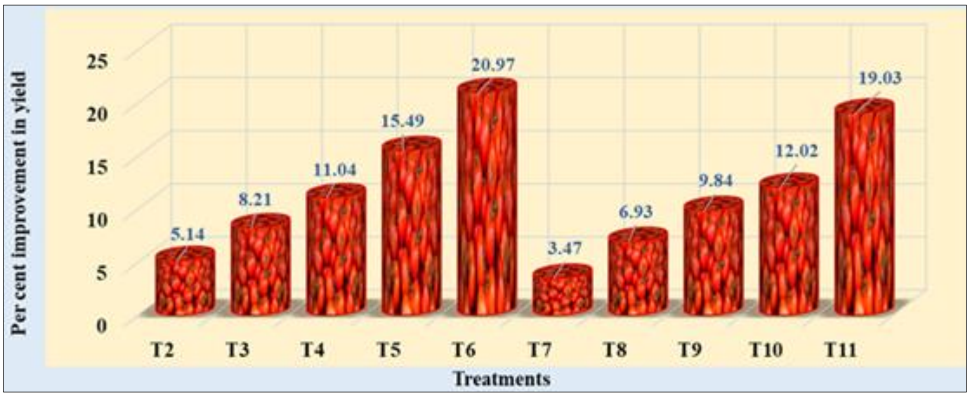

Fig 1: Percent improvement in tomato fruit yield over standard check as influenced by different levels and methods of biostimulant application

Nutrient uptake: The nutrient uptake by the tomato plant and fruit, *viz.*, nitrogen (N), phosphorous (P) and potassium (K), significantly influenced by different levels and methods of biostimulant application at different growth stages (Table 4). Foliar application of biostimulant @ 4 ml l^{-1} (T_6) recorded significantly higher N uptake (63.75, 97.51 and 161.26 kg ha^{-1}), P uptake (10.47, 17.48 and 27.94 kg ha^{-1}) and K uptake (70.73, 164.37 and 235.10 kg ha^{-1}) by the plant (vegetative part), fruit and total uptake by crop, respectively, and was found on par with soil application of biostimulant @ 25 kg ha^{-1} (T_{11}) with N uptake (61.67, 93.27 and 154.93 kg ha^{-1}), P uptake (9.93, 16.61 and 26.54 kg ha^{-1}) and K uptake (69.29, 158.36 and 227.65 kg ha^{-1}) by plant, fruit and total uptake by crop, respectively. Significantly, the least uptake was recorded with the standard check treatment (T_1) with N uptake (40.84, 66.32 and 107.16 kg ha^{-1}), P uptake (7.09, 11.60 and 18.69 kg ha^{-1}) and K uptake (53.89, 97.94 and 151.83 kg ha^{-1}) by plant, fruit and total uptake by crop, respectively

Table 4: Uptake of primary nutrients (Nitrogen, Phosphorus, Potassium) by tomato as influenced by different levels and methods of biostimulant application

Treatments	N uptake (kg ha^{-1})			P uptake (kg ha^{-1})			K uptake (kg ha^{-1})		
	Plant	Fruit	Total	Plant	Fruit	Total	Plant	Fruit	Total
T_1: Standard check	40.84	66.32	107.16	7.09	11.60	18.69	53.89	97.94	151.83
T_2: Foliar application of biostimulant @ 1 ml l^{-1}	45.40	72.96	118.36	7.86	13.06	20.92	57.04	111.83	168.87
T_3: Foliar application of biostimulant @ 2 ml l^{-1}	49.17	77.52	126.69	8.44	13.80	22.24	59.31	124.49	183.80
T_4: Foliar application of biostimulant @ 2.5 ml l^{-1}	51.30	81.77	133.07	8.70	14.93	23.63	61.20	135.38	196.58
T_5: Foliar application of biostimulant @ 3 ml l^{-1}	57.73	85.72	143.45	9.62	15.56	25.19	66.73	148.33	215.06
T_6: Foliar application of biostimulant @ 4 ml l^{-1}	63.75	97.51	161.26	10.47	17.48	27.94	70.73	164.37	235.10
T_7: Soil application of biostimulant @ 10 kg ha^{-1}	44.97	73.21	118.19	7.59	13.22	20.82	56.66	111.27	167.92
T_8: Soil application of biostimulant @ 15 kg ha^{-1}	47.32	76.93	124.25	8.33	13.87	22.20	58.63	120.19	178.82
T_9: Soil application of biostimulant @ 17.5 kg ha^{-1}	50.28	80.79	131.07	8.68	14.54	23.22	60.16	132.85	193.01
T_{10}: Soil application of biostimulant @ 20 kg ha^{-1}	55.01	84.52	139.52	9.22	15.06	24.28	65.46	144.63	210.09
T_{11}: Soil application of biostimulant @ 25 kg ha^{-1}	61.67	93.27	154.93	9.93	16.61	26.54	69.29	158.36	227.65
S.Em. ±	1.70	2.21	6.00	0.27	0.37	0.97	1.76	3.61	6.46
CD (p=0.05)	5.01	6.53	17.70	0.80	1.09	2.87	5.19	10.66	19.06

The extent of nutrient uptake by the crop is going to influence the growth and development of photosynthetic apparatus, ultimately yield and yield components. The highest percent improvement in total uptake of primary nutrients (50, 49 and 55% of N, P and K uptake, respectively), over the standard check treatment was realized with T_6. This was closely followed by T_{11} (45, 42 and 50% of N, P and K uptake, respectively) (Fig. 2). The nitrogen uptake by tomato varied significantly due to the application of humic substances (biostimulant) at crop harvest. It may be due to increased lateral root emergence and inducing smaller but more ramified secondary roots, resulting in better mineral nutrition. The results are in line with the findings of Guminiski *et al*. (1965) [15] and Eyheraguibel *et al*. (2008) [12]. Humic substances help to enhance the microbial activity of ammonifiers and nitrifiers, leading to a consistent supply of nitrogen, resulting in improved dry matter accumulation and nutrient content. Further, an efficient root system with improved cell permeability and better absorption due to better availability of nutrients in the soil solution leads to increased nitrogen uptake (Sumathi and Rao, 2007; Bhandari *et al.*, 2000) [33, 6].

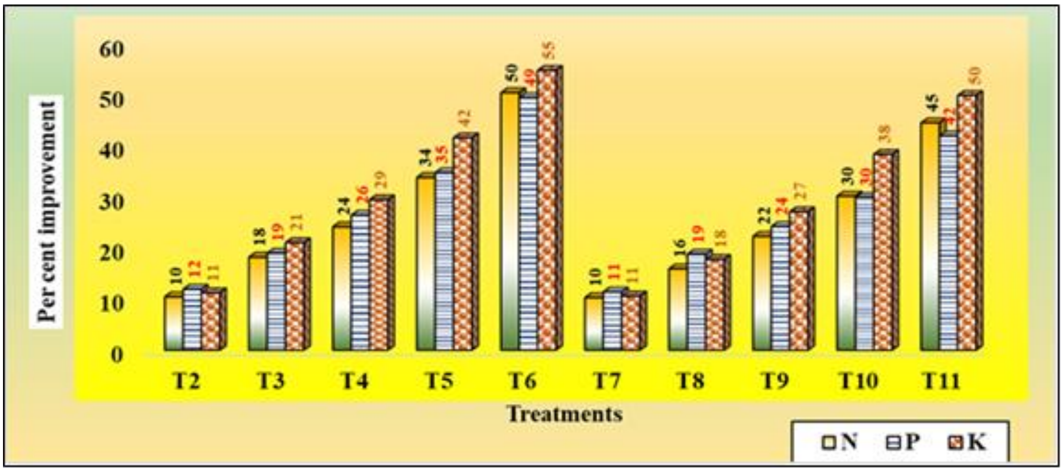

Fig 2: Percent improvement in total uptake of primary nutrients (Nitrogen, Phosphorus and Potassium) by tomato over standard check as influenced by different levels and methods of biostimulant application

Increased electrolyte leakage upon humic acid addition, which is an indication of membrane permeability, may favour increased nutrient uptake (David *et al*., 1994) [10]. The application of HS as a biostimulant has been shown to increase phosphatase activity by soil microorganisms, resulting in increased P solubilization in soil (Sharma *et al.*, 2013) [31]. HA also increases desorption by reducing the sorption of soil phosphate ions, thereby increasing P in the soil solution (Zhu *et al.*, 2018) [37]. Humic substances play a definite role in liberating fixed K because of their chelating power apart from the priming effect of solubilizing native, *i.e.*, fixed and non-exchangeable form of K. The enhanced microbial activity due to humic acid application would also have paved the way for increased availability of K by reducing its fixation in the soil and dissolution of fixed K (Schnitzer and Khan, 1972) [29]. Enhanced uptake of macronutrients with the applications of humic acid has also been reported by Jones *et al.* (2007) [17].

Conclusion

Based on the results obtained in this investigation it can be concluded that the response of tomato to biostimulant application was significant with different levels and methods. Either foliar application of biostimulant @ 4 ml l^{-1} each at pre-flowering, flowering and fruit development stages or soil application @ 25 kg ha^{-1} each at transplanting and pre-flowering stage, in addition to the package of practices, enhanced the crop growth in terms of plant height, number of branches, leaf area $plant^{-1}$, leaf area index and dry matter production and was found beneficial in tomatoes for realizing higher yields with improved nutrient uptake, compared to application of PoP alone.

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Conflict of interest

The authors declare no competing interests.

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