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Effect of Bio-stimulants on Growth and Yield of Potato (*Solanum tuberosum* L.)

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Abstract

The research was carried out at Zonal Agricultural Research Station, UAS, GKVK, Bengaluru during *Rabi* season of 2022 - 23 to evaluate the effect of bio-stimulants for growth and yield potency in potato. An experiment was conducted by adopting randomized complete block design (RCBD) with nine treatments and replicated thrice. The treatments comprised of soil application of humic acid, amino acid, sea weed extract and microbial consortia based bio-stimulants. Maximum plant height (74.04 cm), number of branches (7.73), plant spread (2460.73 cm^2), number of leaves (66.87 $plant^{-1}$), leaf area (3216.80 cm^2), leaf area index (3.57), number of tubers (8.47 $plant^{-1}$), tuber length (8.13 cm), tuber girth (15.19 cm) and tuber yield (28.61 t ha^{-1}) were recorded with treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1}, which was *on par* with the treatment combination of cut tubers + RDF + Humic acid at 2 ml L^{-1} for plant height (71.87 cm), number of branches (7.00), plant spread (2367.13 cm^2), number of leaves (64.53 $plant^{-1}$), leaf area (2848.37 cm^2), leaf area index (3.16), number of tubers (6.87 $plant^{-1}$), tuber length (7.20 cm), tuber girth (14.94 cm) and tuber yield (26.87 t ha^{-1}). Whereas, control (RDF + Whole tuber) registered minimum plant height (59.47 cm), number of branches (5.67), plant spread (2020.20 cm^2), number of leaves (50.87 $plant^{-1}$), leaf area (1812.23 cm^2), leaf area index (2.01) number of tubers (5.53 $plant^{-1}$), tuber length (5.87 cm), tuber girth (11.12 cm) and tuber yield (21.47 t ha^{-1}).

Keywords : Growth and yield of potato, RDF, Bio-stimulants

The potato (*Solanum tuberosum*) is tuberous crop, belongs to Solanaceous family originated from Andes region of South America is an important staple food crop with high nutritional value and adaptability has evolved into a cornerstone of global agriculture and nutrition. It has fourth position after wheat, rice and maize in terms of human consumption. Potato has a rich nutritional profile with rich source of vitamins, including vitamin C and vitamin B6, minerals such as potassium and magnesium and dietary fibre. These nutrients contribute to its role in addressing dietary deficiencies and supporting overall health. Furthermore, the potato's culinary versatility has cemented its place in diverse cuisines worldwide from boiled to mashed and baked to fried preparations, enabling it to meet the dietary preferences and needs of various cultures (Reddy *et al*., 2018).

Economically, the potato is vital, particularly in developing regions where it serves as a staple food and a significant source of income for millions of smallholder farmers. Its relatively short growing cycle and high yield potential make it an attractive crop for farmers seeking to maximize productivity and food security. The economic benefits of potato farming extend beyond the farm gate influencing local markets, trade and food industries (Devaux *et al*., 2014)

However, the cultivation of potatoes is not without challenges. The crop is susceptible to a range of insect pests and diseases. Modern agricultural practices have mitigated some risks, yet climate change poses new threats by altering growing conditions and exacerbating pest pressures. Sustainable farming practices and technological innovations are essential to overcoming these challenges and ensuring the continued productivity of potato crops (Haverkort *et al*., 2009).

One promising approach to enhancing potato cultivation involves the use of bio-stimulants. Bio-stimulants are substances or microorganisms that when applied to plants, seeds or soil, enhance natural processes to improve nutrient uptake, stress tolerance, yield and overall quality. They represent a sustainable and environmentally friendly alternative to traditional chemical inputs. In potato farming, bio-stimulants can play a crucial role in addressing some of the most pressing challenges such as improving resistance to diseases, enhancing drought tolerance, promoting more efficient nutrient use and thereby increasing yield (Du Jardin, 2015).

This research paper seeks to provide a comprehensive exploration of the potato's multidimensional significance with a particular focus on the potential of bio-stimulants to revolutionize potato cultivation.

Material and Methods

The field experiment was conducted at Zonal Agriculture Research Station, University of Agricultural Sciences, GKVK, Bengaluru during *Rabi* season of 2022-23. The experiment having nine treatments set up in RCBD design with three replications. The treatments involved soil application of bio-stimulants *viz*., T_1-Whole tubers + RDF (Control), T_2- Whole tubers + RDF + Humic acid at 2 ml L^{-1}, T_3-Whole tubers + Amino acid at 3 ml L^{-1}, T_4-Whole tubers + RDF + Sea weed extract at 2 ml L^{-1}, T_5-Whole tubers + RDF + Arka microbial consortium at 10 ml L^{-1}, T_6- Cut tubers + RDF + Humic acid at 2 ml L^{-1}, T_7- Cut tubers + RDF + Amino acid at 3 ml L^{-1}, T_8- Cut tubers + RDF + Sea weed extract at 2 ml L^{-1}, T_9- Cut tubers + RDF + Arka microbial consortium at 10 ml L^{-1}. The whole and cut tubers of potato variety Kufri Himalini was planted in lines at 45 cm row to row and 20 cm plant to plant spacing. Soil was provided with 125: 100: 125 kg N:P:K ha^{-1} and 25 t ha^{-1} FYM before planting. The various bio-stimulants *viz*., Humic acid, Amino acid, Sea weed extract and Arka microbial consortia were applied to the crop at 30 and 60 days afters planting at the rate of 1500 litre per hectare as soil application. The growth parameters were recorded at 45 and 75 days after planting and at harvest.

Results and Discussion

Plant Growth

Plant height was significantly differed with the soil application of various bio-stimulants (Table 1). At 45 and 75 days after planting, whole tubers + RDF + Humic at 2 ml L^{-1} registered taller plants (50.67 and 64.67 cm, respectively), which was *on par* with cut tubers + RDF + humic acid at 2 ml L^{-1} (46.80 and 60.93 cm, respectively) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (45.20 and 58.87 cm, respectively) and followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (44.53 and 56.73 cm, respectively). While, control (Whole tubers + RDF) registered shorter plants (37.73 and 50.87 cm, respectively). Whereas, at harvest, the treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in maximum plant height (74.04 cm), which was at *par* with all the treatments except whole and cut tubers + RDF + Microbial consortia at 10 ml L^{-1} (65.93 and 65.00 cm, respectively) and control (59.47 cm).

Among different bio-stimulants, highest number of branches per plant (6.07) was found with whole tubers + RDF + Humic acid at 2 ml L^{-1} which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (5.93), whole tuber + RDF + Sea weed extract at 2 ml L^{-1} (5.60), whole tubers + RDF + Amino acid at 3 ml L^{-1} (5.47) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (5.40) at 45 DAP. The lesser number of branches per plant was observed with control (4.07). While, at 75 DAP, significantly higher number of branches per plant was observed with whole tubers +

TABLE 1
Effect of bio-stimulants on plant height of potato

Treatments	Plant height (cm)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	37.7 c	50.87 c	59.47 c
T_2 - Whole tubers + RDF + Humic acid	50.6 a	64.67 a	74.04 a
T_3 - Whole tubers + RDF + Amino acid	42.3 bc	56.73 bc	67.44 abc
T_4 - Whole tubers + RDF + Sea weed extract	45.2 ab	58.87 ab	69.55 ab
T_5 - Whole tubers + RDF + Microbial consortia	42.0 bc	54.87 bc	65.93 bc
T_6 - Cut tubers + RDF + Humic acid	46.8 ab	60.93 ab	71.87 ab
T_7 - Cut tubers + RDF + Amino acid	42.0 bc	55.40 bc	67.38 abc
T_8 - Cut tubers + RDF + Sea weed extract	44.5 b	56.73 bc	68.67 ab
T_9 - Cut tubers + RDF + Microbial consortia	41.8 bc	55.20 bc	65.00 bc
S Em±	1.83	2.14	2.52
CD at 5%	5.49	6.42	7.54

Note : DAP - Days After Planting

RDF + Humic acid at 2 ml L^{-1} (6.87), which was at *par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (6.53), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.20) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.13) and followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (6.00). Control registered minimum number of branches per plant 5.33. Among the treatments, significantly highest number of haulms were noticed at harvest with whole tubers + RDF + Humic acid at 2 ml L^{-1} (7.73), which was *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (7.00) and followed by whole tubers + RDF + Sea weed extract at 2 ml L-1 (6.80). Whereas, the lowest number of branches (5.67) were observed in control (Table 2).

TABLE 2
Effect of bio-stimulants on number of branches per plant in potato

Treatments	No. of haulms ($plant^{-1}$)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	4.00 c	5.33 c	5.67 c
T_2 - Whole tubers + RDF + Humic acid	6.07 a	6.87 a	7.73 a
T_3 - Whole tubers + RDF + Amino acid	5.47 ab	6.00 bc	6.60 b
T_4 - Whole tubers + RDF + Sea weed extract	5.60 ab	6.20 abc	6.80 b
T_5 - Whole tubers + RDF + Microbial consortia	5.20 b	5.80 bc	6.40 bc
T_6 - Cut tubers + RDF + Humic acid	5.93 ab	6.53 ab	7.00 ab
T_7 - Cut tubers + RDF + Amino acid	5.33 ab	5.93 bc	6.40 bc
T_8 - Cut tubers + RDF + Sea weed extract	5.40 ab	6.13 abc	6.60 b
T_9 - Cut tubers + RDF + Microbial consortia	5.20 b	5.73 bc	6.13 bc
S Em±	0.22	0.26	0.26
CD at 5%	0.67	0.77	0.78

Note : DAP- Days After Planting

The plant spread was significantly differed at 45 DAP, wherein maximum plant spread was generated with whole tubers + RDF + Humic acid at 2 ml L^{-1} (1540.53 cm^2) and statistically *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (1447.13 cm^2), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1404.33 cm^2), which was followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (1293.47 cm^2). Whereas, the least plant spread was observed in control (1122.00 cm^2). At 75 DAP, whole tubers + RDF + Humic acid at 2 ml L^{-1} recorded maximum plant spread (2036.47 cm^2) and found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (1962.20 cm^2), whole tuber + RDF + Sea weed extract at 2 ml L^{-1} (1920.07 cm^2) and cut tuber + RDF + Sea weed extract at 2 ml L^{-1} (1830.93 cm^2) followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (1780.07 cm^2). Whereas, lower plant spread was obtained in control (1616.93 cm^2). At harvest, the greater spreading of plant was noticed with whole tubers + RDF + Humic acid at 2 ml L^{-1} (2460.73 cm^2), which was *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (2367.13 cm^2) followed by whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (2253.13cm^2) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2233.13 cm^2). The control produced lower plant spread of 2020.20 cm^2 (Table 3).

More number of leaves per plant at 45 DAP was produced with treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} (47.27) and was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (42.67) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (41.87) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (40.73). Similarly, highest number of leaves per plant at 75 DAP was noticed with whole tubers + RDF + Humic acid at 2 ml L^{-1} (58.73), which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (56.13), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (54.80) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (53.33) and followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (51.73). Whereas, control produced lowest number of leaves per plant (45.27). More number of leaves at harvest were produced with the treatment comprised of whole tubers + RDF + Humic acid at 2 ml L^{-1} (66.87), which was *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (64.53), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (64.13), cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (60.47) and cut tuber + RDF + Amino acid at 3 ml L^{-1} (59.73). Whereas, lesser number of leaves per plant (50.87) was registered with control (Table 4).

TABLE 3

Plant spread as influenced by bio-stimulants in potato

Treatments	Plant spread (cm^2)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1122.00 ^{d}	1616.93 ^{c}	2020.20 ^{c}
T_2 - Whole tubers + RDF + Humic acid	1540.53 ^{a}	2036.47 ^{a}	2460.73 ^{a}
T_3 - Whole tubers + RDF + Amino acid	1293.47 ^{bc}	1780.07 ^{abc}	2177.33 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	1404.33 ^{ab}	1920.07 ^{ab}	2253.13 ^{abc}
T_5 - Whole tubers + RDF + Microbial consortia	1229.00 ^{cd}	1761.27 ^{bc}	2101.80 ^{c}
T_6 - Cut tubers + RDF + Humic acid	1447.13 ^{ab}	1962.20 ^{ab}	2367.13 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	1233.00 ^{cd}	1718.87 ^{bc}	2057.20 ^{c}
T_8 - Cut tubers + RDF + Sea weed extract	1238.53 ^{cd}	1830.93 ^{abc}	2233.13 ^{abc}
T_9 - Cut tubers + RDF + Microbial consortia	1211.60 ^{cd}	1696.40 ^{bc}	2093.20 ^{c}
S Em±	48.89	82.21	76.53
CD at 5%	146.56	246.47	229.45

Note : DAP- Days After Planting

TABLE 4

Effect of bio-stimulants on number of leaves per plant in potato

Treatments	No. of leaves ($plant^{-1}$)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1122.00 ^{d}	1616.93 ^{c}	2020.20 ^{c}
T_1 - Whole tubers + RDF (Control)	34.73 ^{c}	45.27 ^{d}	50.87 ^{c}
T_2 - Whole tubers + RDF + Humic acid	47.27 ^{a}	58.73 ^{a}	66.87 ^{a}
T_3 - Whole tubers + RDF + Amino acid	39.40 ^{bc}	51.73 ^{bcd}	59.40 ^{b}
T_4 - Whole tubers + RDF + Sea weed extract	41.87 ^{ab}	54.80 ^{abc}	64.13 ^{ab}
T_5 - Whole tubers + RDF + Microbial consortia	38.33 ^{bc}	50.80 ^{bcd}	58.60 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	42.67 ^{ab}	56.13 ^{ab}	64.53 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	39.00 ^{bc}	49.87 ^{bcd}	59.73 ^{ab}
T_8 - Cut tubers + RDF + Sea weed extract	40.73 ^{bc}	53.33 ^{abc}	60.47 ^{ab}
T_9 - Cut tubers + RDF + Microbial consortia	37.53 ^{bc}	48.67 ^{cd}	57.27 ^{bc}
S Em±	1.84	2.19	2.46
CD at 5%	5.51	6.57	7.38

Note : DAP - Days After Planting

At 45 and 75 DAP, maximum leaf area per plant was obtained with whole tubers + RDF + Humic acid at 2 ml L^{-1} (1989.37 and 2752.74 cm^2, respectively), which was followed by cut tubers + RDF + Humic acid at 2 ml L^{-1} (1659.37 and 2352.77 cm^2, respectively), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1591.70 and 2303.71 cm^2, respectively) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (1530.31 and 2154.54 cm^2, respectively). The lesser leaf area per plant was observed with control (1027.70 and 1447.73 cm^2, respectively). The treatment involving whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in significantly highest leaf area per plant at harvest (3216.80 cm^2), which was found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (2848.37 cm^2), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (2808.31 cm^2) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2527.72 cm^2). While, the control exhibited the lesser leaf area of 1812.23 cm^2 per plant (Table 5).

TABLE 5

Effect of bio-stimulants on leaf area in potato

Treatments	Leaf area (cm^2)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1027.70 ^{e}	1447.73 ^{e}	1812.23 ^{d}
T_2 - Whole tubers + RDF + Humic acid	1989.37 ^{a}	2752.74 ^{a}	3216.80 ^{a}
T_3 - Whole tubers + RDF + Amino acid	1461.73 ^{bcd}	1955.07 ^{cd}	2420.01 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	1591.70 ^{bc}	2303.71 ^{b}	2808.31 ^{ab}
T_5 - Whole tubers + RDF + Microbial consortia	1312.19 ^{cde}	1829.40 ^{cd}	2368.70 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	1659.37 ^{b}	2352.77 ^{b}	2848.37 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	1371.45 ^{bcd}	1957.07 ^{cd}	2533.38 ^{bc}
T_8 - Cut tubers + RDF + Sea weed extract	1530.31 ^{bcd}	2154.54 ^{bc}	2527.72 ^{bc}
T_9 - Cut tubers + RDF + Microbial consortia	1295.55 ^{de}	1780.85 ^{de}	2179.77 ^{cd}
S Em±	87.71	104.31	159.36
CD at 5%	262.96	312.72	477.75

Note : DAP- Days After Planting

The treatment combination of whole tubers + RDF + Humic acid at 2 ml L^{-1} resulted in the maximum leaf area index (2.21 and 3.06) followed by cut tubers + RDF + Humic acid at 2ml L^{-1} (1.84 and 2.61), whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (1.77 and 2.56) and cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (1.70 and 2.39). Whereas, control registered lesser leaf area index of 1.14 and 1.61, respectively at 45 and 75 days after planting. At harvest, treatment comprising of whole tubers + RDF + Humic acid at 2 ml L^{-1} obtained maximum leaf area index (3.57), which was found *at par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (3.16) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (3.12) followed by cut tubers + RDF + Sea weed extract at 2 ml L^{-1} (2.81). The control produced lesser leaf area index of 2.01 (Table 6).

An increased in growth attributes of potato *viz*., plant height, number of branches, plant spread, number of leaves, leaf area and leaf area index can likely be attributed to the balanced use of nutrients provided through RDF and bio-stimulants. These treatments may have created optimal conditions for root growth and proliferation, enhancing nutrient absorption from the soil. Consequently, this improved nutrient uptake would have facilitated proper cell division and heightened meristematic activity, ultimately leading to better plant height. The enhanced plant growth attributes might have attributed to the impact of humic acid, which supplies carbon and other essential nutrient minerals that serve as energy sources for nitrogen-fixing bacteria. This boosts bacterial activity and improves their biological functions and ultimately stimulating plant growth (Abdel Mawgaud *et al*., 2007).

Bio-stimulants helps to enhance the growth attributes through different mechanisms and in turn yielded increased number of haulms in potato. Application of humic substances lead to an increase in production of hormones, stimulating plant growth and resulted in more numbers of shoots (EL-Komy *et al*., 2021). Seaweed extract contains different growth regulators *viz*., auxins, cytokinins and gibberellins. They induce cell division and elongation, leading to increased plant spread and growth of potato plants (Khan *et al*., 2009).

The works of Farouk (2015); Arafa and EL-Howeity (2017); Wadas and Dziugiel (2019); Man-Hong *et al*. (2020) in potato; Magalhaes *et al*. (2016); Abah *et al*. (2017); Hammad *et al*. (2024) in cassava; Abuzeed *et al*. (2018) in taro; Sharanya *et al*. (2022) in cowhage and Ayobi *et al*. (2022) in okra are in line with the above findings.

TABLE 6

Effect of bio-stimulants on leaf area index (LAI) in potato

Treatments	Leaf area index (LAI)		
	45 DAP	75 DAP	At harvest
T_1 - Whole tubers + RDF (Control)	1.14 e	1.61 e	2.01 d
T_2 - Whole tubers + RDF + Humic acid	2.21 a	3.06 a	3.57 a
T_3 - Whole tubers + RDF + Amino acid	1.62 bcd	2.17 cd	2.69 bc
T_4 - Whole tubers + RDF + Sea weed extract	1.77 bc	2.56 b	3.12 ab
T_5 - Whole tubers + RDF + Microbial consortia	1.46 cde	2.03 cd	2.63 bc
T_6 - Cut tubers + RDF + Humic acid	1.84 b	2.61 b	3.16 ab
T_7 - Cut tubers + RDF + Amino acid	1.52 cd	2.17 cd	2.81 bc
T_8 - Cut tubers + RDF + Sea weed extract	1.70 bcd	2.39 bc	2.81 bc
T_9 - Cut tubers + RDF + Microbial consortia	1.44 de	1.98 de	2.42 cd
S.Em±	0.10	0.12	0.18
CD at 5%	1.14 e	1.61 e	2.01 d

Note : DAP- Days After Planting

Yield

Significantly more tubers per plant was produced with whole tubers + RDF + Humic acid at 2 ml L^{-1} (8.47) followed by cut tubers + RDF + Humic acid at 2 ml L^{-1} (6.87) and whole tubers + RDF + sea weed extract at 2 ml L^{-1} (6.07). The less number of tubers (5.53) were produced with control (Table 7).

Among different treatments, whole tuber + RDF + Humic acid at 2 ml L^{-1} recorded significantly highest tuber length (8.13 cm), which was statistically *on par* with cut tubers + RDF + Humic acid at 2 ml L^{-1} (7.20 cm) followed by whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (6.60 cm) and whole tubers + RDF + Amino acid at 3 ml L^{-1} (6.53 cm). The shorter tuber length (5.87 cm) was noticed in the control (Table 7).

With respect to tuber girth, whole tubers + RDF + Humic acid 2 ml L^{-1} produced the larger size of tuber (15.19 cm) which was statistically *on par* with all other treatments except control 11.12 cm (Table 7).

The highest tuber yield ha^{-1} was registered with whole tuber + RDF + Humic acid at 2 ml L^{-1} (28.61 t ha^{-1}) which was *on par* with cut tubers RDF + Humic acid at 2 ml L^{-1} (26.87 t ha^{-1}) and whole tubers + RDF + Sea weed extract at 2 ml L^{-1} (24.47 t ha^{-1}) followed by whole tubers + RDF + Amino acid at 3 ml L^{-1} (23.99 t ha^{-1}). Whereas, control produced lowest tuber yield of 21.47 t ha^{-1} (Table 7).

The humic acid significantly increased tuber length and girth in potatoes through several mechanisms. It enhances soil structure and water retention, chelates nutrients for improved availability, stimulates root growth and influences plant hormones like auxins and cytokinins, which are vital for cell division and tuber development. Overall, these effects create an optimal growing environment for tuber development (Khan *et al*. 2009). Bio-stimulants improve potato yield attributes by enhancing nutrient availability, promoting root growth, increasing stress tolerance, optimizing hormonal balance, elevating photo synthesis and improving overall soil health. These factors collectively support robust plant growth and development, upgrading maximum yield of potato tuber at harvest (Canellas *et al*., 2015).

The results are in accordance with the work of Seyedbagheri (2010), Selim *et al*., (2010), Siddagangaiah and Raveesha (2014), Canellas *et al*. (2015), Garai *et al*. (2021) in potato; Duan *et al*. (2024) in sweet potatoes; Sharanya *et al*. (2022) in cowhage and Ayobi *et al*. (2021) in okra.

TABLE 7

Effect of bio-stimulants on number of tubers per plant, tuber length, tuber girth and tuber yield (t ha^{-1}) in potato

Treatments	Number of tubers	Tuber length (cm)	Tuber girth (cm)	Tuber yieldt ha^{-1}
T_1 - Whole tubers + RDF (Control)	5.53 ^{c}	5.87 ^{b}	11.12 ^{b}	21.47 ^{c}
T_2 - Whole tubers + RDF + Humic acid	8.47 ^{a}	8.13 ^{a}	15.19 ^{a}	28.61 ^{a}
T_3 - Whole tubers + RDF + Amino acid	6.07 ^{bc}	6.53 ^{b}	14.63 ^{a}	23.99 ^{bc}
T_4 - Whole tubers + RDF + Sea weed extract	6.47 ^{bc}	6.60 ^{b}	14.89 ^{a}	24.47 ^{abc}
T_5 - Whole tubers + RDF + Microbial consortia	5.87 ^{bc}	6.27 ^{b}	14.60 ^{a}	23.88 ^{bc}
T_6 - Cut tubers + RDF + Humic acid	6.87 ^{b}	7.20 ^{ab}	14.94 ^{a}	26.87 ^{ab}
T_7 - Cut tubers + RDF + Amino acid	5.87 ^{bc}	6.27 ^{b}	14.30 ^{a}	22.83 ^{bc}
T_8 - Cut tubers + RDF + Sea weed extract	6.00 ^{bc}	6.33 ^{b}	14.51 ^{a}	22.65 ^{bc}
T_9 - Cut tubers + RDF + Microbial consortia	5.67 ^{c}	6.20 ^{b}	14.26 ^{a}	22.33 ^{bc}
S Em±	0.32	0.40	0.70	1.39
CD at 5%	0.97	1.21	2.11	4.18

The present investigation revealed that, whole tubers + RDF + Soil application of humic acid at 2 ml L^{-1} resulted in better growth and tuber yield in potato.

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