Suan Sunandha Science and Technology Journal

Enhancement of Growth, Yield and Fruit Quality Attributes of Tomatoes (*Solanum lycopersicum* L.) through Treated Ganga Sludge-based Organic Fertilizers

Acharya Balkrishna[1, 2, 3], Ajay Kumar Gautam[1, 3*], Nidhi Sharma[1], Vedpriya Arya[1, 2], Vikram Khelwade[1], Prashant Kumar[1]

[1] Patanjali Herbal Research Department, Patanjali Research Foundation, Haridwar 249405, India
[2] Department of Allied Sciences, University of Patanjali, Haridwar 249405, India
[3] Patanjali Organic Research Institute (PORI), Padartha, Laksar Road, Haridwar-249404, India
***Corresponding author e-mail: ajay.gautam@patanjali.res.in**

Received: *6 December 2024* / **Revised:** *24 March 2025* / **Accepted:** *10 July 2025*

Abstract
Tomato (*Solanum lycopersicum* L.) is a popular vegetable crop cultivated all around the globe. This vegetable crop requires a significant amount of nitrogen. Farmers often utilize excessive amounts of chemical fertilizers to fulfill this demand. Considering the increased adverse effects of chemical fertilizers on crops, soil and consumers, utilizing organic fertilizers became a hopeful solution to mitigate this problem. Therefore, the present study was carried out to study the effects of Ganga sludge-based that is organic fertilizers) on the growth, yield and fruit quality of tomatoes (*Solanum lycopersicum* L.). A total of seven fertilizer treatments with one control in three replications were prepared and analyzed using a randomized complete block design. All organic fertilizers enhanced the growth and yield of tomato crops, where treatment in a combination of Pori Potash + Jaivik Poshak (T7) significantly impacted growth characteristics along with T5 and T2. Similarly, treatment T5 (Jaivik Khad) was also found important in improving yield parameters of tomato crops followed by T7 (Pori Potash + Jaivik Poshak), T4 (Jaivik Poshak), and T6 (Jaivik Prom+ Jaivik Khad). Based on this study, it can be concluded that the application of organic fertilizer is a sustainable approach to soil health and fertility in agricultural crop production. Further research is required on sludge-based organic fertilizers so that more useful and safer organic fertilizer products can be produced for application in agriculture.

Keywords: Organic farming, Growth and yield, Sludge, Tomato, Vegetable crop

1. Introduction
The tomato (*Solanum lycopersicum* L.) is an edible berry that has been cultivated all around the globe as a vegetable crop. It is the second-most widely consumed vegetable crop in the world. Around 100 million tons of tomatoes were produced worldwide in 2000, compared to 182.05 million tons in 2021. Additionally, the global tomato planting area grew from 3.16 million hectares in 1994 to 5.055 million hectares in 2020 (Fan et al., 2023). The tomato is thought to have originated in Mexico, Central America, and western South America (Barros et al., 2012; Fan et al., 2023; Kumar et al., 2020). It is among the most economically significant vegetable crops that has positioned itself as the kingmaker of all vegetables, as no vegetable can be considered to be tasty without the use of tomatoes. It is cultivated and produced conventionally both in open fields and in greenhouses. The fruits of tomatoes are consumed fresh or used in various food products. They can be processed into juices, ketchup and purees, while, canned and dried tomatoes are economically important processed products. Tomato fruits are rich in vitamins and minerals, including vitamin C, potassium, vitamin K, and folate, and contain a variety of bioactive compounds, including organic acid and phenols (Brunetti et al., 2019; Ilahy et al., 2011; Kalbani et al., 2016). Ali et al. (2020) reported that the nutritional contents and bioactive compounds available in tomatoes have a positive impact on human health and disease management. Their consumption decreased the risk of developing diseases in the digestive tract, prostate cancer, chronic degenerative diseases and cardiovascular diseases (Li et al., 2023).

Similar to other crops, tomato crops need a lot of nitrogen to grow overall. Farmers often utilize excessive amounts of chemical/inorganic fertilizers to fulfill this requirement and to achieve high yields, driven by economic interests and worldwide demand. Utilizing inorganic fertilizers may cause the pH of the soil to drop, which eventually impacts the microbial balance of the soil. The sustainable growth of agriculture has also been gravely endangered by intensive agriculture, which has significantly decreased soil biodiversity and raised the possibility of soil-borne disease outbreaks (Carrara et al., 2018; Thompson et al., 2007; Wang et al., 2021). The overuse of agrochemicals in the cultivation of vegetables has now become a big global problem that is harming the environment and the health of producers and consumers (Sharma et al., 2019).

The recommendation of the use after the 'Green Revolution' and thereafter their long-term use has increased the dependency of producers on synthetic fertilizers (Nyamangara et al., 2020). This use has now reached the extent that every agriculture researcher, scientist and even producer is compelled to consider the alternative to synthetic fertilizers. Several alternative fertilizer and pesticide options are available, which are considered environment-friendly and safer for users and consumers (Guzman-Guzman et al., 2023; Leelavathi et al., 2014; Rini & Sulochana, 2007; Wong et al., 2021). Organic material-based fertilizers are substitutes now trending and becoming popular among farmers moving towards organic farming (Siddique et al., 2014; Yadav & Ramakrishna, 2023). These fertilizers can be produced from agricultural and their degradable waste, which is rich in several nutritional components. These fertilizers can increase crop yield, have positive residue effects on succeeding crops, and supply the majority of vital nutrients to soil and plants. Their application also increases the soil microbial biomass and increases CO_2 emissions which ultimately improves airy soil structure and fertility as well. In comparison to synthetic fertilizers, organic fertilizers are easy to use and available to crops for a longer duration (Terhoeven-Urselmans et al., 2009).

In addition to agricultural waste, food industry waste and city compost are significant issues that pose health and environmental risks. When this waste (often referred to as sewage) is treated, a residual, semi-solid substance called sewage sludge (SS) is produced as a by-product (Tchounwou et al., 2012). Although sludge is handled with methods including composting, burning, and sanitary burial, its management is still crucial from an environmental and financial perspective. Nevertheless, sewage sludge management through its application in agriculture has emerged as one of the most significant sectors because of the high concentrations of phosphorus (P), nitrogen (N), and organic carbon (OC) (Camargo et al., 2016; Velasco-Munoz et al., 2021). The use of sludge as organic fertilizer is an excellent substitute for synthetic fertilizers and a more ecologically friendly method of management. There is still a lack of fundamental research on turning sludge into organic fertilizers. Moreover, the effectiveness of sludge-based fertilizers on different crops has not been thoroughly investigated in field research. Therefore, the objective of this study was to evaluate the effects of Ganga-sludge-based organic fertilizers on the growth, yield parameters and fruit quality of tomato plants.

2. Materials and Methods

Research was carried out on the experimental farms of the Patanjali Research Institute between January and June of 2023. The experimental area, which is situated at 29° 54′ 49″ N and 77°59′ 51″ E, has a warm and temperate environment with a maximum temperature of 27°C, a minimum temperature of 7°C, and an annual rainfall of 16.5mm. The comprehensive metrological data collected at the experimental site during the investigation is presented in Figure 1.

Ganga sludge samples were gathered from the Sludge Treatment Plant (STP) Jagjeetpur, Uttarakhand, India and processed at the Patanjali Organic Research Institute (PORI) for the production of five distinct organic fertilizer products using Patanjali's patented technology (Patent application number: 202211069280). Five important organic fertilizer products, including Jaivik Prom, Pori Potash, Dharti ka Chaukidar, Jaivik Poshak, and Jaivik Khad were prepared and utilized in field trial experiments.

2.1 Experimental design and treatment

With seven treatments and one control (three replications each), the experiment was structured using Randomized Block Design (RBD) (Awadhpersad et al. 2021). The experiment evaluated five different organic fertilizers in seven different treatment combinations: T0 (Control), T1 (Jaivik Prom @ 100 kg/ac), T2 (Pori Potash @ 100 kg/ac), T3 (Dharti ka Chaukidar @ 10 kg/ac), T4 (Jaivik Poshak @ 7 kg/ac), T5 (Jaivik Khad @ 80 kg/ac), T6 (Jaivik Prom+ Jaivik Khad @ 50 + 40 kg/ac), and T7 (Pori Potash + Jaivik Poshak @ 50 + 3.5 kg/ac). To prevent any soil-borne pathogens from attacking tomato seedlings, the roots were dipped in a biopesticide (5 ml/liter each) for 20 to 25 minutes. The experimental fertilizer treatments were applied every 30 days following seeding.

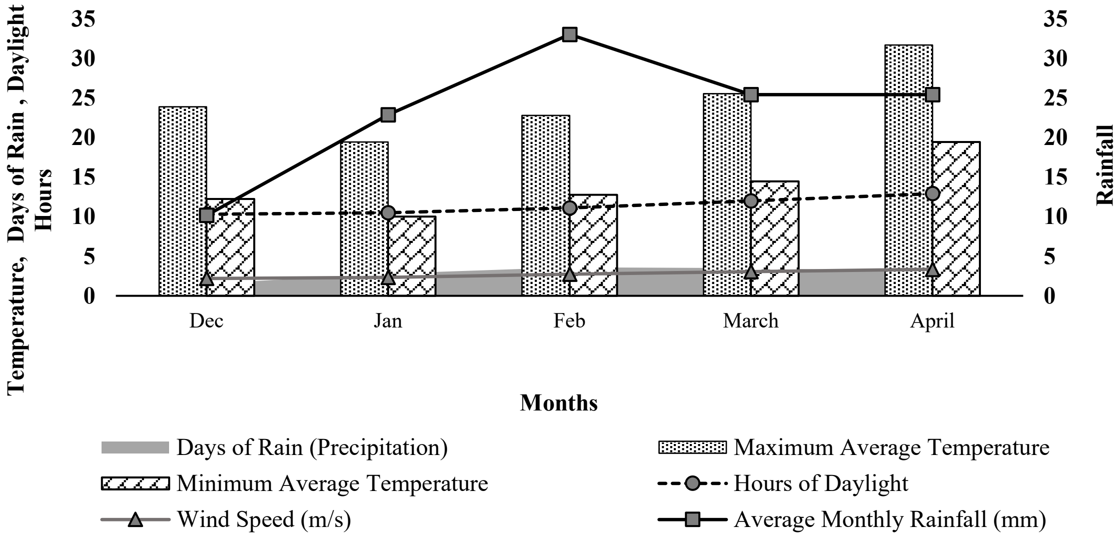

Figure 1. Metrological data of the experimental site during the study.
Source: https://weatherspark.com/y/109648/Average-Weather-in-Haridwar-India-Year-Round

2.2 Plant materials and agronomical practices

The seedlings of fresh and healthy tomato plants used in this study were procured from a local nursery and received on the same day that transplantation was planned for field trials and experimentation. In a plot measuring 2 x 4 m (8 m^2), tomato seedlings were planted with 90 cm between rows and 60 cm between plants after the plants were treated with a biopesticide (*Trichoderma* and *Pseudomonas* @ 5 ml/liter each). The crop was irrigated once every 30 to 35 days, for a total of 4-5 times. Neem oil derived from the seeds of *Azadirachta indica*, was sprayed two to three times to eliminate the attack of several insects and pests. The unwanted weeds were weeded approximately three times during the experiment (Pawar et al., 2016; Wato, 2020).

2.3 Measurement of plant growth and yield parameters

All 15 plants in each plot were assessed for total number of leaves & leaf area, number of fruit bunches per plant, number of fruits per plant, average fruit weight per plant (g), total fruit weight per plant (g), average fruit diameter per plant (mm), plant height, and crop yield to investigate the effects of fertilizer application on plant parameters. About every two weeks, red-to-pink-ripe tomato fruits were harvested, and the final yield was recorded every 30 days until the end harvest (Figure 2). Under measured yield criteria, the average fruit diameter per plant, fruit yield per plant and plot, and quantity of fruits per plant were assessed (Bhattarai et al., 2015; Perez et al., 2022).

2.4 Data analysis

Plant height, leaf number, leaf area, number of bunches, fruit weight, average, yield and obtained experimental data are presented as mean ± standard deviation (SD). ANOVA (one-way) with Dunnett's multiple comparisons test was performed using GraphPad Prism version 8.02 for Windows was performed using GraphPad Prism version 8.02 for Windows. The percent increase in the number of branches and fruits is expressed as the difference between treatment and control multiplied by hundred (Hu et al., 2022).

3. Results

The growth and yield characteristics of the tomato crop were significantly improved with the use of organic fertilizers. Furthermore, using these organic fertilizers altered the soil's chemical makeup and increased the amount of available potassium, phosphorus, and nitrogen, illustrating how organic fertilizers affect the soil's chemical characteristics. This change in the chemical composition of the soil was also evident in tomato crop growth and yield. Organic fertilizer may be a suitable substitute to chemical fertilizers since it is sustainable, eco-friendly, and enhances soil health without disturbing soil microbes. Detailed statistics on the application of organic fertilizers and their effects on the growth and yield of tomato crop is presented here in this section.

Figure 2. Different stages of tomato crop during the trial in the experimental field. (A) tomato in rows trial field (B) tomato plant after transplantation (C) initiation of flowering (D) young fruits (E) initiation of fruits and (F) fruits after harvesting.

3.1 Plant height

In the present study, organic fertilizers showed positive effects on plant height (expressed as shoot length). At 30 days after sowing, the Pori potash (treatment 2) showed a significant effect on shoot length (9.59±0.70cm). Between 30 to 150 days after sowing, treatment 7 (Pori Potash+Jaivik Poshak) was recorded as a potential growth enhancer till the harvest. The combination of Pori Potash + Jaivik Poshak was recorded as the most effective organic fertilizer in comparison to individual treatment. It was clear from the results that plant height was observed to be highest in plants treated with the dose of mixed fertilizers (T7) in the range of 68.29±16.32 cm to 55.11±16.29 cm. Based on the results, it is crucial to note that plant height is affected by all treatments; however, the mixed fertilizers (T7) treatment significant impact ($p \leq 0.05$) on plant height after 90 days of sowing (Table 1).

3.2 Leaf area and total number of leaves

The potential effects of organic fertilizers on the area and total number of leaves were observed during the present study. Treatment 7 (Pori Potash + Jaivik Poshak) impacted the leaf area of the tomato plant after 30 days of sowing (56.72±28.28 cm^2). Similarly, Jaivik Khad (treatment 5) showed potential effects to enhance the leaf area between 30 days to 60 days after sowing (497.66±185.24 cm^2). This long-lasting effect of these fertilizers confirmed the slow-releasing nature of organic fertilizers that provide NPK to the tomato plant, enhancing nutrient uptake. Similar to leaf area and the total number of leaves was also found higher in plants treated with the combination of Pori Potash + Jaivik Poshak (T7), while others exhibited this number between 4.77±0.63 to 3.66±0.46. Irrespective of the increase in leaf area and the total number of leaves in plants grown under different fertilizer treatments, the difference with their respective control was not found significant (Table 1).

3.3 Effect of organic fertilizers on yield parameters

Similar to the effects on growth parameters, the organic fertilizers used in the present study were also found effective on the quality and yield of fruits. While evaluating the number of bunches of tomato fruits per plant from 60-150 days, it was observed that treatment 6 (Jaivik Prom + Jaivik Khad) was found effective on the number of fruit bunches in comparison to others, while treatment 7 (Pori Potash + Jaivik Poshak) expressed themselves during 90 -120 days (Figure 3). The bunches number was found maximum on 120th day in all treatments (except T0, 90th day) that may be because of the full blooming stage of the plant and longer effects of used organic fertilizers. After analysis of the results, it was found that organic fertilizers act as an excellent source of nutrition that can improve the number of fruits per plant. The combination of Jaivik Prom+Jaivik Khad (T6) was found effective in enhancing the total number of fruits per plant after 60 days after sowing (7.88±2.29), whereas, treatment 7 (Pori Potash + Jaivik Poshak) at 90 (3.72±0.24), T3 at 120 (5.81±2.58), and T5 at 150 (8.14±2.16) days after sowing (Figure 4). When we analyzed fruit characteristics in terms of fruit weight, the average fruit weight per plant was found highest in the tomato plants grown under the treatment of Jaivik Khad (T5) at 90 (74.96±8.56), 120 (78.76±15.50) and 150 (91.32 ±9.07) days after sowing (Table 2). The average fruit diameter was also found enhanced in all treatments. Here, treatment 5 (Jaivik Khad) exerted potential effects on fruit diameter initially, whereas treatment 4 (Jaivik Poshak) and treatment 5 (Jaivik Khad) were found effective in increasing the fruit diameter after 120 (8.74±3.06 mm) and 150 (10.61±5.10 mm) days of sowing (Table 3). In the case of total fruit weight per plant, treatments 4, 5 and 3 exerted significant impact at 90 (203.65±8.36 g), 120 (406.95±133.47 g) and 150 (503.26 ±259.92 g) days after sowing (Table 2). Finally, the total fruit weight per plot was also found improved in plots under organic fertilizer application. Here, the application of Pori Potash + Jaivik Poshak (T7) had the maximum yield (3402.13±564.27 g) at 90 days, while the application of Jaivik Khad (T5) and Jaivik Prom+ Jaivik Khad (T6) showed enhanced yield at 120 (8407.24±3043.99 g) and 150 (5222.32 ±2551.67 g) days after sowing, respectively (Table 3).

Table 1. Impact of Ganga sludge-based organic fertilizers on tomato growth.

Treatments	Total No. of leaves	Leaf Area (cm^2)		Plant Height (cm)				
	30 Days	30 Days	60 Days	30 Days	60 Days	90 Days	120 Days	150 Days
T0	4.36 ± 0.23	51.78 ± 18.28	429.01 ± 115.61	8.70 ± 0.57	39.34 ± 3.31	43.13 ± 3.52	46.66 ± 3.64	50.44 ± 3.53
T1	4.20 ± 0.44	42.56 ± 25.99	461.25 ± 142.53	8.46 ± 1.68	49.83 ± 16.07	54.14 ± 15.86	58.61 ± 15.62	62.67 ± 15.76
T2	4.77 ± 0.63	51.09 ± 22.11	390.02 ± 6.96	9.59 ± 0.70	49.40 ± 1.43	54.07 ± 1.43	58.02 ± 1.08	63.04 ± 1.53
T3	4.43 ± 0.61	42.29 ± 20.42	422.28 ± 125.51	8.80 ± 1.09	48.27 ± 12.34	52.40 ± 10.94	56.85 ± 10.59	58.65 ± 8.21
T4	3.67 ± 0.46	32.67 ± 20.50	307.65 ± 148.87	7.44 ± 1.09	39.63 ± 13.68	45.32 ± 13.49	49.50 ± 13.32	53.52 ± 14.22
T5	4.74 ± 0.83	48.44 ± 29.64	497.66 ± 185.24	8.04 ± 0.87	51.27 ± 11.89	55.35 ± 11.32	58.66 ± 10.47	61.84 ± 10.71
T6	4.41 ± 0.62	43.80 ± 26.41	440.00 ± 173.61	8.70 ± 1.32	50.76 ± 14.97	55.16 ± 14.18	58.33 ± 14.11	62.28 ± 14.37
T7	5.02 ± 1.09	56.72 ± 28.28	428.37 ± 157.01	9.27 ± 1.36	55.11 ± 16.29	59.88 ± 15.59*	64.41 ± 15.38*	68.29 ± 16.32*

Note: Mean ± standard deviation of nine replicates. * Significant ($p \leq 0.05$)

Table 2. Impact of Ganga sludge based organic fertilizers on yield of tomato.

Treatments	Average Fruit Weight Per Plant			Total Fruit Weight Per Plant (g)		
	90 Days	120 Days	150 Days	90 Days	120 Days	150 Days
T0	51.97 ± 6.83	43.28 ± 2.97	70.83 ± 3.76	104.09 ± 19.66	200.08 ± 51.45	241.04 ± 100.02
T1	66.22 ± 19.76*	74.43 ± 11.03*	74.63 ± 13.15	150.78 ± 25.71*	315.10 ± 91.12	260.26 ± 96.44
T2	71.58 ± 1.42*	66.09 ± 6.88*	74.30 ± 7.08	162.23 ± 16.45*	289.71 ± 73.36	308.90 ± 68.69
T3	65.21 ± 9.47*	78.75 ± 14.23*	90.01 ± 9.89*	159.14 ± 39.02*	402.55 ± 164.03*	503.26 ± 259.92*
T4	57.99 ± 6.39	72.04 ± 11.35*	91.32 ± 9.07*	203.65 ± 8.33*	298.16 ± 26.45	489.08 ± 157.53*
T5	74.96 ± 8.56*	78.76 ± 15.50*	80.41 ± 3.62	149.08 ± 18.71*	406.95 ± 133.47*	442.66 ± 69.96*
T6	64.73 ± 7.66	76.69 ± 6.46*	76.76 ± 13.99	139.01 ± 42.36*	332.89 ± 43.98*	501.23 ± 45.46*
T7	67.59 ± 11.30*	75.71 ± 21.87*	83.80 ± 28.07	188.05 ± 21.42*	325.62 ± 131.77	440.45 ±133.99*

Note: Mean ± standard deviation of nine replicates. * Significant ($p \leq 0.05$)

Table 3. Impact of organic fertilizers derived from Ganga sewage on yield of tomato.

Treatments	Average Fruit Diameter Per Plant (mm)			Total Yield Per Plot (g)		
	90 Days	120 Days	150 Days	90 Days	120 Days	150 Days
T0	5.85 ± 0.47	7.08 ± 0.16	7.68 ± 0.19	1700.19 ± 660.59	2346.56 ± 797.28	2569.98 ± 654.09
T1	6.12 ± 0.90	7.44 ± 0.28	7.44 ± 0.48	2738.44 ± 392.49*	5593.08 ± 1948.10*	3905.05 ± 350.86
T2	6.60 ± 0.21	6.95 ± 0.18	7.15 ± 0.31	2996.53 ± 313.27*	3801.59 ± 719.72	3945.68 ± 1090.50
T3	6.26 ± 0.34	7.39 ± 0.56	7.68 ± 0.73	3034.13 ± 1233.32*	3843.68 ± 1413.16	4533.50 ± 2483.94
T4	6.73 ± 1.01	8.74 ± 3.06*	8.39 ± 0.39	2878.35 ± 682.64*	4463.76 ± 417.74	4360.24 ± 1175.24
T5	7.11 ± 0.91*	7.13 ± 0.32	10.61 ± 5.10*	2914.06 ± 476.24*	8407.24 ± 3043.99*	2833.50 ± 766.93
T6	7.02 ± 1.01*	7.35 ± 0.35	7.75 ± 0.26	3189.25 ± 147.29*	5449.28 ± 2543.30*	5222.32 ± 2551.67*
T7	6.65 ± 0.63	7.10 ± 1.15	7.87 ± 0.86	3402.13 ± 564.27*	6791.77 ± 412.29*	4913.57 ± 2320.62*

Note: Mean ± standard deviation of nine replicates. * Significant ($p \leq 0.05$)

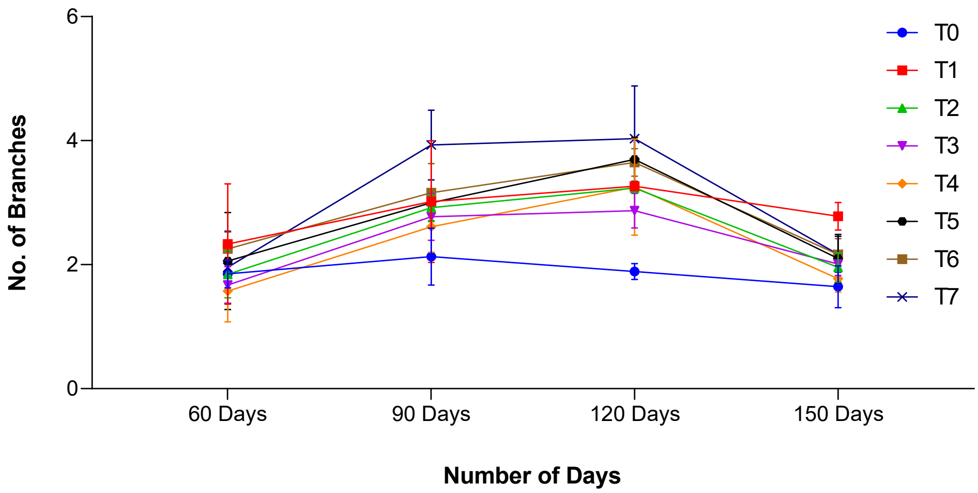

Figure 3. Percent increase Number of bunches of tomato fruits per plant over-control at 60, 90, 120 and 150 DAS.

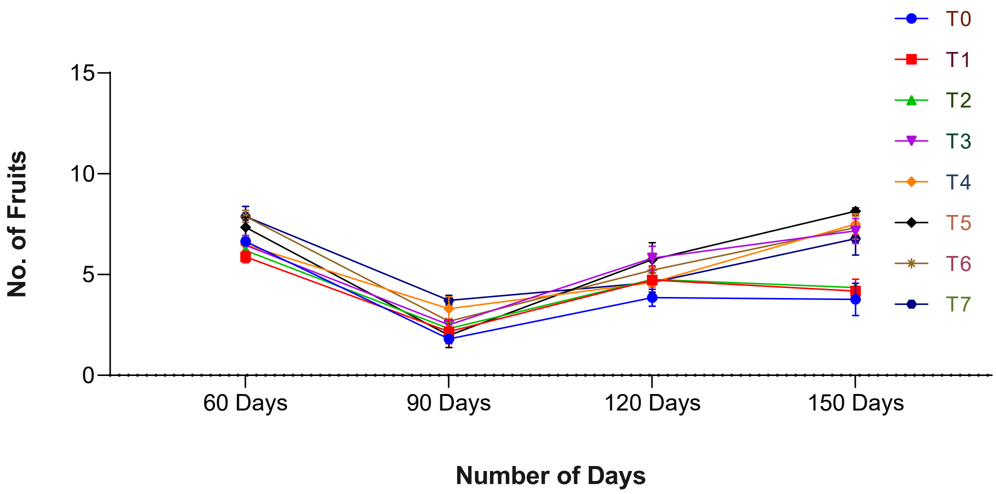

Figure 4. Percent increase in the number of fruits per plant over-control at 60, 90, 120 and 150 DAS.

4. Discussion

The effectiveness of organic fertilizers, even at later stages of plant growth, is due to their slow-release ability, which guarantees nutrient availability for the longest possible crop life (Balkrishna et al., 2024a; Lin et al., 2023). This presumption led to the preparation of the basic organic product composition employed in this study in a way that would supply crops with a complete nutritional balance of nitrogen (N), phosphorus (P), and potassium (K) either through mycorrhiza or organic based materials (Balkrishna et al., 2023; Laily et al., 2021). Several studies published earlier have also reported how organic fertilizers affect leaf area index due to their higher chlorophyll content and impact on crop development, corroborating our current findings (Ahmadpour & Armand, 2020; Aishwarya et al., 2022; Sardans & Penuelas, 2021).

Yang et al. (2015) evaluated the effects of vermicompost on the quality and yield of tomatoes under greenhouse conditions and varying soil water regimes, discovering a positive impact of the organic fertilizers on plant characteristics. The observation of enhanced plant height, along with an increase in the area and number of leaves in plants subjected to different treatments, highlighted the beneficial effects of organic fertilizers on tomato plants. The availability of balanced composition of nitrogen (N), phosphorus (P) and potassium (K) in organic fertilizers is perhaps helpful to enhance crop growth and development (Balkrishna et al. 2023). The previous studies proved that organic fertilizers are not only an excellent source of NPK that are likely to provide balanced essential nutrients are essential for plant development, but they also contribute to improved soil structure and microbial activity that further support plant growth (Balkrishna et al., 2024b; Laxmi et al., 2015). Similar findings were made by Ahmadpour and Armand (2020), who found that organic fertilizers (compost and vermicompost) significantly impact the ecophysiological traits of tomatoes (*Lycopersicon esculentum* L.). This supported the findings that organic fertilizers can enhance the physicochemical characteristics of soil and positively impact plant growth because of their high nutrient content, high water-holding capacity, plant growth regulators, and beneficial microorganisms. Additionally, the impacts of mycorrhizal fungi on pea development and yield were justified by Aishwarya et al. (2022).

Besides growth parameters, the organic fertilizers were also found to be significantly effective on the total yield of the tomato crop. The increase in fruit weight and final yield was possibly due to long-term effects of organic fertilizers and maintenance of nutritional composition in the soil. These earlier studies also advocated the application of organic fertilizers in the enhancement of growth and yield of field and vegetable crops (Raturi et al., 2019; Zhou et al., 2022). The crops like brassica, capsicum, carrot, chilli, lettuce, leafy vegetables and wheat are already reported to show an improved yield with the application of organic fertilizers (Balkrishna et al., 2024a, 2024b, 2025; Balkrishna, Sharma, et al., 2024; Zandvakili et al., 2019; Zhang et al., 2023). In addition to enhanced growth and yield of field crops, this study also provides a management solution of sewage sludge in a more environmentally friendly and safer manner.

5. Conclusions

Based on the results of the present study, it was concluded that Ganga sludge-based organic fertilizers can significantly improve the properties of different field crops including tomatoes. It also demonstrated a positive impact of organic fertilizers on various yield parameters of tomato crops and underscored their importance for improving crop productivity. While their application has a fruitful impact on growth, they also impact the yield potential, and the production of organic fertilizer is highlighted as a good and safer alternative to Ganga sludge management. The significance of organic fertilizers also supports the process of turning sludge into organic fertilizers in terms of their long-term effects on growth and productivity. Therefore, more research is still needed on different aspects of sludge and sludge-based organic fertilizers, including production, processing, and field application on additional field crops.

Acknowledgements

The authors would like to thank their respective organizations for supporting them in every manner and providing the facilities they needed.

Conflict of Interest

The authors declared no conflicts of interest.

Publication Ethic

This manuscript has not been submitted nor under consideration in any print or online journal or source.

References

Ahmadpour, R., & Armand, N. (2020). Effect of ecophysiological characteristics of tomato (*Lycopersicon esculentum* L.) in response to organic fertilizers (compost and vermicompost). *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *48*(3), 1248–1259.

Aishwarya, Manjula, Payal, Kaundal, S., Kumar, R., Singh, R., Avasthi, S., & Gautam, A. K. (2022). Arbuscular mycorrhizal fungal diversity and root colonization in *Pisum sativum*. *Biological Forum – An International Journal*, *14*(1), 1626–1632.

Ali, M. Y., Sina, A. A. I., Khandker, S. S., Neesa, L., Tanvir, E. M., Kabir, A., Khalil, M. I., & Gan, S. H. (2020). Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: A review. *Foods*, *10*(1), 45.

Awadhpersad, V. R. R., Ori, L., & Ansari, A. A. (2021). Production and effect of vermiwash and vermicompost on plant growth parameters of tomato (*Lycopersicon esculentum* Mill.) in Suriname. *International Journal of Recycling of Organic Waste in Agriculture*, *10*(4), 397–413.

Balkrishna, A., Arya, V., Bhat, R., Chaudhary, P., Mishra, S., Kumar, A., Sharma, V., Sharma, V., Sharma, N., & Gautam, A. K. (2023). Organic farming for sustainable agriculture and public health: Patanjali's perspective. *Vegetos*, *37*, 2220–2229. https://doi.org/10.1007/s42535-023-00717-y

Balkrishna, A., Gautam, A. K., Sharma, N., Arya, V., & Khelwade, V. (2024a). Growth and yield potential of sludge-based organic fertilizers on bell pepper *Capsicum annum*. *Asian Journal of Agriculture*, *8*(1), 18–24.

Balkrishna, A., Gautam, A. K., Sharma, N., Arya, V., & Khelwade, V. (2024b). Growth and yield enhancement of carrot (*Daucus carota* L.) through treated Ganga sludge-based organic fertilizers. *Biological Forum – An International Journal*, *16*(3), 175–180.

Balkrishna, A., Gautam, A. K., Sharma, N., Arya, V., & Khelwade, V. (2025) Effects of organic and bio-fertilizers on growth and yield performance of leafy vegetables. *Journal of Wastes and Biomass Management*, *7*(1), 22–28.

Balkrishna, A., Sharma, N., Gautam, A. K., Arya, V., & Khelwade, V. (2024). Enhancement of wheat (*Triticum aestivum* L.) growth and yield attributes in a subtropical humid climate through treated Ganga sludge-based organic fertilizers. *Recent Advances in Food, Nutrition & Agriculture*, *15*(3), 178–192.

Barros, L., Duenas, M., Pinela, J., Carvalho, A. M., Buelga, C. S., & Ferreira, I. C. F. R. (2012). Characterization and quantification of phenolic compounds in four tomatoes (*Lycopersicon esculentum* L.) farmers' varieties in northeastern Portugal homegardens. *Plant Foods for Human Nutrition*, *67*, 229–234.

Bhattarai, P., Kaushik, R. A., Ameta, K. D., Jain, H. K., Kaushik, M. K., Sharma, F. L. (2015). Effect of plant geometry and fertigation on growth and yield of cherry tomato (*Solanum lycopersicon* var. *cerasiforme*) under zero energy polyhouse conditions. *Indian Journal of Horticulture*, *72*(2), 297–301.

Brunetti, G., Traversa, A., & De Mastro, F., & Cocozza, C. (2019). Short term effects of synergistic inorganic and organic fertilization on soil properties and yield and quality of plum tomato. *Scientia Horticulturae*, *252*, 342–347. https://doi.org/10.1016/j.scienta.2019.04.002

Camargo, F. P., Tonello, P. S., dos Santos, A. C. A., & Duarte, I. C. S. (2016). Removal of toxic metals from sewage sludge through chemical, physical, and biological treatments-a review. *Water, Air and Soil Pollution*, *227*, 433.

Carrara, J. E., Walter, C. A., Hawkins, J. S., Peterjohn, W. T., Averill, C., & Brzostek, E. R. (2018). Interactions among plants, bacteria, and fungi reduce extracellular enzyme activities under long-term N fertilization. *Global Change Biology*, *24*(6), 2721–2734.

Fan, H., Zhang, Y., Li, J., Jiang, J., Waheed, A., Wang, S., Rasheed, S. M., Zhang, L., & Zhang, R. (2023). Effects of organic fertilizer supply on soil properties, tomato yield, and fruit quality: A global meta-analysis. *Sustainability*, *15*(3), 2556. https://doi.org/10.3390/su15032556

Guzman-Guzman, P., Kumar, A., de los Santos-Villalobos, S., Parra-Cota, F. I., Orozco-Mosqueda, M. D. C. Fadiji, A. E., Hyder, S., Babalola, O. O., & Santoyo, G. (2023). *Trichoderma* species: Our best fungal allies in the biocontrol of plant diseases - A review. *Plants*, *12*(3), 432. https://doi.org/10.3390/plants12030432

Hu, Y., Bandara, A. R., Xu, J., Kakumyan, P., Hyde, K. D., & Mortimer, P. E. (2022). The use of *Agaricus subrufescens* for rehabilitation of agricultural soils. *Agronomy*, *12*(9), 2034.

Ilahy, R., Hdider, C., Lenucci, M. S., Tlili, I., & Dalessandro, G. (2011). Phytochemical composition and antioxidant activity of high-lycopene tomato (*Solanum lycopersicum* L.) cultivars grown in Southern Italy. *Scientia Horticulturae*, *127*(3), 255–261.

Kalbani, F. O. S. A., Salem, M. A., Cheruth, A. J., Kurup, S. S., & Senthilkumar, A. (2016). Effect of some organic fertilizers on growth, yield and quality of tomato (*Solanum lycopersicum*). *International Letters of Natural Sciences*, *53*, 1–9.

Kumar, A., Kumar, V., Gull, A., & Nayik, G. A. (2020). Tomato (*Solanum Lycopersicon*). In G. A. Nayik & A. Gull (Eds.), *Antioxidants in vegetables and nuts - Properties and health benefits* (pp. 191–207). Springer, Singapore.

Laily, U. K., Rahman, M. S., Haque, Z., Barman, K. K., & Talukder, M. A. H. (2021). Effects of organic fertilizer on growth and yield of tomato. *Progressive Agriculture*, *32*(1), 10–16.

Laxmi, P. R., Saravanan, S., & Naik, M. L. (2015). Effect of organic manures and inorganic fertilizers on plant growth, yield, fruit quality and shelf life of tomato (*Solanum lycopersicon* L.) C.V. PKM-1. *International Journal of Agriculture Science and Research*, *5*(2), 7–12.

Leelavathi, M. S., Vani, L., & Reena, P. (2014). Antimicrobial activity of *Trichoderma harzianum* against bacteria and fungi. *International Journal of Current Microbiology and Applied Sciences*, *3*(1), 96–103.

Li, F., Yuan, Y., Shimizu, N., Magana, J., Gong, P., & Na, R. (2023). Impact of organic fertilization by the digestate from by-product on growth, yield and fruit quality of tomato (*Solanum lycopersicon*) and soil properties under greenhouse and field conditions. *Chemical and Biological Technologies in Agriculture*, *10*(1), 70.

Lin, S., Wang, C., Lei, Q., Wei, K., Wang, Q., Deng, M., Su, L., Liu, S., & Duan, X. (2023). Effects of combined application of organic fertilizer on the growth and yield of pakchoi under different irrigation water types. *Agronomy*, *13*, 2468.

Nyamangara, J., Kodzwa, J., Masvaya, E. N., & Soropa, G. (2020). The role of synthetic fertilizers in enhancing ecosystem services in crop production systems in developing countries. In L. Rusinamhodzi (Ed.), *The role of ecosystem services in sustainable food systems* (pp. 95–117). Academic Press.

Pawar, G. S., Kale, M. U., & Lokhande, J. N. (2016). Response of AquaCrop model to different irrigation schedules for irrigated cabbage. *Agricultural Research*, *6*(1), 73–81.

Perez, C. M., Ayala, C. R., Ruiz, A. M., Bustamante, W. O., Islas, J. D. R. R., Ascencio-Hernández, R., López-Ordaz, A., & Núñez-Ramírez, F. (2022). Leaf area and its impact in yield and quality of greenhouse tomato (*Solanum lycopersicum* L.). *Revista de la Facultad de Ciencias Agrarias UNCuyo*, *54*(1), 57–69.

Raturi, H. C., Uppal, G. S., Singh, S. K., & Kachwaya, D. S. (2019). Effect of organic and inorganic nutrient sources on growth, yield and quality of bell pepper (*Capsicum annuum* L.) grown under polyhouse condition. *Journal of Pharmacognosy and Phytochemistry*, *8*(1), 1788–1792.

Rini, C. R., & Sulochana, K. K. (2007). Usefulness of *Trichoderma* and *Pseudomonas* against *Rhizoctonia solani* and *Fusarium oxysporum* infecting tomato. *Journal of Tropical Agriculture*, *45*, 21–28.

Sardans, J., & Penuelas, J. (2021). Potassium control of plant functions: Ecological and agricultural implications. *Plants*, *10*(2), 419. https://doi.org/10.3390/plants10020419

Sharma, A., Kumar, V., Shahzad, B., Tanveer, M., Sidhu, G. P. S., Handa, N., Kohli, S. K., Yadav, P., Bali, A. S., Parihar, R. D., Dar, O. I., Singh, K., Jasrotia, S., Bakshi, P., Ramakrishnan, M., Kumar, S., Bhardwaj, R., & Thukral, A. K. (2019). Worldwide pesticide usage and its impacts on ecosystem. *SN Applied Science*, *1*, 1446. https://doi.org/10.1007/s42452-019-1485-1

Siddique, S., Hamid, M., Tariq, A., & Kazi, A. G. (2014). Organic farming: The return to nature. In P. Ahmad, M. Wani, M. Azooz, & L. S. Phan Tran (Eds.), *Improvement of crops in the era of climatic changes* (Vol. 2, pp. 249–281). Springer.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K., & Sutton, D. J. (2012). Heavy metal toxicity and the environment. In A. Luch (Ed.), *Molecular, clinical and environmental toxicology* (Vol. 3, pp. 133–164). Springer.

Terhoeven-Urselmans, T., Scheller, E., Raubuch, M., Ludwig, B., & Joergensen, R. G. (2009). CO_2 evolution and N mineralization after biogas slurry application in the field and its yield effects on spring barley. *Applied Soil Ecology*, *42*(3), 297–302. https://doi.org/10.1016/j.apsoil.2009.05.012

Thompson, R. B., Martinez-Gaitan, C., Gallardo, M., Gimenez, C., & Fernandez, M. D. (2007). Identification of irrigation and N management practices that contribute to nitrate leaching loss from an intensive vegetable production system by use of a comprehensive survey. *Agricultural Water Management*, *89*(3), 261–274. https://doi.org/10.1016/j.agwat.2007.01.013

Velasco-Munoz, J. F., Mendoza, J. M. F., Aznar-Sanchez, J. A., & Gallego-Schmid, A. (2021). Circular economy implementation in the agricultural sector: Definition, strategies and indicators. *Resources, Conservation and Recycling*, *170*, 105618. https://doi.org/10.1016/j.resconrec.2021.105618

Wang, J., Lu, X., Zhang, J., Wei, H., Li, M., Lan, N, & Luo, H. (2021). Intercropping perennial aquatic plants with rice improved paddy field soil microbial biomass, biomass carbon and biomass nitrogen to facilitate soil sustainability. *Soil and Tillage Research*, *208*, 104908. https://doi.org/10.1016/j.still.2020.104908

Wato, T. (2020). The role of allelopathy in pest management and crop production-A review. *Food Science and Quality Management*, *93*, 13–21.

Wong, C. K. F., Zulperi, D., Saidi, N. B., & Vadamalai, G. (2021). A consortium of *Pseudomonas aeruginosa* and *Trichoderma harzianum* for improving growth and induced biochemical changes in *Fusarium* wilt infected bananas. *Tropical Life Sciences Research*, *32*(1), 23–45.

Yadav, R., & Ramakrishna, W. (2023). Biochar as an environment-friendly alternative for multiple applications. *Sustainability*, *15*(18), 13421. https://doi.org/10.3390/su151813421

Yang, L., Zhao, F., Chang, Q., Li, T., & Li, F. (2015). Effects of vermicomposts on tomato yield and quality and soil fertility in greenhouse under different soil water regimes. *Agricultural Water Management*, *160*, 98–105. https://doi.org/10.1016/j.agwat.2015.07.002

Zandvakili, O. R., Barker, A. V., Hashemi, M., & Etemadi, F. (2019). Biomass and nutrient concentration of lettuce grown with organic fertilizers. *Journal of Plant Nutrition*, *42*(5), 444–457. https://doi.org/10.1080/01904167.2019.1567778

Zhang, X., Li, J., Shao, L., Qin, F., Yang, J., Gu, H., Zhai, P., & Pan, X. (2023). Effects of organic fertilizers on yield, soil physico-chemical property, soil microbial community diversity and structure of *Brassica rapa* var. *Chinensis*. *Frontiers in Microbiology*, *14*, 1132853. https://doi.org/10.3389/fmicb.2023.1132853

Zhou, Z., Zhang, S., Jiang, N., Xiu, W., Zhao, J., & Yang, D. (2022). Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Frontiers in Environmental Science*, *10*, 1058071. https://doi.org/10.3389/fenvs.2022.1058071