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Research Article

The Usage of Tea Factory Waste as Soil Substrate for the Production of Snap Bean (*Phaseolus vulgaris* L.)

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Yield

Abstract: Intensive use of inorganic chemicals in agriculture causes soil inefficiency. Alternative sources are needed to ensure the sustainability of agriculture. Utilizing organic wastes presents a feasible solution as they can support plant growth while ensuring their elimination. This study investigated the potential for utilizing the large amount of waste generated during tea processing in tea factories every year in snap bean cultivation. The effects of tea factory waste mixed into the soil at four different rates were compared to the soil and the soil to which farmyard manure was added. The study was conducted in pots. The experiment was designed with three replications according to randomized complete blocks. The effects of the growth media were determined using 26 parameters related to plant development and yield. Observations made 30 days after seed sowing and at the end of harvest revealed that tea factory waste treatments made significant contributions to plant height, stem diameter, and the number of trifoliate leaves compared to soil, which had no added organic matter. However, the SPAD values were negatively affected. All findings revealed that the T4 medium containing equal parts soil and tea waste created the best results, except for the growth medium containing the farmyard. In conclusion, it was found that tea factory waste can be a beneficial organic matter for the growth and development of snap bean plants. To maximize its usefulness as a new source, promoting the populations of fungal and bacterial agents that facilitate its rapid decomposition in the soil is necessary.

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1. Introduction

Tea factory waste consists of the fiber part of the leaves, dust, and some tea leaves of *Camellia sinensis* (L.) plant, is generated during the processing of tea in a factory. It is projected that global tea production will reach 7.5 million tons by 2025, and nearly 10% of it may become waste during processing in factories. This biomass waste, which causes environmental problems, has the potential to be utilized in the food and agriculture sectors (Seth et al., 2023). Although this abundant and easily available material has found some applications in environmental management, animal feed, bioenergy, and green packaging materials, there is still needs to reveal its different potential benefits (Karataş, 2022; Wang et al., 2024; Yazıcı, 2025). Easily degradable biomass wastes can be transformed into valuable resources in the agricultural sector. They have the potential to provide the necessary nutrients for plants and improve soil properties (Koul et al., 2022). Tea waste can increase agricultural productivity thanks to its low carbon and rich mineral content. Moreover, it has appropriate pH and electrical conductivity (EC) values and does not contain any toxic metals. Successful results had been achieved, especially in its biological conversion to compost and organic fertilizer (Peksen and Yakupoglu, 2009; Mahaly et al., 2018; Morales-Corts et al., 2018). In the composting process, the high amount of nitrogen in tea waste is converted into nitrate, a valuable form for the plants to absorb (Khan et al., 2009; Negi et al., 2022; Garg and Rakshit, 2024). However, this process takes a long time and creates additional costs and lands that can be used for agricultural production are needed for compost production. Utilizing the large amount of these waste generated each year from tea processing directly in agricultural production can eliminate these requirements. In fact, a previous study proved that it can serve as a maintainable substance when balanced with a co-matter in pepper cultivation. (Karatas, 2024). However, these findings may not be eligible for other crops. Its usage should be tested, especially considering the phytotoxic effects of polyphenols (Kumar et al., 2023). Due to its high nitrogen content, tea waste can be particularly beneficial for plants that require high nitrogen levels for growth and development (Zaine et al, 2023).

Nitrogen is directly related to plant growth and yield in snap beans (Yuan et al., 2017). *Phaseolus vulgaris* L. is the most important legume worldwide for human consumption, providing as a source of vegetable protein, minerals, antioxidants, and bioactive compounds. Therefore, increasing its yield and quality is crucial (Karavidas et al., 2022). However, excessive application of chemical-based fertilizers has led to changes in soil properties and reduced the yield of beans (*Phaseolus vulgaris* L.). That is why different organic sources are needed to reduce chemical residues and achieve more sustainable production (Kumari et al., 2022). Organic resources contribute to increasing the organic matter of the soil and reducing soil problems. It also increases soil quality and productivity in sustainable agriculture (Çirka et al., 2022).

Nitrogen deficiency leads to a reduction in leaf area and productivity in snap beans. For plants to benefit from nitrogen, soil moisture levels must also be appropriate (Yuan et al., 2017). Nitrogen fertilization provides optimum pod quality and yield while reducing the number of rhizobium nodules in the roots (dos Santos Sousa et al., 2022; Singh et al., 2024).

This study examined whether incorporating tea factory waste into soil could enhance the growth and nitrogen-related performance of snap bean plants, positioning it as a sustainable alternative to conventional nitrogen sources such as farmyard manure. It also explored how varying application rates of tea waste affect plant development, with the expectation that moderate to high proportions would yield the most favorable results.

2. Materials and Methods

This study was conducted during 2024 growth season at the greenhouse of Recep Tayyip Erdogan University Agriculture Faculty. A snap bean (*Phaseolus vulgaris* L.) variety, Atlantis (Arzuman Seed Company), was tested in four different mixtures of tea factory waste and soil (Table 1). Soil and soil:farm yard media were used as control groups.

Table 1. The composition of plant growing media used in the experiment

Code	Media	Mixture rate (w/w)
C1	Soil (Control1)	7:0
T1	Soil:Tea Factory Waste	6:1
T2	Soil:Tea Factory Waste	5:2
T3	Soil:Tea Factory Waste	4:3
T4	Soil:Tea Factory Waste	4:4
C2	Soil:Farmyard Manure (Control2)	2:1

The tea factory waste used in the study was provided from a tea factory in Pazar District of Rize province, and the farmyard manure was supplied from a producer in Rize. The garden soil was provided from faculty experimental area at university. The physico-chemical characteristics and chemical composition of the tea factory waste and soil are presented in Table 2.

Table 2. Physico-chemical characteristics and chemical composition of the tea factory waste and soil used in the study

Tea Factory Waste Analysis Parameters	Analysis results	Soil Analysis Parameters	Analysis results
pH	4.9	pH	3.9
EC (µS/cm)	1899	Lime (%)	0.8
Lime (%)	2.0	Salinity (%)	0.003
Relative humidity (%)	23.5	Saturation (%)	64
Water holding capacity (%)	595.9	Organic matter (%)	1.26
Organic matter (%)	93.5	Total N (%)	0.094
Ash	6.5	P (ppm)	4.30
Total N (%)	0.952	K (ppm)	33.2
P (ppm)	397.1	Ca (ppm)	250.8
K (ppm)	5689	Mg (ppm)	28.2
Ca (ppm)	378.4	Fe (ppm)	88.7
Mg (ppm)	104.0	Mn (ppm)	2.48
Fe (ppm)	1.66	Zn (ppm)	0.83
Mn (ppm)	6.43	Cu (ppm)	0.55
Zn (ppm)	0.29		
Cu (ppm)	0.66		

2.1. Pot experiment

The experiment was held in a glasshouse with 5 L plastic pots. The trial was conducted in a randomized block layout with three replicates containing five pots. Before sowing, the seeds were soaked for three hours. They were planted in 5-liter plastic pots with two seeds in each pot on April 8, 2024. The environmental data regarding the experimental site's temperature, relative humidity, and soil temperature were recorded. During the trial, glasshouse interior air temperature and humidity were between 9 °C and 42 °C (Figure 1), and between 27% and 90% (Figure 2) respectively. The soil temperature also ranged between 12 °C and 34 °C in that term (Figure 3). The pots were irrigated regularly, and no nutrient supplements were applied to support the plants during the growth season. Pod harvesting per treatment was performed from mid-June to the end of August.

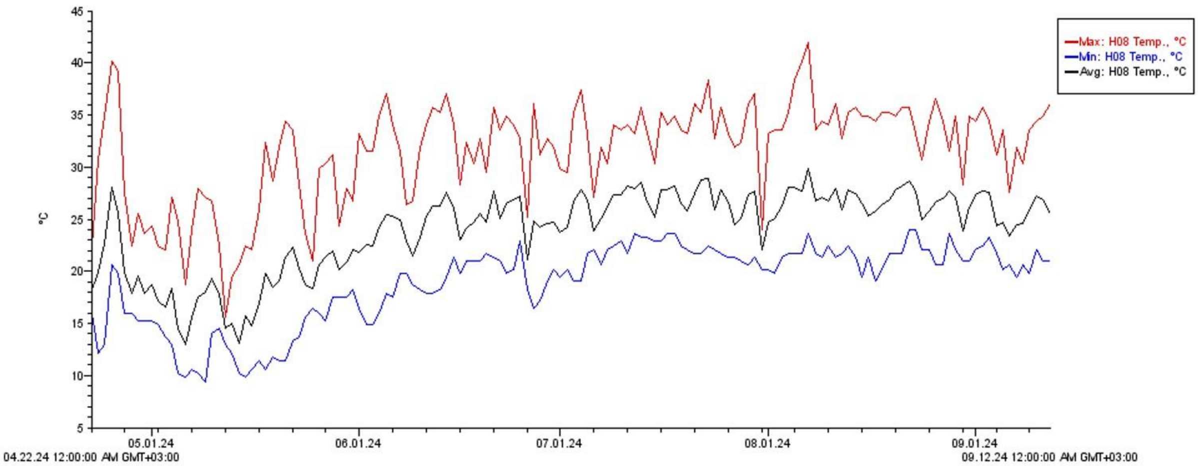

Figure 1. The maximum, minimum, and average air temperature (°C) values in the glasshouse during the trial period.

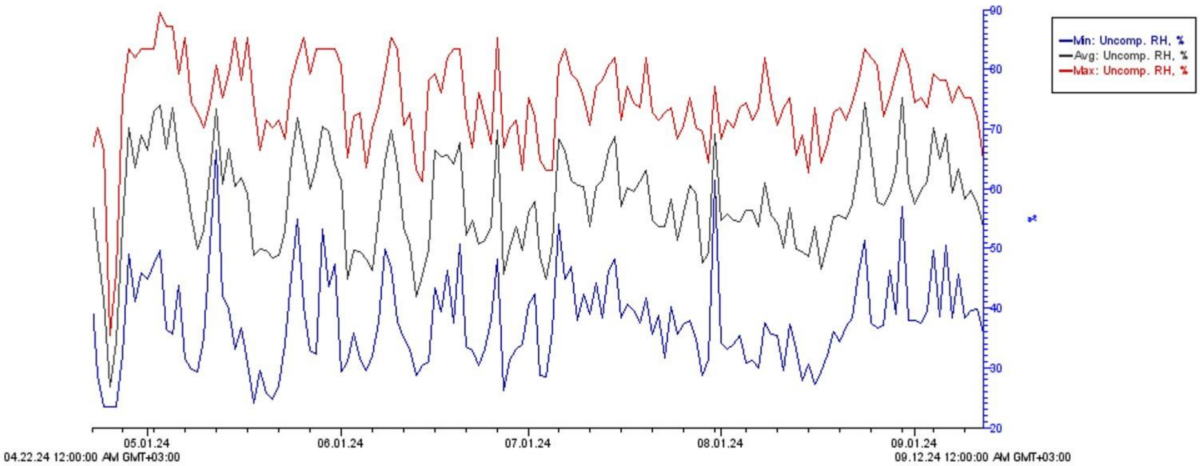

Figure 2. The maximum, minimum, and average relative humidity (%) values in the glasshouse during the trial period.

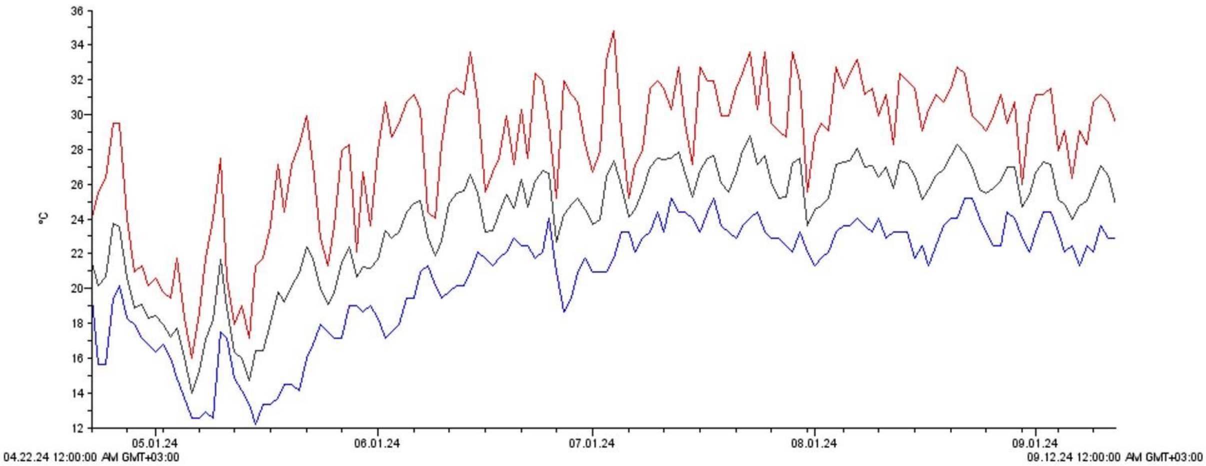

Figure 3. The maximum, minimum, and average soil temperature (°C) values in the pot during the trial period.

2.2. Plant growth and yield measurements

Some of the measurements regarding plant development were taken at both the 30 days after the seed sowing (30DAS) and end of the harvest (EOH). These are as follows:

The plant height in each pot was measured in cm from the distance from the potting soil to the apical node. The stem diameter was studied using a caliper at the top of the root collar. All trifoliate leaves on the plant were counted to determine total leaf number in per plant. The portable SPAD-502 chlorophyll meter was utilized to measure the leaf chlorophyll index.

The observations collected at the end of the harvest (EOH) are as follows:

Data on stem length in cm were collected from the part between the root collar of the plants and the first node. Unifoliate leaf width and length, and terminal leaflet width and length were determined using a ruler. The differences in leaf color among the treatments were detected by using a CR400 color meter (Konica Minolta, Japan). The plants were uprooted and their green parts and roots were separated. The fresh and dry weights of these parts were weighed separately using a digital scale. The root length was estimated using a ruler, starting from the most apical point. The degree of root branching and the amount of root nodules were evaluated using a 1-9 visual scale (1=very little, 3=little, 5=moderate, 7=much, 9=too much). To determine the total yield for each treatment, the pods of snap beans that reached the harvest size specific to the variety were harvested six times and recorded per pot. The total fruit numbers were calculated by recording the number of fruits harvested for each treatment in all replicates in every harvests. To assess pod quality, the pods' length, width, and thickness were measured, and their weights were recorded. Twenty fruits from each treatment were evaluated for these observations.

The total nitrogen content of leaves was measured according to the standard Kjeldahl method (AOAC, 1999).

2.3. Statistical analysis

The data was analyzed using standard analysis of variance (ANOVA) with the JMP 13.0 statistical software program, followed by the Least Significant Difference (LSD) to separate means.

3. Results

The effects of tea factory waste treatments were statistically significant on the development parameters and yields of snap bean. Significant differences in their comparison with the controls, which consisted of soil without tea waste and soil mixed with animal manure, were also exposed. In the observations made 30 days after planting (30DAS), plant height varied between 20.20 cm (T3) and 12.23 cm (C1) depending on the growing medium. The stem diameter was measured as 4.19 mm in T4, and the lowest value was recorded in the T2 medium, which was 3.36 mm. The number of trifoliate leaves was highest in T2, T3, and T4 media, all of which had two leaves. The chlorophyll index value obtained with the SPAD meter was higher in tea waste treatments than in the controls. The highest value was measured in the T4 medium. At the end of the harvest (EOH), the highest values in plant height and stem diameter were obtained from T3, T4, and C2 media, and they were in the same statistical group. However, the highest trifoliate leaves number and SPAD values were obtained in the C2 medium (Table 3).

Table 3. Effects of treatments on plant height, stem diameter, trifoliate leaf number, and SPAD value in snap bean at 30 days after seed sowing (30DAS) and end of harvest (EOH) periods

Treatments	Plant height 30DAS (cm)	Plant height EOH (cm)	Stem diameter 30DAS (mm)	Stem diameter EOH (mm)	Trifoliate leaves number 30DAS	Trifoliate leaves number EOH	SPAD value 30DAS	SPAD value EOH
C1	12.23 d	13.83 c	3.83 bc	4.52 c	1.00 c	8.00 d	32.90 c	35.39 abc
T1	16.16 c	18.00 b	3.57 c	4.52 c	1.40 b	9.33 cd	36.75 ab	32.24 d
T2	18.03 b	21.25 a	3.36 c	5.50 b	2.00 a	10.58 c	36.23 ab	34.24 bcd
T3	20.20 a	22.67 a	4.13 ab	6.59 a	2.00 a	15.67 b	35.43 b	33.56 cd
T4	18.90 ab	22.67 a	4.19 a	6.37 a	2.00 a	15.08 b	37.31 a	36.19 ab
C2	20.06 a	22.54 a	3.79 bc	6.28 a	1.93 a	23.75 a	29.40 d	37.29 a
LSD (5%)	1.38	1.98	0.36	0.48	0.32	2.55	1.48	2.26
CV (%)	4.32	5.36	5.11	4.65	10.31	10.21	2.34	3.57

Within each column, means followed by the same letters are not significantly different at $P \leq 0.05$ according to the LSD test.

The differences between the values in plant height, stem diameter, trifoliate leaf number, and SPAD value in snap beans at 30 days after seed sowing (30DAS) and end of the harvest (EOH) periods of snap beans according to the growth media were assessed. It was revealed that the effects of the growth media varied for each feature. The maximum plant height increase was observed in the T4 medium, whereas the most significant rise in the number of leaves was noted in the C2 medium. The maximum development in stem diameter was detected in the C2 and the T3 media. The relationship between SPAD values and growth medium was interestingly different from the other attributes. While the growth medium containing tea factory waste contributed positively to the examined traits in the development period between 30DAS and the end of harvest compared to the control, these media negatively affected SPAD values (Figure 4).

According to observations collected at the end of harvest, the longest stem was recorded in the C2, T3, and T4 growth media, and they statistically belonged to the same group. The highest values in unifoliate leaf width and length were measured in the T3 medium. However, the highest terminal leaflet width and length values were measured in the T4 and T3 media, which had similar effects. The lightness

(L*) of the leaves decreased in a growth media consisting of different levels of tea factory waste. The highest L* value was recorded in the growth medium that contained animal manure. (C2). In contrast, the leaf redness (a*) of plants grown in C2 medium increased. Similarly, according to Hunter's value, the yellowness (b*) value was higher in controls (C2 and C1, respectively) than in the growth medium containing tea factory waste (Table 4).

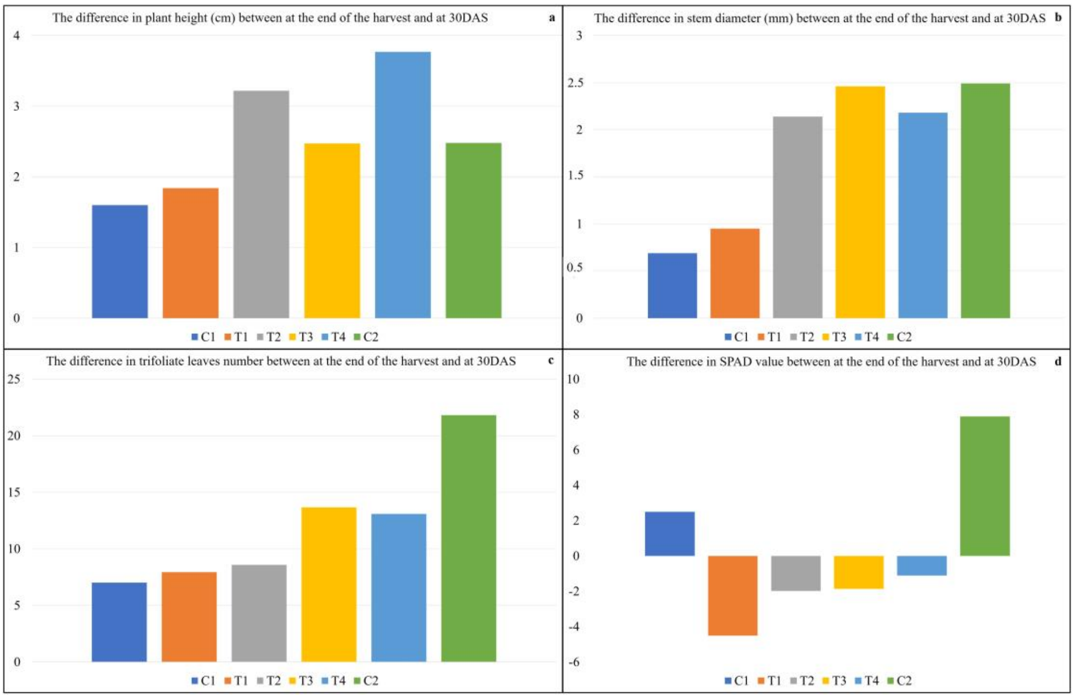

Figure 4. The difference in plant height (a), stem diameter (b), trifoliate leaves number (c), and SPAD value (d) between at the end of the harvest (EOH) and at 30DAS (cm) according to the treatments in snap bean.

Table 4. Effects of treatments on stem length, unifoliate leaf width, unifoliate leaf length, terminal leaflet width, terminal leaflet length, and leaf color (L, a, b) in snap bean at end of harvest (EOH) period

Treatments	Stem length (cm)	Unifoliate leaf width (cm)	Unifoliate leaf length (cm)	Terminal leaflet width (cm)	Terminal leaflet length (cm)	Leaf color (L)	Leaf color (a)	Leaf color (b)
C1	9.40 b	6.47 d	6.79 d	2.13 d	4.02 e	44.03 b	-12.21 a	25.00 b
T1	10.17 ab	7.54 c	7.49 c	2.87 c	5.71 d	41.62 d	-12.16 a	23.89 c
T2	10.50 ab	8.51 b	9.20 b	3.85 b	6.43 c	40.08 e	-11.60 a	21.00 e
T3	11.30 a	9.56 a	10.19 a	5.93 a	11.12 a	42.77 c	-12.18 a	22.41 d
T4	11.10 a	8.62 b	9.50 b	5.79 a	10.68 a	42.06 cd	-11.90 a	23.41 cd
C2	11.13 a	7.51 c	8.03 c	4.10 b	7.37 b	46.52 a	-14.28 b	30.29 a
LSD (5%)	1.32	0.47	0.61	0.57	0.69	0.89	0.83	1.05
CV (%)	6.85	3.22	3.90	7.63	4.99	1.14	3.67	2.36

Within each column, means followed by the same letters are not significantly different at P ≤ 0.05 according to the LSD test.

The highest values in fresh and dry weight of the green part and root dry weight were obtained from the C2 growth medium, followed by T4 and T3 media. The data collected from these three growth media for root dry weight were similar and statistically belonged to the same group. The longest root was obtained from T3 growth medium. The degree of root branching was highest in the C2, T4, and T3 media; these media were statistically grouped together. The amount of root nodules was highest in the C2 medium, followed by T4 (Table 5).

Table 5. Effects of treatments on fresh and dry weight of green part, fresh and dry weight of root, root length, the degree of root branching, and the amount of root nodules in snap bean at end of harvest (EOH) period

Treatments	Fresh weight of green part (g plant^{-1})	Dry weight of green part (g plant^{-1})	Fresh weight of root (g plant^{-1})	Dry weight of root (g plant^{-1})	Root length (cm)	The degree of root branching (1-9 scale)	The amount of root nodules (1-9 scale)
C1	5.96 d	1.39 c	2.99 c	0.36 d	20.00 d	2.67 c	3.50 c
T1	7.17 d	1.80 c	2.77 c	0.24 d	25.32 c	5.83 b	1.67 d
T2	13.37 c	2.34 c	6.41 b	0.89 c	27.66 b	5.00 d	3.50 c
T3	24.34 b	5.52 b	12.21 a	1.33 b	31.05 a	7.17 a	3.50 c
T4	24.89 b	5.61 b	12.12 a	1.32 b	28.66 b	7.83 a	5.83 b
C2	42.98 a	7.62 a	11.34 a	1.65 a	25.36 c	7.17 a	7.00 a
LSD (5%)	1.41	1.02	1.06	0.21	1.36	5.15	0.83
CV (%)	3.92	13.80	7.31	11.91	2.83	8.91	11.18

Within each column, means followed by the same letters are not significantly different at $P \leq 0.05$ according to the LSD test.

The total yield per pod was highest in the C2 growth medium and lowest in the C1 medium. The yield values obtained from the T3 and T4 media were found to be statistically similar. The highest total fruit number was recorded in the C2 and T4 media. Average pod length was similar in the C2, T4 and T3. While the average pod width was highest in T3 and T2, the highest average pod thickness was recorded in T3. Average pod weight was found to be highest in the T4, followed by T3. The difference between the treatments for total nitrogen amount in the leaves was not found to be statistically significant. However, the highest value was acquired from T4, and the minimum value was recorded from T3 (Table 6).

Table 6. Effects of treatments on the total yield and total fruit number, average pod lenght, width, thickness and, weight, and the amount of total nitrogen in leaves in snap bean at end of harvest (EOH) period

Treatments	Total yield (g pot^{-1})	Total fruit number (number pot^{-1})	Average pod length (cm)	Average pod width (mm)	Average pod thickness (mm)	Average pod weight (g)	Amount of total nitrogen in leaves
C1	53.50 e	16.33 e	9.94 c	9.47 b	8.68 ab	3.20 c	2.62
T1	79.73 d	29.00 d	10.19 b	9.45 b	8.53 ab	3.75 c	2.45
T2	152.45 c	45.57 c	12.02 a	9.65 a	8.75 ab	5.04 b	2.62
T3	221.95 b	59.00 b	12.81 a	10.38 a	9.06 a	5.48 ab	2.35
T4	233.61 b	72.00 a	12.59 a	9.46 b	8.52 ab	5.87 a	2.85
C2	338.16 a	79.00 a	12.15 a	9.57 b	8.39 b	4.98 b	2.58
LSD (5%)	22.43	8.22	0.70	0.55	0.55	0.60	
CV (%)	6.85	9.01	3.27	3.10	3.42	6.95	

Within each column, means followed by the same letters are not significantly different at $P \leq 0.05$ according to the LSD test.

4. Discussion

Inorganic fertilizers are commonly used to support plant growth and productivity because they allow nutrients to reach the plant quickly. However, they are easily washed from the soil. In contrast, organic matter slowly releases nutrients because microbial activity is required to decompose. The long-term benefits of adding organic substance to the soil have been proven by various studies (Wang et al., 2022; Priya et al., 2024). The use of organic matter improves the physical, chemical, and biological properties of the soil. However, amendments such as farmyard manure, vermicompost, leonardite, rose pulp, biochar, biogas residue, and seaweed have a more pronounced effect on the chemical quality of the soil than on its other properties (Alaboz et al., 2022). In this study, the impact of adding the waste generated from the processing of tea plants in factories to the soil as organic waste on the plant growth and yield of snap bean plants was investigated. Raguraj et al. (2025) stated that tea factory waste contains humic and fulvic acid. In their study, it has been determined that purified humic and fulvic acid extracts obtained from waste, when applied to the plant as a foliar spray together with a full rate of fertilization, increase the growth parameters, leaf, stem, and root dry weight, and nutrient uptake in the tea plant. As expected, our study demonstrated that plant growth and yield were higher in a growth medium containing tea factory waste compared to the control, which was soil without added organic matter. However, the positive effect was less pronounced in a growing medium with a low ratio of tea waste mixture. As the proportion of tea waste in the soil increased, its beneficial impact on the plant also became more evident. Similarly, in a previous study on kale, the application of tea waste at a 5% rate under drought stress was found to intensify oxidative and osmotic stress, thereby exacerbating growth inhibition, likely as a result of residual phenolics and temporary nitrogen immobilization. In contrast, a 10% application was observed to improve water retention, sustain relative water content, and partially restore pigment stability and biomass production, which was attributed to increased organic matter input and the enhanced availability of exchangeable minerals (Oğuz and Boyacı, 2025). Karavidas et al. (2022) expressed that humic acid application improved nodulation by 18% in common bean. In this study, the T4 growth medium, a mixture of equal soil and tea factory waste, increased the nodulation rate by approximately 67% compared to the control. These results indicate that tea factory waste provided a suitable environment for the development of snap bean plants' roots. Tea waste enhances soil structure, boosts effective cation exchange capacity, and enables better root retention and water infiltration by forming stable soil aggregates that facilitate nutrient access (Turgut and Köse, 2016; Debnath et al., 2021; Kumar et al., 2023). Nevertheless, tea factory waste did not contribute as positively as the effect of farmyard manure on snap bean plants' development and yield. Some studies indicated that farmyard manure had a more positive impact on the growth and yield of snap bean plants compared the various organic matters. In the study conducted by Yağmur and Okur (2017), the yields of snap bean plants were evaluated in growing media containing different ratios and mixtures of compost obtained from plant waste and farmyard manure. It was determined that all treatments contributed positively to the yield compared to the control medium, where only essential fertilization was applied. The highest yield was obtained in farmyard manure treatment compared to all other growing media. Engin et al. (2019) compared bean yields in Algreen and macroalgae treatment with farmyard manure added and non-added media and reported that the highest yield was achieved from farmyard manure added media. Similar results were obtained in our study. In this study, the highest yield was acquired from the growth medium containing farmyard manure, and the results are parallel to those of the other two studies.

The differences in the impact of tea factory waste and farm manure growth media on the plant development and yield of beans arise from the properties of the substances. Farmyard manure improves soil aggregate stability the most by week two, while tea waste reaches its peak effect by week eight (Turgut and Köse, 2016). This six-week period may create a significant difference in the growth rate of snap beans. In fact, in the study conducted on pepper, similar development differences were observed between the treatments using tea factory waste and farm manure treatments. It was suggested that these two substances could be used by mixing for better development in pepper (Karataş, 2024). Similarly, a mixture of these substances may allow better plant development and higher yields in snap beans.

Chlorophyll meters are practical tools to guide nitrogen (N) management by monitoring leaf N status. SPAD readings of light-induced chloroplast movement without foliar N supplementation provide information about leaf N availability (Xiong et al., 2015). Leaf chlorophyll content is an important determinant of photosynthetic efficiency. Variations in chlorophyll and carotenoid levels, caused by pigment degradation or enhanced synthesis, can lead to photosynthetic deficiencies and yield reduction under stress conditions. Conversely, plants treated with organic fertilizers generally exhibit higher chlorophyll concentrations, which contribute to improved photosynthetic capacity and overall plant vigor (Rahimi et al., 2023). In our study, although the results of the nitrogen analysis in snap bean leaves did not demonstrate a statistically significant difference according to the growing media, the difference between SPAD values was found to be significant. There were visual differences in leaf color between the treatments. The variations in SPAD values may be atributed to the phenolic substances in the tea factory waste or environmental conditions.

Conclusion

In conclusion, tea factory waste affects the development and yield of snap bean plants. However, this effect varies and is closely related to the amount of tea waste incorporated into the soil. The best results were achieved by mixing the waste with soil in equal proportions. This study indicates that tea factory waste can be effectively used in snap bean cultivation to support growth and yield, especially on soil with no organic matter added. However, it can be mixed with farmyard manure for more effective results, or the soil microbiota can be supported to decompose the tea waste quickly. It is necessary to examine the fungi and bacteria in soil microbiota that contribute to the decomposition of waste. Tea factory waste, because of the particularly with high levels of phenolic compounds, may be putting pressure on decomposition bacteria and fungi. Furthermore, the populations of these microorganisms that compete in the soil and facilitate decomposition may not be adequate. Additional research is required to address these issues more effectively.

Ethical Statement

Ethical approval is not required for this study because no harm was done to nature and the environment.

Conflict of Interest

The authors declare that there are no conflicts of interest.

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Author Contributions

The research concept and experimental design were formulated by author 1. The experiment was conducted under the supervision of Author 2, and data collection was carried out jointly by author 1 and author 2. The manuscript was written collaboratively by author 1 and author 2.

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