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Agronomic traits of lettuce (*Lactuca sativa* L.*)* under different temperatures as influenced by black soldier fly frass and vermicompost derived from kitchen waste

Suma Akter*, Khalid Mahmud, Afifah Maqsurah, Sumaiya Jannat Supty and Md. Harunor Rashid Khan

Department of Soil, Water and Environment, University of Dhaka, Dhaka-1000, Bangladesh

Keywords: Agronomic traits, Black soldier fly frass, Dry matter, Lettuce, Vermicompost

Abstract

Lettuce (*Lactuca sativa* L.) is an annual leafy herb and one of the most widely consumed salad vegetables. Due to its rich nutritional profile including vitamins, minerals, and folate - it has garnered significant research interest concerning its health benefits and cultivation practices. This study aimed to evaluate the influence of kitchen waste-mediated organic composts on the agronomic traits of lettuce under two distinct temperature regimes. Two pot experiments were conducted in the greenhouse of the University of Dhaka, Bangladesh, at constant temperatures of 22°C and 30°C during December 2023 to February 2024. Each pot was filled with 1.5 kg of processed soil and treated with black soldier fly (BSF) frass and vermicompost (V) at 0%, 25%, and 50% of the soil volume. The experiments ran for 70 days, and agronomic traits such as plant height, number of leaves per plant, leaf length and width, stem girth, and fresh and dry weights were recorded at 20, 45, and 70 days after transplanting (DAT), while root length was measured at final harvest (70 DAT). Results revealed that the higher temperatures (30°C) promoted greater plant height across all treatments compared to 22°C. The number of leaves per plant was significantly affected by compost type and temperature. Leaf dimensions increased progressively with time. The percentage increase over control (IOC) was consistently higher at 22°C across all sampling times, except in the V 50% treatment at 30°C. Dry matter content was also greater at 22°C for all compost levels. The highest fresh (43.4 g and 42.0 g) and dry (2.4 g and 2.2 g) weights were recorded under the V 50% treatment at both temperatures, whereas control pots yielded the lowest values. Overall, the higher dry matter content indicated greater yield potential in lettuce under cooler growing conditions.

Introduction

Lettuce (*Lactuca sativa* L.), an annual leafy herb of the family Compositae, is one of the most popular salad crops worldwide. It primarily grows in temperate regions, though it can also be cultivated in tropical and subtropical areas under controlled conditions. Owing to its high nutritional value; rich in vitamins (A and C), minerals (such as calcium, phosphorus, and iron), folate, protein, carbohydrates, and other micronutrients; lettuce has drawn

* Author for Correspondence: suma.soil93@gmail.com

considerable scientific interest in both nutritional research and cultivation optimization[1,2]. It is also known for its medicinal properties, acting as an anodyne, sedative, diuretic, and expectorant[3]. Moreover, its short growing cycle makes it an attractive crop for researchers and producers alike[4].

Temperature plays a critical role in plant development and productivity. Variations in temperature can significantly affect crop growth and yield. In general, higher temperatures tend to shorten crop duration, potentially reducing the yield of determinate crops. Many developmental processes, such as flowering and germination, show a linear response to temperature; positively between base and optimal levels, and negatively beyond the optimum[5]. For lettuce, the ideal temperature range for optimal growth is 18–25°C during the day and 10–15°C at night[6,7]. In Bangladesh, lettuce is a relatively new crop, gradually gaining popularity. However, standardized production practices, including appropriate nutrient management strategies, are not yet widely adopted by local farmers.

Nutrient supply and production technology play a pivotal role in determining both the yield and quality of lettuce. It is well established that lettuce responds positively to organic fertilization. Nevertheless, the ideal source and dosage of organic fertilizers remain inconsistent in the literature, as outcomes may vary depending on soil type, climate conditions, and the cultivar used[8-10].

Human activities generate a large volume of waste, and in recent decades, the global production of solid waste has risen to alarming levels-now exceeding three million tons per day. A significant portion of this is kitchen organic waste generated by households and restaurants, much of which is disposed of in uncontrolled landfills, leading to environmental degradation and public health concerns[11]. Although incineration could serve as an alternative method, it is often inefficient due to the high moisture content of kitchen waste[12]. Composting has proven to be a sustainable and efficient approach for treating biodegradable kitchen waste[13].

Organic kitchen waste can be converted into valuable composts such as vermicompost and black soldier fly frass using earthworms and BSF larvae, respectively. These composts are produced under aerobic conditions at specific temperatures over fixed durations. The use of *Hermetia illucens* frass as an organic fertilizer is increasingly gaining attention for its environmental benefits and role in promoting a circular economy[14]. Black soldier fly (BSF) has been thought to be effective to convert organic wastes which should have high quality essential nutrients. Accordingly, this has attracted interest in the face of rising prices of animal feedstuff and accumulating amounts of waste. The main by-product of this bio-conversion technology is BSF Frass (BSFF), which can be used as an organic fertilizer in agriculture. BSF-based composting offers two main advantages: (i) conversion of waste into protein-rich biomass suitable for animal feed, and (ii) production of frass, a nutrient-rich byproduct composed of unconsumed substrate and insect excreta[15-17].

Compared to other insect-based composts, BSF frass has shown higher efficiency in nutrient cycling and fertilization potential[18]. It contains essential macronutrients, minerals, chitin, and biostimulants conducive to plant growth[19]. Thus, BSF technology contributes to a closed-loop waste management system, where organic waste supports larval growth, and the resulting biomass and frass are repurposed as animal feed and organic fertilizer, respectively[20]. Given these considerations, the present study focuses on assessing the agronomic attributes of lettuce (*Lactuca sativa* L.) influenced by kitchen waste-mediated vermicompost and black soldier fly frass under two distinct temperature conditions.

Materials and Methods

Layout of the experiment: To evaluate the influence of kitchen waste-mediated organic composts on the agronomic traits of lettuce (*Lactuca sativa* L.) under different temperature regimes, two pot experiments were conducted in the greenhouse of the University of Dhaka, Bangladesh. The experiments were maintained at two constant temperature levels such as 22°C and 30°C throughout the growing period from December 2023 to February 2024 (Photographs 1 & 2). Surface soil samples were collected from a medium highland agricultural field in Parchar village, located in the Krishnanagar Union of Faridpur Sadar Upazila, Faridpur District (Map 1). The soil is classified as calcareous dark grey floodplain soil, belonging to the Sara series[21]. The geographical coordinates of the study location are 23°35′8′′ N and 89°46′52′′ E, situated within Agro-Ecological Zone (AEZ) 12, known as the Low Ganges River Floodplain. The initial soil sample had a pH of 7.08, electrical conductivity (EC) of 336 $\mu S\ cm^{-1}$, organic matter (OM) content of 1.85%, and total nitrogen of 0.15%. The cation exchange capacity (CEC) of the soil was measured at 24.08 cmolc kg^{-1}. For the experiment, 1.5 kg of processed soil was placed in each pot. Kitchen waste-derived organic composts, specifically, black soldier fly (BSF) frass and vermicompost (V) were applied at rates of 0%, 25%, and 50% by volume of the soil. The applied organic compost were prepared at the net house of the dept. of Soil, Water and Environment, University of Dhaka, Bangladesh. The composts were thoroughly mixed into the soil before transplanting lettuce seedlings. Selected properties of the composts are presented in Table 1. No inorganic fertilizers were added. The experiment was arranged in a completely randomized design (CRD) with three replications. A total of 30 pots were used; 15 for each of the two temperature conditions (22°C and 30°C). The treatment groups were as follows:

- **Control:** No organic fertilizer applied
- **BSF 25% and BSF 50%:** BSF frass applied at 25% and 50% of the soil volume
- **V 25% and V 50%**: Vermicompost applied at 25% and 50% of the soil volume

Transplantation: Healthy lettuce seedlings, 15 days old, were obtained from a local nursery and transplanted into each pot (two seedlings per pot). Five days after transplanting, the pots were placed in the greenhouse under the respective temperature conditions as 15 pots at 22°C and 15 pots at 30°C. Regular irrigation, weeding, and intercultural operations were carried out as needed. Agronomic traits were recorded at regular intervals throughout the growing period.

Map 1: Site of the soil sample collection (Banglapedia)

Photograph 1: Visual appearance of lettuce plants under 22°C temperature level

Photograph 2: Visual appearance of lettuce plants under 30°C temperature level

Table 1. Some selected properties of the organic composts

Properties	Black Soldier Fly (BSF) Frass	Vermicompost (V)
Organic Carbon (%)	19.60	15.85
Total N (%)	3.02	3.16
C/N Ratio	6.49	5.02
Total P (%)	0.16	0.36
Total S (%)	0.20	0.14
Total K (%)	0.54	0.57
Total Na (%)	0.08	0.33
Total Ca (%)	0.42	3.90
Total Mg (%)	1.67	2.44
Total Ni (%)	*nd	0.09
Total Pb (%)	nd	
Total Cr (%)	nd	
Total Cd (%)	nd	
Total Fe (%)	0.34	0.09
Total Mn (%)	0.01	0.05

*nd = not in detectatable range

Data Collection and Statistical Analyses: Statistical analyses of the collected data were conducted using the computer-based software programs Minitab 20 and Microsoft Excel. Two-way analysis of variance (ANOVA) and Tukey's multiple comparison test were performed at a 5% significance level to evaluate the effects of treatments and temperature on the measured agronomic parameters. These parameters included plant height, number of leaves, leaf length, leaf width, stem girth, fresh weight, and dry weight recorded at 20, 45, and 70 days after transplantation (DAT), as well as root length measured at harvest.

Results and Discussion

Plant height: Monitoring plant height is critical for agronomists and breeders to assess growth performance and manage fields effectively. It serves as a vital indicator for evaluating crop vigor, biomass accumulation, and potential yield[22-24]. Additionally, lettuce height data can aid intelligent harvesting systems[25]. Plant height (cm) was recorded at 20, 45, and 70 DAT. Two-way ANOVA revealed significant differences ($p < 0.05$) in plant height due to temperature and organic compost application at all three intervals. At 30°C, all treatments showed higher plant heights compared to their 22°C counterparts. At 20 DAT, plant heights ranged from 6.7 to 11.0 cm at 22°C, and 19.7 to 20.3 cm at 30°C, indicating a significant early-stage response to temperature, though differences among compost treatments were not statistically significant. A similar trend continued at 45 DAT. However, at 70 DAT, compost treatments also showed significant differences. The tallest plant (133.7 cm) was observed in the V 50% treatment under 30°C, while the same treatment at 22°C yielded a height of only 81.7 cm. These results suggest that lettuce plant height is strongly influenced by temperature, with compost application especially vermicompost which enhancing this effect under higher temperatures (Fig. 1).

Number of leaves per plant: Significant differences in leaf number were observed across treatments and temperature levels. At 20 DAT, ANOVA did not indicate statistically significant interactions, but numerical differences due to treatment were evident. At 45 and 70 DAT, significant differences ($p < 0.05$) were recorded for both temperature and compost applications (Fig. 2). Across the three observation points, the highest number of leaves per plant (34) was recorded under the V 25% treatment at 30°C, while the lowest (19) occurred in the control group at 22°C. At each time point, control treatments at 22°C consistently exhibited fewer leaves than those at 30°C. These findings indicate that both temperature and compost application significantly influenced leaf development, with vermicompost particularly effective in increasing leaf number. This aligns with findings by Wang *et al.*[26], who reported that vermicompost and chicken manure compost significantly enhanced vegetative growth parameters such as stem diameter and plant height in vegetable crops.

Leaf length and width: Leaf length and width of the studied lettuce plants were not significantly influenced by the treatments in statistical terms; however, numerical differences were observed among the compost treatments (Tables 2 & 3). To better illustrate treatment effects, the percentage increase over control (IOC) was calculated. Leaf length increased progressively throughout the growing period. At 20 DAT, the highest IOC in leaf length was recorded under the 22°C temperature condition. This trend continued at 45 and

70 DAT under the same temperature, with the exception of the V 50% treatment at 30°C, which showed a higher IOC at the final stage. Although the IOC values were generally more pronounced at 22°C, absolute leaf length values tended to be higher at 30°C. This suggests that while relative growth compared to control was greater at lower temperatures, higher temperatures supported greater overall leaf elongation. Both BSF frass and vermicompost showed noticeable effects on leaf length, particularly at higher application rates.

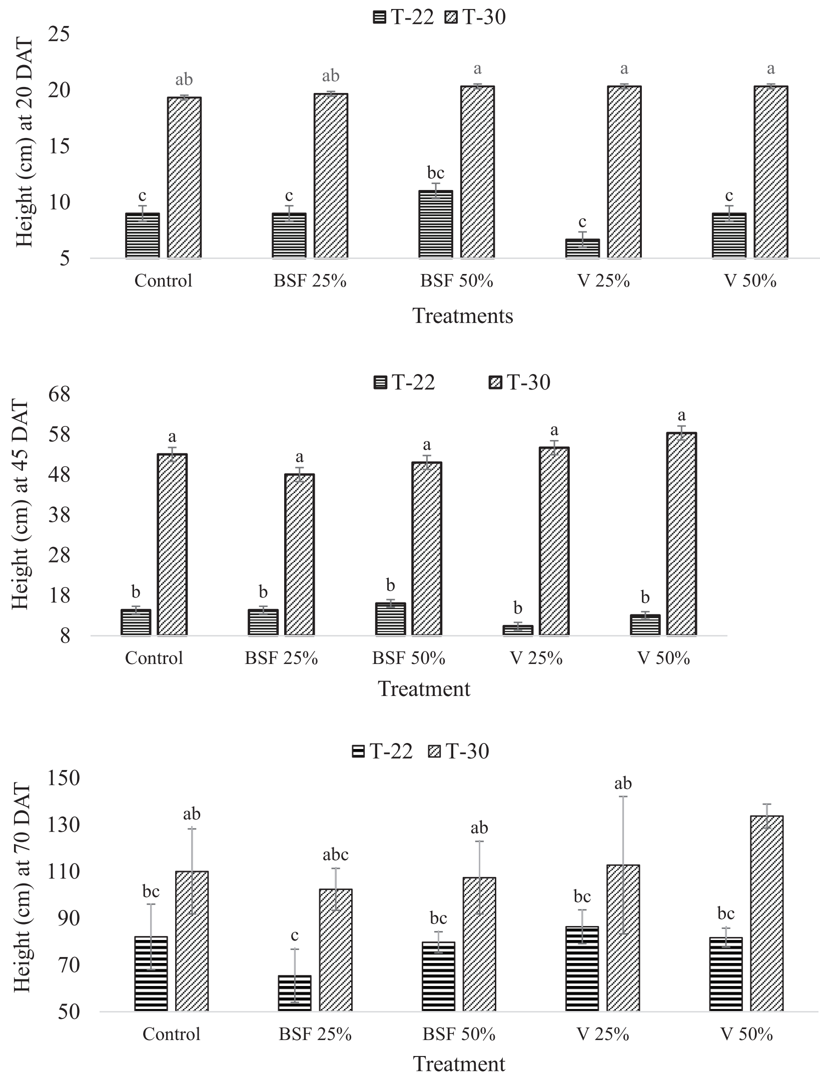

Fig. 1. Height of lettuce plants at 20, 45 and 70 DAT as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

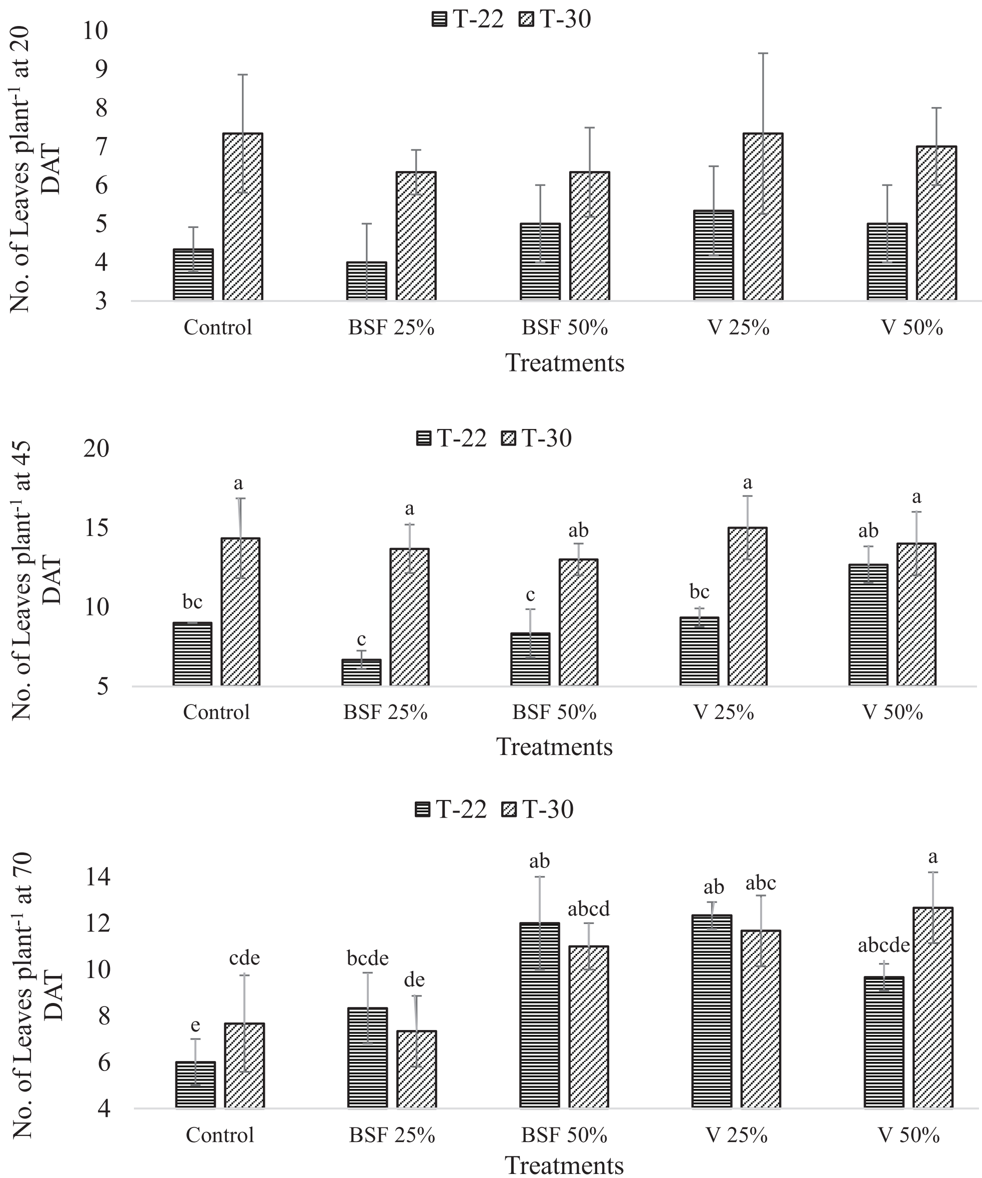

Fig. 2. Number of leaves per plant at 20, 45 and 70 DAT as influenced BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

At harvest (70 DAT), the highest IOC (44.4%) in leaf length was observed in the V 50% treatment under the 30°C condition, followed by the BSF 50% and V 50% treatments at 22°C. These findings suggest that temperature, combined with organic compost application, can influence leaf growth dynamics, with vermicompost particularly enhancing leaf elongation under warmer conditions.

Table 2. Leaf length (cm) of lettuce at 20, 45 and 70 DAT as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels

Treatment	22^{0}C Temperature						30^{0}C Temperature					
	20 *DAT	IOC (%)	45 DAT	IOC (%)	70 DAT	IOC (%)	20 DAT	IOC (%)	45 DAT	IOC (%)	70 DAT	IOC (%)
Control	8.3	-	11.3	-	8.9	-	9.3	-	12.1	-	11.0	-
BSF 25%	8.5	2.4	11.9	5.3	9.3	4.5	10	7.5	13.3	9.9	11.9	7.6
BSF 50%	8.9	7.2	11.7	3.5	12.6	41.6	9.4	1.1	12.7	13.2	13.3	20.3
V 25%	9.5	14.5	14	23.9	11.0	23.6	9.5	2.2	15.2	25.3	12.7	14.9
V 50%	9.2	10.8	15.5	37.2	12.6	41.6	10	7.5	14.9	23.1	15.9	44.4

*DAT - Days after Transplantation

Table 3. Leaf width (cm) of lettuce at 20, 45 and 70 DAT as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels

Treatment	22^{0}C Temperature						30^{0}C Temperature					
	20 *DAT	IOC (%)	45 DAT	IOC (%)	70 DAT	IOC (%)	20 DAT	IOC (%)	45 DAT	IOC (%)	70 DAT	IOC (%)
Control	5.6	-	7.1	-	6.6	-	5.3	-	7.8	-	6.9	-
BSF 25%	6.2	10.7	7.6	7.0	7.0	6.5	6.2	17.0	8.2	5.1	7.6	10.6
BSF 50%	5.9	5.4	7.6	7.0	8.8	33.8	5.6	5.7	8.9	14.1	8.0	16.9
V 25%	5.8	3.6	8.6	21.1	8.0	21.7	5.8	9.4	9.4	20.5	8.6	25.2
V 50%	5.9	5.4	10.3	45.1	8.7	31.4	6.0	13.2	9.8	25.6	9.7	40.8

*DAT - Days after Transplantation

In terms of leaf width, the highest percentage increase over control (IOC) was observed in the V 50% treatment at 22°C, reaching 45.1%. In contrast, the lowest IOC (1.1%) was recorded under the BSF 50% treatment at 30°C. Overall, vermicompost demonstrated a more pronounced effect on leaf width compared to black soldier fly frass, with the 50% application rates of both compost types generally outperforming their respective 25% doses. Among the two temperature conditions, lettuce leaves grown at 22°C exhibited a more attractive and visually appealing morphology than those grown at 30°C, suggesting that moderate temperatures favor better leaf development in terms of both form and dimension.

Stem Girth: Stem girth was significantly influenced ($p < 0.05$) by both temperature and treatment at the final harvest (70 DAT). Across all growth stages (20, 45, and 70 DAT), most treatments resulted in greater stem girth at 22°C, except for a few exceptions. Specifically, BSF 25% and V 50% at 20 DAT, and BSF 25% and 50% at 45 DAT, showed slightly higher girth at 30°C. However, by 70 DAT, all treatments exhibited greater stem girth at the 22°C condition. The maximum stem girth (4.5 cm) was recorded in the V 50% treatment at 22°C, followed closely by BSF 50%, indicating that both types of compost contributed to stem thickening, with vermicompost being slightly more effective (Fig. 3).

Fresh and dry weight: Fresh and dry weights of harvested lettuce leaves were recorded to evaluate the yield potential under varying temperature and compost treatments. The application of organic composts under both temperature levels had a statistically significant ($p < 0.05$) effect on these parameters (Fig. 4 & 5). For most treatments, fresh weight was higher under 30°C, except in the control group, which performed better at 22°C. In contrast, dry weight was consistently higher at 22°C across all treatments. This suggests that lettuce plants accumulated more dry matter at the cooler temperature, indicating potentially higher nutritional value and yield quality at 22°C. The maximum fresh weights (43.4 g at 30°C and 42.0 g at 22°C) and dry weights (2.4 g at 22°C and 2.2 g at 30°C) were recorded in the V 50% treatment. The control treatment yielded the lowest values for both fresh and dry weights. These results are consistent with the findings of Abd El-Fattah *et al.*[27], and Naznin *et al.*[28] who reported that organic fertilizers significantly enhanced yield-related parameters in vegetable crops, including number of leaves per plant, head size, and both fresh and dry biomass.

Root length: A statistically significant variation in root length was observed among the different treatments (Fig. 6). The maximum root length was recorded in treatments involving vermicompost, while the minimum was found in the control group. The highest root length (7.3 cm) was recorded under the V 25% treatment, which was statistically similar to the V 50% treatment (7.2 cm). The shortest root length (5.1 cm) was observed in the control treatment. Across both temperature regimes, all treatments produced longer roots at 30°C compared to 22°C, indicating a positive effect of elevated temperature on root elongation. These findings support the conclusion that kitchen waste-derived organic fertilizers significantly enhance root development in lettuce plants, with vermicompost demonstrating the most effective response.

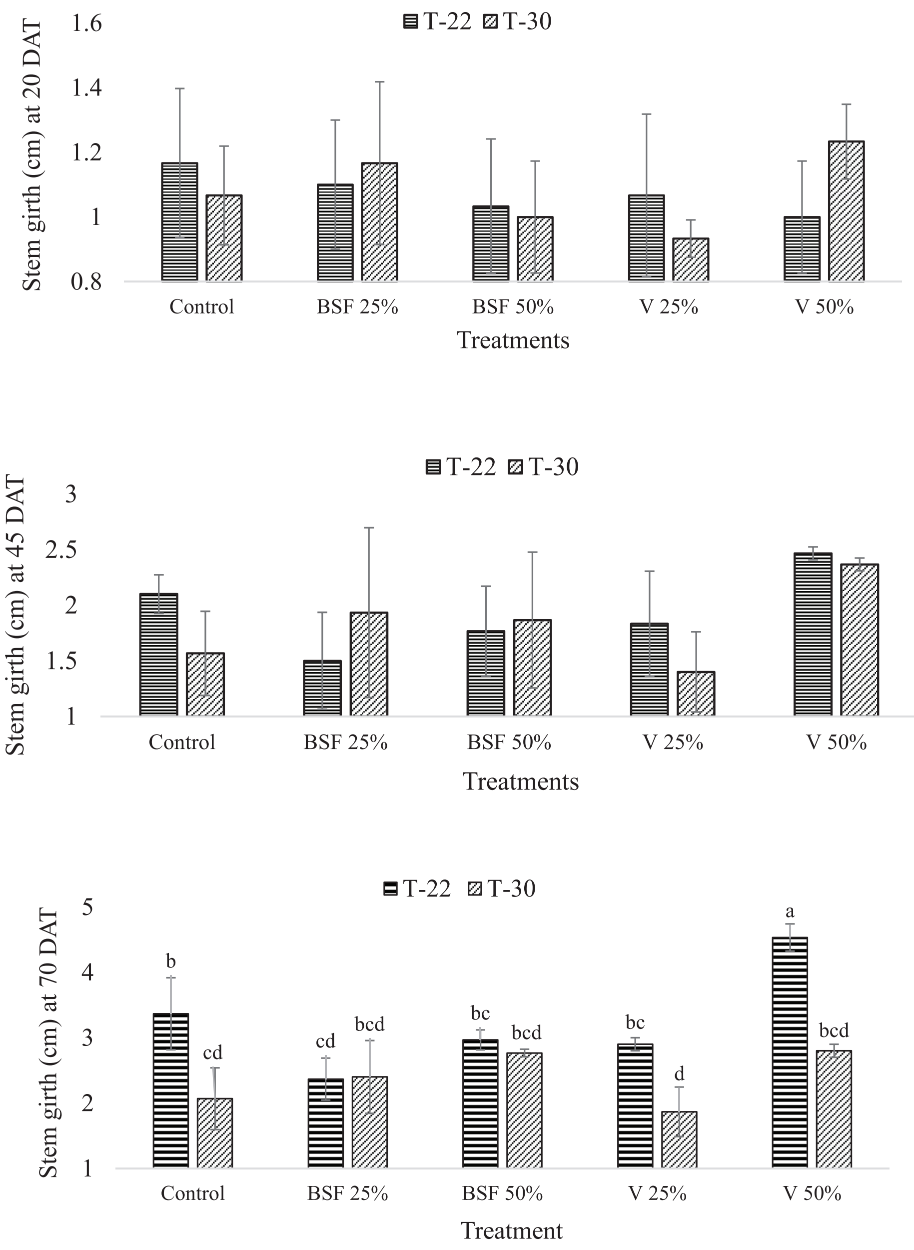

Fig. 3. Stem girth of lettuce plants at 20, 45 and 70 DAT as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

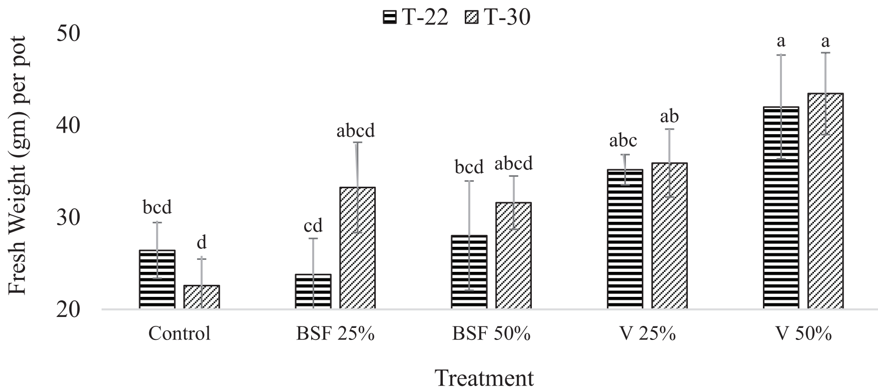

Fig. 4. Fresh weight of lettuce plants as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

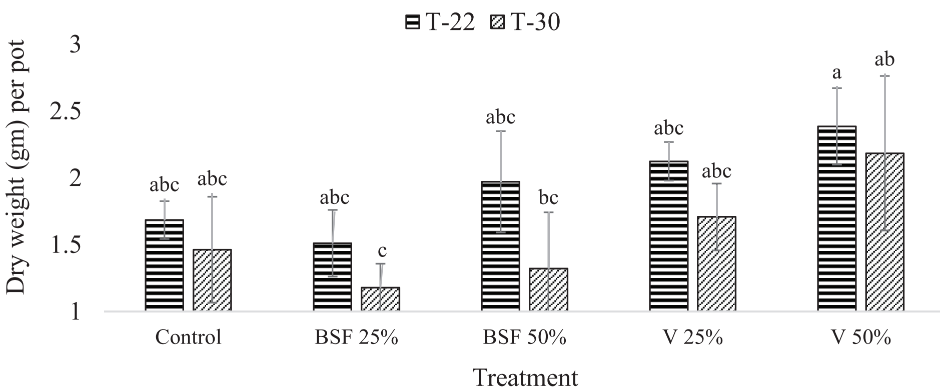

Fig. 5. Dry weight of lettuce plants as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

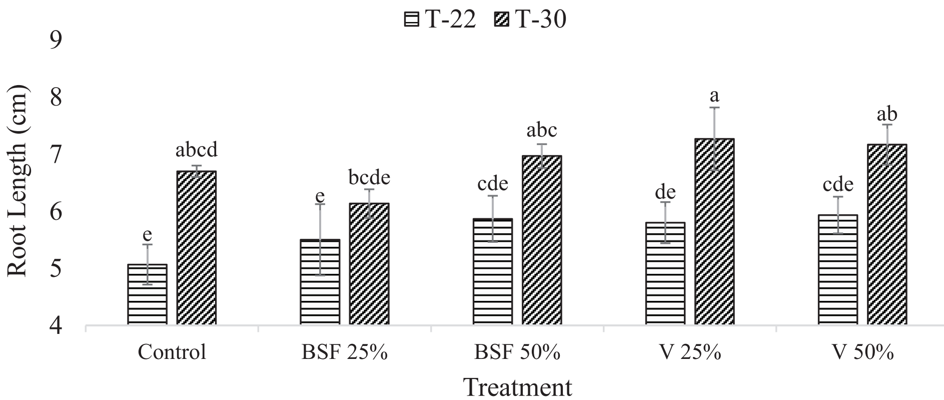

Fig. 6. Root length of lettuce plants as influenced by BSF frass and vermicompost derived from kitchen waste under two temperature levels. In the bars, means that do not share a common letter are significantly different at 5% level by Tukey's range test.

The present study demonstrated that the application of organic fertilizers prepared from kitchen waste produced the anticipated improvements in the growth of lettuce plants under two temperature regimes. Vermicompost showed the most positive effects on agronomic traits such as plant height, number of leaves per plant, leaf length and width, stem girth, fresh and dry weight, and root length, followed closely by black soldier fly frass. These findings are consistent with those of de Paula *et al.*[13], who reported that compost derived from kitchen waste enhances lettuce growth and has a residual effect on soil fertility. Several factors justify the improved plant growth observed with the addition of organic compost to agricultural soils. The mineralization of nitrogen, phosphorus, and sulfur from organic fertilizers derived from recycled waste increases the availability of these essential nutrients. When combined with sustainable management practices, such as the use of green manure, this approach can lead to higher yields and the preservation of soil fertility[29]. Additionally, increased enzymatic activity, enhanced microbial communities, and elevated levels of plant hormones contribute to greater plant development. Organic composts are also rich in humic substances, which can alter plant gene expression related to various physiological processes (e.g., the Krebs cycle, metabolism, and photosynthesis) of the plant[30].

Conclusion

Black soldier fly frass and vermicompost derived from kitchen waste significantly influenced the agronomic performance of lettuce plants under two temperature regimes. Most growth parameters, including plant height, leaf number, leaf length and width, stem girth, fresh weight, and root length, showed improved values under the 30°C temperature condition. However, dry weight and dry matter content were higher at 22°C, suggesting that lower temperatures favor dry matter accumulation in lettuce an important trait for this leafy vegetable, as the leaf is the main edible yield. Both compost types significantly improved the agronomic traits of lettuce compared to the control, with vermicompost consistently outperforming BSF frass. Additionally, higher compost doses (50%) were more effective than that of 25% doses for both types. Notably, only organic composts derived from kitchen waste were used in this study, yet the crop response was visually and statistically positive. These findings underscore the potential of organic farming in vegetable crop production as a sustainable strategy to enhance food security and contribute toward achieving the Sustainable Development Goals (SDGs).

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