Nutritional quality of spinach (Amaranthus hybridus L.) cultivated using black soldier fly (Hermetia illucens) waste compost

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Nutritional quality of spinach *(Amaranthus hybridus L.)* cultivated using black soldier fly *(hermetia illucens)* waste compost

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Abstract: The spinach can be cultivated on urban farms using compost from black soldier fly (BSF) larvae and urban organic waste. The study examined (1) the existence of heavy metal pollutants in household and market waste, (2) the impact of BSF larvae waste compost on spinach growth and product quality, and (3) the ingestion of compost components in spinach plant tissue. The experiment used a complete randomised block design (RCBD) with five treatments, specifically: (1) soil media without compost or urea; (2) soil with BSF compost as household waste substrate without fertiliser; (3) soil with household waste substrate BSF compost fertilised with urea; (4) soil with BSF compost as fruit waste substrate without fertiliser; and (5) soil with BSF compost as fruit waste substrate with fertiliser. Spinach growth and product, nutrient content, and heavy metal absorption in spinach tissue were parameters. BSF larva waste compost with household or fruit

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PUBLIC INTEREST STATEMENT

Spinach vegetables become part of our daily diet and as a very important source of nutrition. Organic vegetables grown using organic fertilizers, without chemical fertilizers and pesticides are considered healthier because they contain higher nutrition, taste better, have brighter colors, and don't spoil quickly. However, it can be otherwise, it can threaten human health because it contains toxic materials in its tissues when it grows in contaminated media. Compost produced from decomposition organic waste using Black Soldier Fly (BSF) is considered a suitable fertilizer in organic farming systems. The results showed that compost can contain heavy metals from organic waste raw materials that are composted. The presence of heavy metals in compost can threaten food safety and human health. The results of the research become inputs in the development of management and prevention strategies in protecting and saving the sustainable soil-food subsystem.

waste as a substrate contains macro and micronutrients required by plants and heavy metals that may harm vegetable plant tissues. Applying BSF larvae waste compost increased the vitamin A, vitamin C, chlorophyll, and carotene content in spinach production. The spinach product showed no significant difference in fibre, nitrate, nitrite, and oxalate levels compared to the control (100% soil). While the plant did absorb heavy metals (Cu, Pb, Cd, Zn) from the compost, the concentrations were below the threshold set by WHO/FAO. The use of compost for organic vegetable cultivation ought to be appropriately evaluated due to the potential existence of heavy metals.

Subjects: Agriculture and Food; Food Additives & Ingredients; Clean Technologies

Keywords: vegetables; nutrition; food safety; organic fertiliser; urban waste

1. Introduction

Consumer demand for nutritious foods and government policies to sustain agricultural environments must be met to establish a stable foundation for developing organic farming systems (Maggio et al., 2013). Conventional vegetable cultivation methods can present hazards to human health because of the accumulation of heavy metals, chemical pollution, and detrimental microorganisms (Hisham et al., 2021). Using organic fertiliser reduces the concentration of Pb, Cu, and Cr while amplifying nutrient absorption efficiency in tomatoes (Hameeda et al., 2019). Biochar derived from faecal matter promotes growth and influences the build-up of heavy metals in spinach plant tissues (Tahir et al., 2018). Compared to control and chemical fertilisers, the use of organic cow manure as a fertiliser improves the quantity of marketable spinach leaves and improves the nitrogen, phosphorus, sulphur, and selenium levels of plants. Cow manure enhances production by 88.08% compared to the control group (without fertiliser) and shows a 41.16% increase compared to chemical fertilisers like N, P2O5, and K2O (Turkkan & Kibar, 2022). Organic farming will benefit society and the environment by producing chemical-free, safe, healthful, and nutritious organic food. Organically cultivated spinach contains higher levels of carotene, vitamin C, and calcium (Sharma & Agarwal, 2014). The development of organic agriculture must consider the detrimental effects of chemicals on human health, natural resources, and the global demand for high-quality products (Rathore et al., 2014).

Spinach (vegetable) farming plays an essential role in earning income, increasing revenue, ensuring food security, and alleviating poverty (Mdoda et al., 2022). Spinach is a leafy green vegetable that grows quickly and has significant nutritional value. It is rich in minerals, vitamins, phytochemicals, and bioactive compounds that are beneficial to health, although it does accumulate oxalate and nitrate in its leaves (Giménez et al., 2021). Spinach is a great source of vitamin B6, riboflavin, folate, niacin, soluble fibre, omega-3 fatty acids, and iron, which can prevent conditions such as osteoporosis and anaemia. It is known for its effectiveness in treating digestive issues, promoting blood formation, stimulating growth in children, stimulating appetite, aiding in fatigue recovery, and acting as an antioxidant and anticancer agent (Miano, 2016). Spinach leaf meal, due to its available iron content, can be utilised to fortify infant formula and other food products (Tedom et al., 2020). Spinach juice can be utilised as an alternative nutritional therapy to improve haemoglobin (Hb) levels and prevent anaemia anemia (Purba et al., 2021).Spinach plants provide crucial vitamins, minerals, essential amino acids, high fibre content, no cholesterol, and are low in fat and calories, making them a precious resource for tackling nutritional deficiencies in individuals (Terfa, 2021).

Fertilisers impact the growth, production and nutrient content of spinach vegetables. Nitrogen, phosphorus and potassium fertilisers enhance spinach plants' total phenols, antioxidant activity, flavonoids and vitamin C (Zikalala et al., 2017). The use of compost extract improves resistance to soil-borne illnesses, secondary metabolic results, and antioxidant capacity (Giménez et al., 2021).

Fertilising compost with leaf litter and manure reduces N, Zn, Fe, Cu, and Cd levels in spinach production while increasing soil P and K (except for N, NO3, and NH4) (Anwar et al., 2017). Slow-release organic fertilisers effectively use nitrogen and reduce nitrate levels in spinach while increasing ascorbic acid content (Vigardt et al., 2020). Food waste and cow manure improve spinach production, nitrogen, phosphorus, and potassium (Kelley et al., 2022). The various spinach varieties maintain their vitamin C, nitrite, nitrate, and oxalate levels. Both organic and inorganic fertilisers enhance stem diameter, root development, plant height, leaf number, and leaf surface area. Using fertiliser increases vitamin C content and decreases nitrite and oxalate levels (Alessa et al., 2017).Utilising a blend consisting of 75% remaining sludge and 25% NPK leads to improved kale and spinach growth, yield, and quality. Several parameters associated with plant quality, such as ascorbic acid, carbohydrate, and protein content, exhibit noteworthy increments (Zafar et al., 2021).

Black soldier fly (BSF) larvae bioconversion of organic waste is a promising innovation due to its high production rate, cost-effectiveness, and short production time. The consequences of bioconversion lead to compost for plants and larvae as a feed source for livestock and fish (Siddiqui et al., 2022). Compost produced from food waste processed with BSF larvae comprises 18.37% organic carbon, 1.45% total nitrogen, 1.58% total phosphorus, and a C/N ratio of 12.66, satisfying the criteria of the Indonesian National Compost Standard (SNI) (Widyastuti et al., 2021). The technology for treating solid organic waste using BSF larvae can contribute to addressing the shortage of organic fertilisers and provide new income opportunities for small businesses (Sarpong et al., 2019). Compost produced from household waste by BSF larvae does not contain any toxic elements and is safe for use as plant fertiliser (Rahmat et al., 2021). The use of 1,240 kg/ha of BSF compost and 322 kg/ha of NPK fertiliser for vegetable crops can improve soil health, improve production, and enhance the nutritional quality of vegetable plants, particularly in protein and ash content (Anyega et al., 2021). BSF waste compost, which acts as an organic fertiliser, displays high levels of ammonium nitrogen and reduced levels of nitrate nitrogen, resulting in a rise in vegetable dry matter weight (Kawasaki et al., 2020). Compost produced via the bioconversion process by BSF larvae can offer phosphorus and potassium for plants (Putra et al., 2017).

Urban agriculture, which uses compost as a planting medium, encourages people to shift towards healthier food consumption habits, focusing on organic and locally-produced produce from residential areas (Puigdueta et al., 2021). Extensive urban agriculture has a significant role in establishing strong food security systems and promoting sustainable management of organic waste in urban areas (Weidner & Yang, 2020). The careful application of compost and chemical fertilisers can improve the quality of spinach by augmenting vitamin C content, diminishing nitrite and oxalate levels, and upholding a balanced nitrate content (Alessa et al., 2017). The use of compost obtained from urban waste as organic fertiliser, particularly in the context of urban agriculture, has grown increasingly popular (Haryanta & Rejeki, 2021). Urban agricultural products, however, pose food safety risks associated with the use of fertilisers derived from waste containing hazardous elements, inadequate sanitation during planting and harvesting, excessive nitrate compounds, and pesticide waste (Buscaroli et al., 2021). There are concerns regarding the potential contamination of food crops by urban waste pollutants crops (Paradelo et al., 2020). The use of compost in urban agriculture offers a perfect solution for handling the copious organic waste produced in urban areas. By establishing a value-added cycle that involves using organic waste as raw material for compost, implementing composting processes, developing effective marketing strategies, and applying compost in organic farming systems, long-term organic waste management can be ensured (Woldeamanuel et al., 2022). The use of compost usually improves vegetable nutrition with components like nitrogen (N), phosphorus (P), potassium (K), sodium (Na), manganese (Mn), zinc (Zn), and magnesium (Mg) (Mu et al., 2020). Nonetheless, one must be careful to keep clear of using compost that is contaminated, as it may present a potential hazard to human health by assisting the digestion of high levels of heavy metals, particularly zinc (Zn), nickel (Ni), cadmium (Cd), and lead (Pb) by vegetable plants (Eissa & Negim, 2018).

Table 1. Nutrient and heavy metal content in the BSF larvae compost

Indicator	BSF Larvae Compost from Jambangan Recycling Center	BSF Larvae Compost from Puspa Agro market
C/N ratio	15.80	17.90
N (%)	1.22	1.05
P2O5 (%)	0.68	0.48
K2O (%)	0.77	0.51
Ca (%)	0.42	0.31
Mg (%)	0.30	0.23
Pb (ppm)	0.02	0.01
Cu (ppm)	0.10	0.12
Cd (ppm)	0.01	0.02
Zn (ppm)	2.06	2.15

Compost made from urban organic waste can be fertilised in urban agriculture systems. Black soldier fly (BSF) larvae waste with urban organic waste as a substrate can be used as organic fertiliser in urban farming systems to cultivate spinach. Urban rubbish may contain heavy metals that can be absorbed into the tissues of spinach plants, resulting in harmful substances to humans. The waste compost produced by BSF larvae is an organic fertiliser that can be used in urban agriculture. The objectives of this study were to (1) determine the occurrence of heavy metal pollutants in household and market rubbish, (2) examine the impact of BSF larvae rubbish compost on spinach growth and production quality, and (3) investigate the absorption of compost constituents in spinach plant tissue. The advantage of the research is to provide information that not every compost can be used as a medium for spinach plants, it is necessary to pay attention to the presence of heavy metal contamination in the composted material.

2. Materials and Methods

2.1. BSF compost

Black Soldier Fly (BSF) larvae compost consists of the waste produced during the breeding of BSF larvae, which includes the leftover substrate, larval excrement, and the exoskeleton discarded during moulting. The BSF larvae compost, using household waste substrate, was acquired from the Jambangan Recycling Centre operated by Surabaya City, while the BSF larvae compost using fruit waste substrate was obtained from the Puspa Agro Market managed by the East Java Province. To ensure proper maturation and preparation of the compost for use as fertiliser, it was carefully packed in bags and stored at the Black Soldier Fly breeding site for a period of 60 days. The results of the analysis on the nutrient and heavy metal content in the BSF Larvae Compost are displayed in Table 1. The percentages and parts per million (ppm) measurements are expressed in relation to the dry weight of the material.

2.1.1. Experimental design

The experiment aimed to investigate BSF Larvae Compost's effect on spinach's nutritional quality. The treatments consisted of the following additions to the growing media:

P_0K_0: Control − 100% soil

P_1K_0: 50% soil and 50% BSF Larvae Compost from household waste, without urea

P_1K_1: 50% soil and 50% BSF Larvae Compost from household waste, with urea

P_2K_0: 50% soil and 50% BSF Larvae Compost from fruit waste, without urea

P_2K_1: 50% soil and 50% BSF Larvae Compost from fruit waste, with urea

Each treatment was repeated thrice, resulting in 15 plot units. A plot unit of one spinach plant cultivated in a black polythene container with a diameter of 25.5 cm and a height of 40 cm, filled with 30 cm of planting substrate. The 15 plot units were arranged in a randomised complete block design (RCBD), with three rows serving as blocks, each containing five plot units. The distance between rows was 150 cm, while the distance between plot units within a row was 100 cm.

2.1.2. Spinach cultivation

Certified *Spinacia oleracea var. caudatus* seeds were procured from an esteemed agricultural establishment in Surabaya. The seeds underwent germination using rockwool media. The planting media was meticulously prepared by blending vertisol soil (sourced from Mojosari, Mojokerto Regency) with BSF larva compost, adhering to the prescribed proportions outlined in the treatment design. The meticulously prepared planting media was subsequently filled into black plastic bags, possessing a diameter of 25.5 cm and a height of 40 cm. The media was carefully filled up to 30 cm within the bags. Transplantation of the spinach seedlings occurred when they attained age 15 days or possessed three fully formed leaves. Plant maintenance encompassed essential tasks such as watering, weed control, and implementing necessary pest and disease management measures following the plant's requirements. Urea fertiliser was applied as per the treatment design, with a dosage of 1.5 g per plant, administered at the 7-day and 21-day mark. The spinach harvest was conducted precisely 35 days after the initial planting.

2.1.3. Heavy metal content analysis

A comprehensive analysis was carried out to evaluate the heavy metal content in both the samples of BSF larva compost and the harvested spinach vegetables. Around 20–30 g of the edible part for the plant samples was carefully gathered and then dried in an oven until it turned into dry ash. On the other hand, the BSF larva waste compost sample was obtained from a measured quantity of 25 g, extracted from the residual substrate used in larva rearing. Heavy metals, particularly Cu, Zn, Pb, and Cd, were analysed using accurate spectrophotometric and atomic absorption spectrophotometric techniques (Raden et al., 2017; Tiwow et al., 2019).

2.1.4. Nutrient content of spinach measurement

The measurement of nutrient content in spinach involves the examination of samples obtained from the consumed portion of the plant. The quantification of total nitrogen (N) within the plant tissue is carried out using the Kjeldahl method, employing dry samples (Zikalala et al., 2017). Furthermore, the levels of Vitamin C, Vitamin A, chlorophyll, phenols, flavonoids, tannins, total antioxidants, nitrate, nitrite, oxalate, and saponin are determined using a spectrophotometer and AAS methods (Jabeen et al., 2019). Moreover, spinach's fibre content is evaluated using the distillation-gravimetry method (Rashid et al., 2022).

2.1.5. Plant growth measurement

Plant growth is measured using indicators such as plant height, number of leaves, and stem diameter every 7 days starting from 7 days after planting until harvest, while above-ground biomass is measured at harvest. Plant height is measured from the soil surface (root collar) to the highest point of growth using a ruler. The number of leaves is counted for fully grown leaves that have not yet yellowed and are still green. Leaf area is calculated using the formula length times width times a constant.

$$\text{Area} = \text{Length x Width x Constant}$$

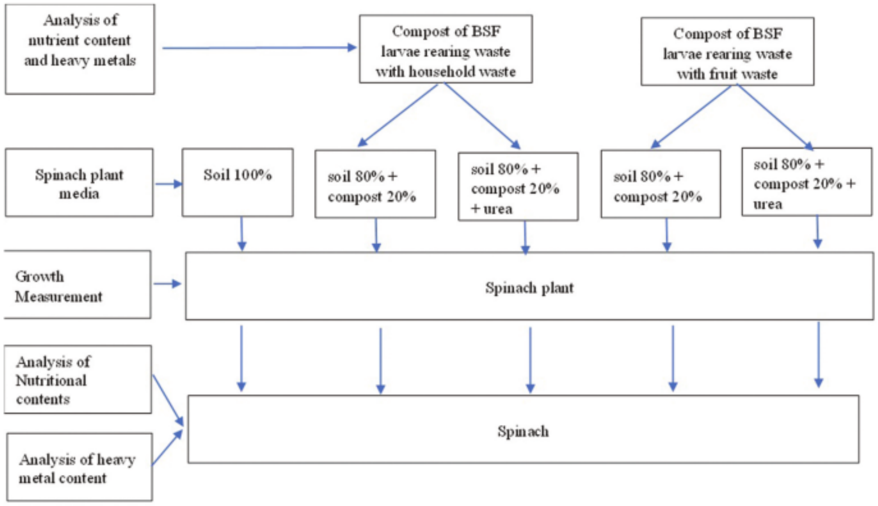
The constant is obtained from the average of five leaf samples and is calculated using the formula:

$$\text{Constant} = \frac{\textit{The actual leaf area}}{\textit{Length x Width}}$$

The actual leaf area is obtained by drawing the leaf on millimeter paper.

The stem diameter is measured using a caliper at half of the plant height, the above-ground biomass is obtained by weighing the plant parts above the soil surface, and the consumption weight is obtained by weighing the edible leaves at harvest using an analytical balance.

Figure 1. Research stages.



2.1.6. Statistical analysis

Spinach plants growth, production, and nutritional content data were analysed using Analysis of Variance (ANOVA). If the F-test result shows a significant treatment variance, a post-hoc comparison test using Least Significant Difference (LSD) test with $\alpha = 5\%$ is conducted to determine the significantly different treatment means. Statistical analysis was performed using Excel program.

2.1.7. Research flow chart

The stages of the research are outlined in the flowchart shown in Figure Figure 1.

3. Results

The nutritional composition of spinach can be evaluated by analysing its constituents, including fibre, vitamin C, vitamin A, iron (Fe) elements, chlorophyll, carotene, and nitrate. The fibre content of harvested spinach samples was 15.30% to 17.63%. Similarly, the vitamin C content was between 309.07 mg/100 g and 353.87 mg/100 g, while the vitamin A content was 38.97 mg/100 g to 42.32 mg/100 g. Moreover, the Fe content ranged from 18.37 mg/100 g to 21.47 mg/100 g, the chlorophyll content was between 206.93 mg/100 g and 353.50 mg/100 g, and the carotene content was from 62.57 to 68.57 mg/100 g (Table 2). The fibre content in the BSF larvae waste compost treatment was not significantly different from the control. The Vitamin C, Vitamin A, Fe elements, chlorophyll and carotene content in the compost treatment of BSF larvae waste was higher than the control.

The nitrate content in spinach ranged from 0.10–0.14 ppm and was not significantly different between BSF larvae waste compost treatment and control, although the nitrite content ranged from 0.10–0.23 ppm and tended to decrease with compost treatment from fruit waste. Following BSF larvae waste compost treatment, the oxalate content was 0.263–0.363 parts per million. Though they did not exceed the WHO or FAO thresholds, heavy metal elements Cu, Pb, Cd, and Zn were discovered while spinach plants. The WHO/FAO permits a maximum limit of heavy metal content in vegetable tissue, with Fe at 425 mg/kg, Pb at 0.3 mg/kg, Zn at 99.4 mg/kg, Cd at 0.2 mg/kg, and Cu at 73 mg/kg (Alkhatib et al., 2022). Generally speaking, blending BSF larvae waste compost with household and fruit waste substrates increased the heavy metal content of Cu, Pb, and Cd, but not Zn. Table 3 displays nitrate and nitrite levels and various heavy metals that serve as indicators of substandard spinach production.

BSF larva waste compost and chemical fertilisers affected spinach plant growth, referring to the variable of plant height, the number of leaves, and stem diameter 28 days after planting. When

Table 2. Quality data of spinach product given BSF larvae compost fertiliser

Treatment	Nutritional content/nutrition					
	Fibre (%)	Vit C (mg/100g)	Vit A (mg/100g)	Fe (mg/100g)	Chlorophyll (mg/100g)	Carotene (mg/100g)
P_0K_0	16.67 ab	309.07 d	39.07 b	18.37 d	206.93 d	62.57 b
P_1K_0	17.14 a	336.13 b	42.32 a	20.57 bc	344.83 b	67.64 a
P_1K_1	15.30 c	353.87 a	39.05 b	21.23 ab	353.50 a	65.97 ab
P_2K_0	17.63 a	321.30 c	41.13 ab	20.38 c	240.57 c	68.57 a
P_2K_1	15.67 bc	350.30 a	38.97 b	21.47 a	344.14 b	65.14 ab
LSD 5%	1.16	11.99	3.15	0.70	6.91	3.71

Note: Numbers in one column followed by the same letter are not significantly different based on the 5% LSD test; NS = Not significant

P0K0:: Control – 100% soil

P1K0: Soil: 50% BSF household waste compost: 50%, without urea

P1K1: soil: 50% BSF household waste compost: 50%, and 3 g/plant urea

P2K0: soil : BSF compost fruit waste 50% : 50%, without urea

P2K1: soil: 50% BSF fruit waste compost: 50%, and 3 g/plant urea

treating BSF larvae waste compost with fruit waste substrate and chemical fertilisers, the highest value of the plant height variable was 83.67 cm, the number of leaves was 89.67, and the stem diameter was 22.57 mm. The control treatment has the lowest value of the growth variable (without compost and chemical fertilisers). Table 4 displays variable data on the growth of harvested spinach 28 days post-planting.

Data on spinach crop yields are presented in Table 5. The variables for the harvest production of spinach are measured by the biomass weight and the weight of consumable materials, such as leaves and young shoots, which are measured at harvest. The treatment with black soldier fly larvae compost and chemical fertiliser can increase the above-ground biomass weight more than five times compared to the control. The percentage of material consumed did not differ between the fertilised plants and the control, and there was even a tendency for the control treatment to consume more material. Fertilised plants had more stem and branch organs but not more leaves.

4. Discussion

BSF larva waste compost increases the weight of harvested stover and the portion consumed from spinach plants because it consists of of organic matter that gradually releases bound nutrients owing to environmental factors (Bziouech et al., 2022). The application of organic fertilisers alone or together with the application of inorganic fertilisers to picking spinach plants significantly increases leaf area, stem diameter, and fresh weight of vegetative parts, carotene content (Alessa et al., 2017), and weight of dry matter above ground (Kawasaki et al., 2020). According to (Mu et al., 2020), applying compost at a high percentage generally provides elements of N, P, K, Na, Mn, Zn and Mg in vegetable nutrition, while applying at a low percentage increases the content of Ca, Al, and Fe. BSF larva waste compost also improves the quality of harvested spinach vegetables, specifically increasing the content of vitamin C, vitamin A, chlorophyll, carotene, and the mineral iron. Kale and spinach plants that were given organic fertilisers showed significantly higher leaf area, ascorbic acid content, carbohydrate content and protein content than the control treatment (Zafar et al., 2021).The synergistic impact of compost with NPK fertiliser will enhance the overall phenol content, antioxidant activity, flavonoids and vitamin C of spinach vegetables (Zikalala et al., 2017). The conclusion of the study (Anyega et al., 2021) suggests that the most effective way to use element N, increase ash concentration, enhance soil health, boost production, and improve the nutritional quality of vegetable plants is by fertilising with compost made from BSF larvae waste and chemical fertilisers.

Table 3. Quality data of spinach product given BSF larvae compost fertiliser

Treatment	Hazardous material content						
	Nitrates (ppm)	**Nitrite (ppm)**	**Nitrite (ppm)**	**Cu (ppm)**	**Pb (ppm)**	**Cd (ppm)**	**Zn (ppm)**
P_0K_0	0.12	0.022 a	0.022 a	0.012 c	0.029 c	0.011 c	0.039 a
P_1K_0	0.13	0.023 a	0.023 a	0.020 b	0.030 c	0.011 c	0.022 d
P_1K_1	0.14	0.022 a	0.022 a	0.021 b	0.039 b	0.030 a	0.034 b
P_2K_0	0.13	0.010 b	0.010 b	0.013 c	0.020 d	0.021 b	0.030 c
P_2K_1	0.10	0.018 a	0.018 a	0.034 a	0.049 a	0.021 b	0.021 d
LSD 5%	NS	0.007	0.007	0.002	0.002	0.003	0.003

Note: Numbers in a column followed by the same letter are not significantly different based on the 5% LSD test; NS = Not significant

P0K0: Control – 100% soil

P1K0: Soil: 50% BSF household waste compost: 50%, without urea

P1K1: soil: 50% BSF household waste compost: 50%, and 3 g/plant urea

P2K0: soil : BSF fruit waste compost 50% : 50%, without urea

P2K1: soil: 50% BSF fruit waste compost: 50%, and 3 g/plant urea

Table 4. Data on the growth of spinach at the age of 28 days given BSF larvae compost fertiliser

Treatment	Plant height (cm)	Number of leaves	Stem diameter (mm)
P_0K_0	51.33 d	73.67	14.13 c
P_1K_0	80.67 ab	85.67	17.83 bc
P_1K_1	64.67 cd	78.00	19.43 ab
P_2K_0	67.67 bc	78.00	21.40 ab
P_2K_1	83.67 a	89.67	22.57 a
LSD 5%	13.35	NS	3.85

Note: Numbers in a column followed by the same letter are not significantly different based on the 5% LSD test; NS = Not significant

P0K0: Control − 100% soil

P1K0: Soil: 50% BSF household waste compost: 50%, without urea

P1K1: soil: 50% BSF household waste compost: 50%, and 3 g/plant urea

P2K0: soil: BSF fruit waste compost 50% : 50%, without urea

P2K1: soil: 50% BSF fruit waste compost: 50%, and 3 g/plant urea

Table 5. Quantitative data of spinach product given BSF larvae compost fertiliser

Treatment	Biomass weight (g)	Consumed materials	
		Weight (g)	%
P_0K_0	112.67 c	29.03 b	26.59
P_1K_0	646.67 ab	138.23 a	21.33
P_1K_1	547.53 b	135.50 a	27.36
P_2K_0	848.23 a	153.23 a	17.98
P_2K_1	710.67 ab	137.27 a	19.32
LSD 5%	243.51	37.71	NS

Note: Numbers in a column followed by the same letter are not different based on the 5% LSD test; NS = Not significant

P0K0: Control − 100% soil

P1K0: Soil: 50% BSF household waste compost: 50%, without urea

P1K1: soil: 50% BSF household waste compost: 50%, and 3 g/soil urea

P2K0: soil : BSF fruit waste compost 50% : 50%, without urea

P2K1: soil: 50% BSF fruit waste compost: 50%, and 3 g/soil urea

The application of compost did not affect the content of nitrite, nitrate and oxalate groups in pickled spinach vegetables. According to Alessa et al. (2017), the application of organic fertiliser alone or together with inorganic fertilisers has no effect on the content of nitrate, nitrite, and oxalate in picking spinach plants. High nitrate and oxalate content in leaf vegetables can be related to plant fertilisation activity, lighting and plant nature factors (Solberg et al., 2015). BSF waste compost on mustard plants causes higher ammonium and lower nitrate nitrogen (Kawasaki et al., 2020).

Heavy metal contamination in urban waste affects human health and safety through heavy metal contamination in food due to agricultural and environmental activities through compost and polluted water sources (Anani et al., 2020). BSF larva waste compost, which contains various heavy metals, does not affect the harvested spinach quality because the tissue's heavy metal content is well below the permitted threshold. Council waste compost increases Cd, Cu, Pb, and Zn levels in spinach leaves beyond the authorised thresholds. On the other hand, the concentrations of metals (Cd, Cu, Pb, and Zn) in agricultural waste compost are beneath the threshold, suggesting that municipal waste compost could comprise substances detrimental to human health (Saleem et al., 2018).

Compost affects the concentration of heavy metals and nutrient content in lettuce leaf tissue (Alromian, 2020). As per research findings (Głodowska & Krawczyk, 2017), conventionally grown vegetables tend to contain more significant amounts of heavy metals (Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, and Zn) in comparison to organic farming methods. The use of urban waste compost for leafy vegetable plants displays the existence of the heavy metal Zn, Cu, Pb, and Cd in plant tissues, with differing levels depending on the pollution level in the waste materials (Paradelo et al., 2020). Oguntade et al. (2019) suggested that fertilisation with compost containing high concentrations of heavy metals but bioaccumulation in leaf vegetables is lower than the maximum allowed by WHO/FAO, specifically for Cu the limit is 0.1 mg/kg, and for Mn, Fe and Zn it is 0.3 mg/kg. The WHO/FAO permits a maximum limit of heavy metal content in vegetable tissue, which includes Fe at 425 mg/kg, Pb at 0.3 mg/kg, Zn at 99.4 mg/kg, Cd at 0.2 mg/kg, and Cu at 73 mg/kg (Alkhatib et al., 2022).

BSF larva waste compost contains macro and micro nutrients that plants require and contains heavy metals, which can be harmful if they enter vegetable plant tissues. The presence of heavy metals is dependent on the substrate utilised in rearing BSF larvae. BSF larvae waste compost is slightly alkaline with a pH of 7.5, rich in nutrients, especially micro-nutrients, and low ammonium nitrogen content indicating a slow nutrient release process to supply nutrients in the longer term (Gärttling & Schulz, 2022). As per the discoveries of (Widyastuti et al., 2021), the C-organic content of BSF waste compost was 18.37%, the total nitrogen content was 1.45%, the total phosphorus content was 1.58%, the pH was 6.8, and the C/N ratio was 12.66, which fulfilled the criterion as an organic fertiliser for vegetables. Micronutrients Zinc (60.55ppm), Manganese (36.55ppm), and Boron (12.07 ppm) were discovered in BSF larvae waste compost with the household waste substrate (Rahmat et al., 2021). Due to the high metal content, it is safe to utilise as plant fertiliser. The analysis of compost made from BSF larvae waste revealed that it met the standard for organic fertiliser, with N: 1.04%, P: 2.25%, K: 1.55, and C/N 14.14% (Mutiar & Yulhendri, 2020).

5. Conclusion

BSF larva waste compost with household waste or fruit waste as a substrate contains macro and micronutrients required by plants and comprises of heavy metals that can be detrimental if they enter vegetable plant tissues. The application of BSF larvae waste compost increased growth, the weight of harvested stover, and the weight of the part consumed from the picked spinach plants. Treatment of BSF larvae waste compost significantly increased the content of vitamin A, vitamin C, chlorophyll, and carotene in spinach plants and had no effect on fibre, nitrate, nitrite, and oxalate content. The heavy metals Cu, Pb, Cd, and Zn present in the compost are absorbed into the spinach plant tissues but at low concentrations below the limits permitted by WHO/FAO. This study concludes that compost made from BSF larvae and household or fruit waste can be used as organic fertiliser for spinach plants to enhance the growth, yield, and nutritional value of spinach vegetables. Processing organic waste using BSF larvae must be integrated with urban farming development to produce healthy food products through independent urban organic farming.

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