



International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

NAAS Rating (2026): 5.20

www.agronomyjournals.com

2026; 9(7): 1650-1654

Received: 19-05-2026

Accepted: 21-06-2026

V Anithaa

Department of Entomology,
College of Agriculture,
University of Agricultural
Sciences, Dharwad,
Karnataka, India

Mallapur CP

Department of Entomology,
College of Agriculture,
University of Agricultural
Sciences, Dharwad,
Karnataka, India

Kambrekar DN

Department of Entomology,
College of Agriculture,
University of Agricultural
Sciences, Dharwad,
Karnataka, India

Rajasekar A

Zigma Global Environ
Solutions Private Limited,
Erode, Tamil Nadu, India

Salakinkop SR

Department of Agronomy,
Principal Scientist and Head of
AICRP on Maize, University
of Agricultural Sciences,
Dharwad, Karnataka, India

Santhosh GP

Department of Microbiology,
Junior Microbiologist, AICRP
on EAAI (Bioconversion
Technology), University of
Agricultural Sciences,
Dharwad, Karnataka, India

Akbar S Md

Department of Biochemistry
and Scientist, Agricultural
Research Station (Cotton),
University of Agricultural
Sciences, Dharwad,
Karnataka, India

Corresponding Author:**V Anithaa**

Department of Entomology,
College of Agriculture,
University of Agricultural
Sciences, Dharwad,
Karnataka, India

Feedstock heterogeneity influences the physicochemical characteristics and nutrient quality of black soldier fly frass fertilizer

V Anithaa, Mallapur CP, Kambrekar DN, Rajasekar A, Salakinkop SR, Santhosh GP and Akbar S Md

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i7u.6184>

Abstract

The quality of black soldier fly (*Hermetia illucens* L.) frass is largely influenced by the composition of the organic feedstock used for larval rearing, yet comparative information on frass derived from different heterogeneous waste streams remains limited. This study evaluated the physicochemical properties and nutrient composition of frass produced from heterogeneous kitchen waste and heterogeneous market waste to determine the influence of feedstock on fertilizer quality. Five-day-old larvae were reared on the respective feedstocks for 18 days under a completely randomized design with five replications. The harvested frass was analysed for physicochemical properties and nutrient composition according to the Fertilizer (Control) Order standards for city compost. Statistical comparisons were performed using an independent samples t-test, and the magnitude of treatment effects was assessed using Hedges' g. Feedstock type significantly influenced 13 of the 16 parameters evaluated. Frass produced from kitchen waste contained significantly higher concentrations of nitrogen, potassium, sulphur, magnesium, zinc, iron, sodium, organic carbon and carbon-to-nitrogen ratio, whereas frass derived from market waste was enriched with calcium, manganese and boron. Both frass types exhibited similar electrical conductivity, phosphorus and copper contents, and satisfied the prescribed standards for pH, electrical conductivity and carbon-to-nitrogen ratio. The effect size analysis confirmed that feedstock composition produced substantial and biologically meaningful differences in frass quality. Overall, the findings demonstrate that feedstock selection can be strategically used to produce nutrient-specific black soldier fly frass, providing a rapid and sustainable approach for converting biodegradable wastes into high-quality organic fertilizer while supporting circular nutrient recycling.

Keywords: Black soldier fly, frass fertilizer, organic amendment, nutrient quality

Introduction

Agriculture is fundamental to global food and nutritional security. With the world's population projected to reach nearly 9.7 billion by 2050, food production must increase by approximately 70 % to meet future demand (Hamed and Tayel, 2025). However, achieving higher productivity without compromising environmental sustainability remains a major challenge. While intensive agricultural practices have substantially increased crop yields since the Green Revolution, they have also contributed to soil degradation, nutrient depletion, erosion, salinization, declining organic matter, and reduced soil microbial diversity (Turpin *et al.*, 2017) ^[1]. Consequently, sustainable nutrient management has become essential for maintaining crop productivity while preserving soil health (Juncal *et al.*, 2023) ^[2, 3].

Synthetic fertilizers have played a crucial role in enhancing agricultural production, but their excessive use has raised environmental and economic concerns. Their manufacture is energyintensive and contributes to greenhouse gas emissions, while nutrient losses through leaching and runoff lead to eutrophication and groundwater contamination (Xing *et al.*, 2025) ^[4]. In addition, increasing fertilizer prices have encouraged the search for sustainable alternatives that can reduce dependence on mineral fertilizers without compromising crop performance (Timsina, 2018) ^[5]. Organic amendments are increasingly recognized as viable alternatives because they improve soil fertility while supplying nutrients gradually through microbial mineralization. Besides providing essential nutrients, they enhance soil organic carbon, improve soil structure, increase water-holding capacity, and stimulate beneficial microbial activity (Lopes *et al.*, 2025; Wang *et al.*, 2018) ^[6, 7]. However, conventional organic amendments such as farmyard

manure and compost often exhibit inconsistent nutrient composition and may pose concerns related to pathogens or contaminants, highlighting the need for alternative organic fertilizers with more predictable quality. Black soldier fly (*Hermetia illucens* L.) frass has recently emerged as a promising organic fertilizer. Produced during the bioconversion of organic wastes by black soldier fly larvae, frass consists of larval excreta, undigested feed residues, and shed exoskeletons (Beesingamukama *et al.*, 2020). It contains appreciable amounts of macro- and micronutrients and has been reported to improve plant growth, soil microbial activity, and nutrient availability (Poveda, 2021) [8]. Furthermore, because it is generated through the recycling of organic waste streams, BSF frass supports circular economy principles by converting biodegradable wastes into value-added agricultural inputs (Klammsteiner *et al.*, 2020) [9]. Despite its potential, the fertilizer quality of BSF frass is strongly influenced by the feedstock used for larval rearing. Variations in substrate composition can alter important physicochemical properties such as pH, electrical conductivity, nutrient concentration, carbon content and CN ratio, thereby affecting its agronomic value (Klammsteiner *et al.*, 2020) [9]. Although several studies have demonstrated the benefits of BSF frass, comparatively little information is available on how different heterogeneous organic feedstocks influence its nutrient composition and fertilizer quality (Lopes *et al.*, 2025) [6]. Kitchen waste and market waste are among the most abundant biodegradable waste streams used for black soldier fly production, yet they differ considerably in their composition. Understanding how these feedstocks affect the characteristics of the resulting frass is important for developing standardized production protocols and ensuring consistent fertilizer quality. Therefore, the present study aimed to compare the physicochemical properties and nutrient composition of black soldier fly frass produced from heterogeneous kitchen waste and market waste feedstocks to better understand the influence of feedstock composition on frass quality.

Materials and methods

The experiment was conducted at the Department of Entomology, University of Agricultural Sciences, Dharwad, Karnataka, India. Two biodegradable feedstocks, namely heterogeneous kitchen waste (KW) and heterogeneous market waste (MW), were evaluated for the production of black soldier fly (*Hermetia illucens* L.) frass. The kitchen waste was collected from the university hostel and consisted mainly of cooked rice, chapati, dhal, and cooked vegetables. The market waste was collected from a local fruit and vegetable market and predominantly comprised raw fruit residues, including banana, muskmelon, papaya, and watermelon, along with vegetable residues such as brinjal, gourds, and pumpkin.

Each feedstock was weighed separately and placed into individual rearing trays. Five hundred five-day-old BSF larvae were introduced into each tray, and the experiment was laid out in a completely randomized design with five biological replications for each feedstock. The larvae were reared for 18 days under identical environmental conditions until they reached the prepupal stage. At harvest, the prepupae were separated manually, and the residual frass was collected and sieved through a 4.0 mm IS sieve to remove undecomposed particles. The processed frass samples were subjected to

physicochemical analysis following the procedures prescribed under Schedule IV of the Fertilizer Control Order (FCO), 1985. Parameters including pH, electrical conductivity, total nitrogen, phosphorus, potassium, sulphur, calcium, magnesium, zinc, iron, manganese, copper, sodium, boron, organic carbon and carbon-to-nitrogen ratio were determined. Data were analysed using an independent samples *t*-test and differences were considered significant at $P < 0.05$. In addition, *Hedges' g* effect size was calculated to quantify the magnitude of differences between the two feedstocks, and the results were presented using a forest plot with 95% confidence intervals. Since *Hedges' g* incorporates a correction for small sample sizes, it is considered a more appropriate measure of effect size than *Cohen's d* for the present study.

Results and Discussion

The physicochemical properties of BSF frass varied significantly with the type of feedstock used. Of the 16 parameters evaluated, 13 showed significant differences between frass produced from heterogeneous kitchen waste (KW) and market waste (MW), whereas electrical conductivity, phosphorus, and copper remained comparable between the two feedstocks (Table 1). The observed trend of predominantly significant, feedstock dependent variation supports the main hypothesis of this study and is consistent with other reports that BSF frass composition is not an intrinsic, immutable characteristic of the insect but is largely dictated by the substrate on which the larvae are reared (Klammsteiner *et al.*, 2020; Gebremikael *et al.*, 2022) [9, 10]. Any compositional difference in the parent feedstock is expected to be carried through in the frass as a composite of larval excreta, shed exuviae and undigested feed residues (Klammsteiner *et al.*, 2020) [9], either directly through undigested residues or indirectly through the larval gut microbiome and metabolism into measurable differences in the harvested frass.

pH and Electrical Conductivity: The pH of BSF frass was significantly influenced by the feedstock, with kitchen waste (KW) frass recording a slightly higher pH (7.157) than market waste (MW) frass (6.990). Nevertheless, both values were within the acceptable range (6.0– 8.0) specified under FCO standards indicating their suitability for agricultural use. The relatively higher pH of KW frass may be attributed to the predominance of cooked food residues such as rice, chapati and dhal, which are rich in starch and proteins. During larval digestion and microbial decomposition, these substrates undergo ammonification, releasing alkaline compounds that can increase the pH of the resulting frass. In contrast, the market waste consisted largely of raw fruits and vegetables, which naturally contain higher levels of organic acids and sugars, contributing to a comparatively lower pH. Similar feedstock-dependent variation in BSF frass pH has been reported by Klammsteiner *et al.* (2020) [9].

Electrical conductivity (EC), however, did not differ significantly between the two feedstocks. The comparable EC values indicate that, despite differences in substrate composition, both feedstocks produced frass with similar concentrations of soluble salts. Importantly, the EC values were well below the maximum limit of 4.0 dS m⁻¹ prescribed under FCO standards, suggesting that both frass types can be applied to soil without posing a salinity risk.

Table 1: Comparison of physicochemical properties and nutrient composition of black soldier fly (*Hermetia illucens* L.) frass produced from heterogeneous kitchen waste and market waste feedstocks

S. No.	Parameters (Unit)	Kitchen Waste Frass	Market Waste Frass	t-value	p-value
1	pH	7.157	6.990	5.423	0.0059**
2	EC	2.653	2.395	2.353	NS
3	Nitrogen (%)	1.887	1.633	7.677	0.0051**
4	Phosphorus (%)	1.393	1.350	2.335	NS
5	Potassium (%)	2.410	2.150	10.615	0.0004***
6	Sulphur (%)	3.720	3.130	18.065	<0.0001***
7	Calcium (%)	4.577	4.880	-7.000	0.0029**
8	Magnesium (%)	2.750	2.160	20.438	<0.0001***
9	Zinc (ppm kg ⁻¹)	298.620	219.100	30.791	<0.0001***
10	Iron (ppm kg ⁻¹)	259.887	188.133	31.730	<0.0001***
11	Manganese (ppm kg ⁻¹)	60.147	122.173	-60.702	<0.0001***
12	Copper (ppm kg ⁻¹)	56.840	56.953	-0.213	NS
13	Sodium (%)	2.610	2.160	18.371	<0.0001***
14	Boron (%)	0.566	0.683	-14.018	0.0016**
15	Carbon (%)	20.880	17.753	5.135	0.0293*
16	C:N ratio	10.817	9.847	12.985	0.0017**

NS = Not significant ($P > 0.05$); $\backslash P < 0.05$; $\backslash\backslash P < 0.01$; $\backslash\backslash\backslash P < 0.001$.

Macronutrients

Feedstock composition had a clear influence on the macronutrient profile of BSF frass. Kitchen waste-derived frass contained significantly higher nitrogen than market waste-derived frass, which is likely due to the presence of protein-rich cooked food, particularly dhal, in the hostel waste. Protein-rich substrates supply more nitrogen to the larvae, resulting in greater nitrogen retention in the final frass. Similar observations have been reported by Klammsteiner *et al.* (2020) [9] and Gebremikael *et al.* (2022) [10], who demonstrated that the nutrient composition of BSF frass is closely linked to the nutritional characteristics of the larval feedstock.

A similar trend was observed for potassium and sulphur, both of which were significantly higher in KW frass. The elevated sulphur content can be explained by the abundance of sulphur-containing amino acids, such as methionine and cysteine, present in pulse-based food residues like dhal. In contrast, phosphorus content remained comparable between the two feedstocks, indicating that phosphorus accumulation in BSF frass is less responsive to differences in substrate composition. This finding agrees with previous studies, which reported relatively smaller variations in phosphorus than in nitrogen across different BSF diets (Klammsteiner *et al.*, 2020) [9].

From a practical perspective, both frass types contained considerably higher nitrogen and potassium than those typically reported for farmyard manure and were comparable to or higher than the nutrient concentrations commonly observed in vermicompost. This highlights the ability of BSF larvae to rapidly convert biodegradable wastes into a nutrient-rich organic amendment within a relatively short rearing period, making BSF frass a promising alternative to conventional organic fertilizers.

Secondary and Micronutrients

The secondary and micronutrient composition of BSF frass was significantly influenced by feedstock type. Kitchen waste-derived frass contained higher concentrations of magnesium, zinc, iron and sodium, which can be attributed to the nutrient-rich cooked food residues used as the larval substrate. In contrast, market waste-derived frass was enriched with calcium, manganese and boron, likely due to the predominance of raw fruits and vegetables, whose peels and structural tissues naturally contain higher levels of these minerals. Similar feedstock-dependent variation in BSF frass composition has been reported by Klammsteiner *et al.* (2020) [9]. Copper showed no significant difference between the two feedstocks, indicating that its concentration was relatively unaffected by substrate composition. Overall, the results demonstrate that BSF frass provides an important source of secondary and micronutrients, and that feedstock selection can be strategically used to produce frass with nutrient profiles suited to specific soil fertility requirements.

Organic Carbon and C-N Ratio: Kitchen waste-derived frass contained significantly higher organic carbon than market waste-derived frass, resulting in a slightly higher C:N ratio, likely due to the greater proportion of starch-rich cooked food residues such as rice and chapati. However, both frass types recorded C:N ratios below 11, well within the FCO standards, indicating a stable and mature organic amendment. A low C:N ratio is an important indicator of efficient organic matter stabilization and nutrient mineralization. The present findings suggest that BSF larvae rapidly transformed both feedstocks into stabilized frass within only 18 days. Compared with conventional organic amendments such as farmyard manure and vermicompost, which require several weeks to months for maturation, BSF-mediated bioconversion offers a faster route for producing a nutrient-rich and stable organic fertilizer (Lopes *et al.*, 2025) [6].

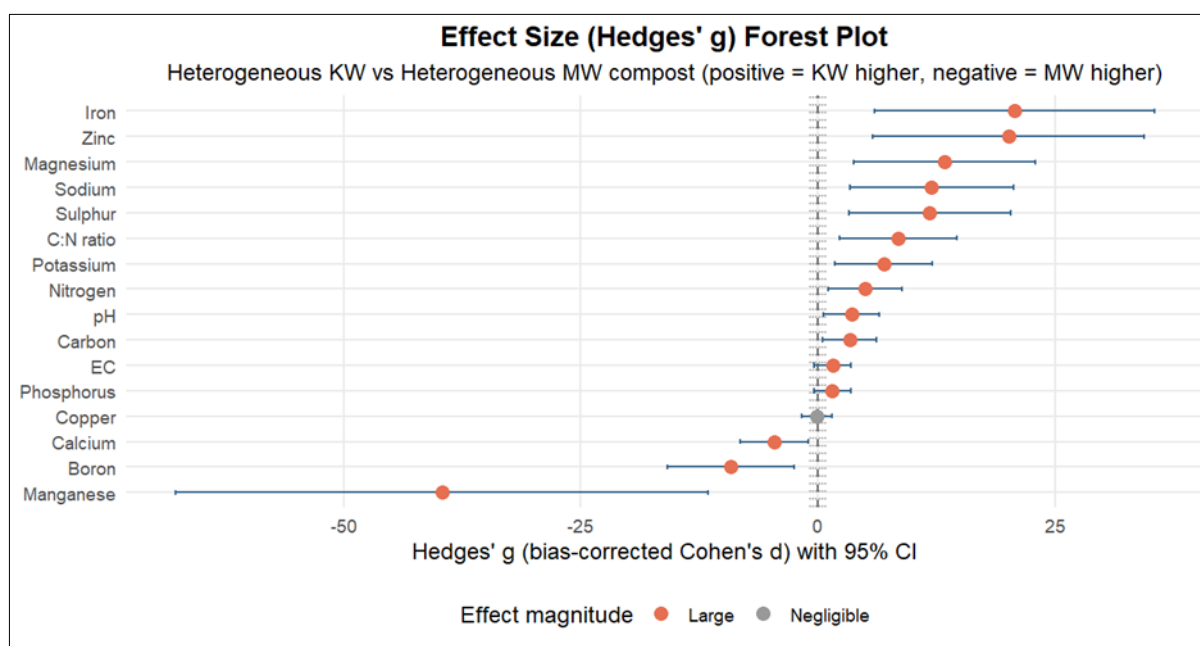


Fig 1: Hedges' g forest plot showing the magnitude and direction of differences in physicochemical properties and nutrient composition between kitchen waste- and market waste-derived black soldier fly frass

Magnitude of feedstock-driven variation

Although the *t*-test identified statistically significant differences between the two feedstocks, the *Hedges' g* forest plot (Figure 1) provided additional insight into the magnitude of these differences. The effect size analysis revealed that most of the physicochemical and nutrient parameters were strongly influenced by feedstock type. Manganese exhibited the largest negative effect size, indicating a substantial enrichment in market waste-derived frass, whereas zinc, iron, sodium, sulphur, magnesium and the C:N ratio showed large positive effect sizes, reflecting their higher concentrations in kitchen waste-derived frass. In contrast, copper exhibited a negligible effect size, with the confidence interval crossing zero, which supports the non-significant difference observed in the *t*-test. These findings demonstrate that the differences between the two frass types are not only statistically significant but also practically meaningful from an agronomic perspective.

The direction of the effect sizes was consistent with the nutrient profiles observed in Table 1. Kitchen waste, which contained cooked starch- and protein-rich food residues, produced frass enriched with nitrogen, potassium, sulphur, magnesium, zinc, iron and sodium. Conversely, market waste, composed mainly of raw fruits and vegetables, produced frass with higher concentrations of calcium, manganese and boron. Among these, the markedly higher manganese content in market waste-derived frass is of particular interest because manganese deficiency is a common nutritional constraint in many agricultural soils. This suggests that frass produced from different feedstocks could be selected according to specific soil nutrient requirements, with kitchen waste-derived frass serving as a richer source of major nutrients, while market waste-derived frass may be more suitable where supplementation of calcium, manganese and boron is desirable.

Comparison with other organic sources

The nutrient composition of BSF frass obtained in the present study compares favourably with that of conventional organic amendments such as farmyard manure (FYM) and vermicompost. Farmyard manure generally contains about 0.5% nitrogen, 0.2% phosphorus (P_2O_5) and 0.5% potassium

(K_2O), whereas vermicompost typically contains 1–2% nitrogen and 0.8–2.25% each of phosphorus and potassium. Both kitchen waste and market waste-derived frass contained nitrogen levels comparable to vermicompost, while their potassium concentrations exceeded those commonly reported for both FYM and vermicompost. These findings indicate that BSF bioconversion can effectively concentrate nutrients from heterogeneous organic wastes into a nutrient-rich organic fertilizer. Similar observations were reported by [Poveda \(2021\)](#) [8], who highlighted that BSF frass often possesses nutrient concentrations comparable to or greater than those of several conventional organic manures. Moreover, this nutrient enrichment was achieved within only 18 days of larval rearing, compared with the several months required for FYM maturation and the 45–90 days typically needed for vermicomposting. Another important advantage of BSF frass is its low C:N ratio, which reflects a high degree of stabilization within a relatively short period. While conventional composting and vermicomposting rely on prolonged microbial decomposition and earthworm activity to gradually reduce the C:N ratio ([Edwards and Arancon, 2022](#)) [11], BSF larvae rapidly transform organic wastes into a stabilized product through their digestive and metabolic activities. Overall, the findings clearly demonstrate that feedstock composition is one of the primary factors determining the physicochemical and nutrient characteristics of BSF frass. Significant differences were observed for 13 of the 16 parameters evaluated, indicating that frass produced from different organic waste streams cannot be considered compositionally identical. This observation supports the findings of [Lopes et al. \(2025\)](#) [6], who emphasized that variations in feedstock are a major challenge in standardizing BSF frass quality and developing consistent fertilizer recommendations. At the same time, feedstock-dependent variation should not be viewed solely as a limitation. Instead, it provides an opportunity to tailor the nutrient composition of BSF frass according to specific agricultural requirements. In the present study, kitchen waste-derived frass was enriched with nitrogen, potassium, sulphur, magnesium, zinc and iron, whereas market waste-derived frass contained higher concentrations of calcium, manganese and boron. Such

differences suggest that the choice of feedstock can be strategically used to produce frass with nutrient profiles suited to particular soil deficiencies or crop nutrient demands.

Despite these compositional differences, both kitchen waste- and market waste-derived frass satisfied the standards framed by FCO confirming their suitability as quality organic fertilizers. The study therefore demonstrates that BSF frass produced from different biodegradable waste streams not only offers an efficient approach for organic waste valorization but also provides a nutrient-rich organic amendment for crop cultivation.

Acknowledgment

I extend thanks to Anusandhan National Research Foundation (ANRF), GOI, Confederation of Indian Industry (CII) and Zigma Global Environ Solutions Private Limited (Part of Blue Planet groups), India for the financial support provided under “Prime Minister Fellowship for Doctoral Research”.

Conflict of interest: The authors declare that they have no known competing financial or other conflicts of interest.

References

1. Turpin N, Ten Berge H, Grignani C, Guzmán G, Vanderlinden K, Steinmann HH *et al.* An assessment of policies affecting sustainable soil management in Europe and selected member states. *Land Use Policy*. 2017;66:241-249.
2. Juncal MJL, Masino P, Bertone E, Stewart RA. Towards nutrient neutrality: A review of agricultural runoff mitigation strategies and the development of a decision-making framework. *Science of Total Environment*. 2023;874:162408.
3. Juncal MJL, Masino P, Bertone E, Stewart RA. Towards nutrient neutrality: A review of agricultural runoff mitigation strategies and the development of a decision-making framework. *Science of Total Environment*. 2023;874:162408.
4. Xing Y, Xie Y, Wang X. Enhancing soil health through balanced fertilization: A pathway to sustainable agriculture and food security. *Frontiers in Microbiology*. 2025;16:1536524.
5. Timsina J. Can organic sources of nutrients increase crop yields to meet global food demand? *Agronomy*. 2018;8(10):214.
6. Lopes IG, Gómez-Brandón M, Praeg N, Claeys J, Yakti W, Bitterlich M *et al.* BugBook: Critical considerations for evaluating and applying insect frass. *Journal of Insects as Food and Feed*. 2025;1-28.<https://doi.org/10.1163/23524588-bja10254>
7. Wang X, Song D, Liang G, Zhang Q, Ai C, Zhou W. Maize biochar addition improves soil fertility and microbial activity in agricultural soils: A review of organic amendment effects. *Soil and Tillage Research*. 2018;182:112-123.
8. Poveda J. Insect frass in the agriculture industry: A challenge for crop production, waste management, and circular economy. *Agronomy*. 2021;11(10):1940.
9. Klammsteiner T, Turan V, Fernández-Delgado Juárez M, Oberegger S, Insam H. Suitability of black soldier fly frass as soil amendment and implication for organic waste hygienization. *Agronomy*. 2020;10(10):1578.
10. Gebremikael MT, van Wickeren N, Hosseini PS, De Neve S. The impacts of black soldier fly frass on nitrogen availability, microbial activities, C sequestration and plant growth. *Frontiers in Sustainable Food System*. 2022;6:795950.
11. Edwards CA, Arancon NQ. The role of earthworms in organic matter and nutrient cycles. In: Edwards CA, Arancon NQ, editors. *Biology and ecology of earthworms*. Springer; 2022:233-274.
12. Beesigamukama D, Mochoge B, Korir NK, Fiaboe KKM, Nakimbugwe D, Khamis FM *et al.* Exploring black soldier fly frass as novel fertilizer for improved growth, yield and nitrogen use efficiency of maize under field conditions. *Frontiers in Plant Science*. 2020;11:574592.
13. Gold M, Tomberlin JK, Diener S, Zurbrugg C, Mathys A. Decomposition of biowaste: Macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. *Waste Management*. 2018;82:302-318.
14. Hamad A, Tayel A. Food 2050 concept: Trends that shape the future of food. *Journal of Future Foods*. 2025.<https://doi.org/10.1016/j.jfutfo.2025.03.003>