



Evaluation of potential of black soldier fly larvae for organic waste management and production of nutrient-dense organic amendments

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Abstract

This study aimed at evaluating the potential of black soldier fly (BSF) larvae for effective organic waste management and the production of nutrient-rich organic fertiliser. The experiment was carried out at Teaching and Research farm, Obafemi Awolowo University, Ile-Ife, Nigeria, where BSF larvae were reared on poultry, cattle, swine, rabbit, and combined wastes. Data were collected on waste reduction efficiency, larval biomass yield, feed conversion ratio (FCR), bio-conversion efficiency (BCE), and nutrient composition of frass. The results showed that poultry waste decreased in mass from 25 kg to 19.59 kg frass, and an increase in weight gained by larvae from 0.250 kg to 1.1925 kg. Rabbit waste produced the highest final frass among all the wastes used, with the decrease in mass of larvae from 0.25 kg to 0.1149 kg. Cattle and swine wastes produced almost the same amount of frass weight, whereas in combined waste mixture, the quantity gained in mass (153.1g) by the larvae was lower than expected, likely due to imbalance of nutrient present in the waste. The Feed Conversion Ratio (FCR) values were lowest in poultry manure (26.53), indicating more efficient feed-to-biomass conversion. In contrast, swine manure and the combined substrate mixture recorded very high FCR values (>150), reflecting inefficient conversion. Poultry manure recorded the highest BCE, followed by cow dung. Poultry frass had high P and K contents, a favourable C:N ratio, and optimum pH, making it ideal for soil fertility improvement. Cattle frass recorded high ash and calcium content, making it suitable for correcting soil acidity and calcium deficiencies. These variations in the nutrient present in these frass samples are strongly influenced by the initial waste and the biochemical transformations during BSF digestion. The study concluded that initial elemental composition of the waste influenced the nutrient composition of the BSF larvae-frass produced. The waste selection for BSF rearing should align with the intended soil fertility goals and specific crop nutrient requirements. Further study on the field is highly recommended to demonstrate the performance of BSF larvae-frass from different organic wastes on nutrient uptake by plants.

Introduction

The exponential increase in population growth, urbanization, and agro-industrial activities has led to a corresponding rise in the generation of organic wastes worldwide (World bank, 2018). The growing population also led to increase diversification and investment in Agriculture to produce more food for the population leading to more farm wastes generation. Improper management of these wastes poses serious

environmental challenges, including greenhouse gas emissions, soil and water pollution, and public health risks (Zang *et al.*, 2024). Conventional waste management strategies such as incineration, landfilling and composting are often constrained by high operational costs, limited efficiency, and negative environmental impacts. As a result, there is a growing need for sustainable, cost-effective, and environmentally friendly approaches for organic waste conversion to useful resources.

In recent years, insect-based bio-conversion has emerged as a promising alternative for organic waste

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management. Among the various insect species studied, the black soldier fly (*Hermetia illucens* L.) has gained significant attention due to its exceptional ability to rapidly convert a wide range of organic wastes, including household food waste, agricultural residues, livestock manure, and agro-industrial by-products, into valuable biomass (Ahmad-Basri, *et al.*, 2022). Furthermore, BSF larvae convert organic wastes into high-quality nutrients for pet foods, fish and poultry feeds, and exhibit high feed conversion efficiency, short life cycles, and adaptability to diverse substrates, making them highly suitable for large-scale waste recycling systems (Anokye, 2025; Siddiqui *et al.*, 2022).

Beyond waste reduction, BSF larvae bioconversion generates nutrient-rich by-products with considerable agronomic value. The larval frass – a mixture of larval excreta, undigested substrate, and shed exoskeletons—has been shown to contain essential plant nutrients such as nitrogen, phosphorus, potassium, and organic carbon. This residue has potential application as an organic fertilizer or soil amendment, contributing to improved soil fertility, microbial activity, and crop productivity (Foscari *et al.*, 2024). The use of BSF larvae derived organic fertilizers aligns with the principles of circular economy and sustainable agriculture by closing nutrient loops and reducing reliance on synthetic fertilizers (Anokye, 2025). This underscores the significance of transitioning towards a more sustainable agricultural approach, wherein organic fertilisers are favoured over synthetic fertilizers (Thomas *et al.* 2019; Lawrence and Melgar, 2023). The use of fertilisers from organic materials could replace chemical fertilisers, contributing to resources preservation and recycling of organic matter. .

BSF frass is generally rich in macronutrients such as nitrogen (N), phosphorus (P), and potassium (K), as well as beneficial secondary nutrients and trace elements. Typical nutrient ranges reported include N roughly 2-4%, P about 1-2%, and K: 1–3% on a dry matter basis (Beesigamukama *et al.*, 2020; Choi *et al.*, 2009). In addition to nutrient content, BSF frass contains chitin derived from larval exoskeletons, which can stimulate plant defense responses and improve resistance to pests and diseases (Li *et al.*, 2011).

In spite of increasing interest in BSF larvae technology, variations in substrate composition, rearing conditions, and processing methods can significantly influence larval growth performance, waste reduction efficiency, and fertilizer quality. Comprehensive assessment of the potential of BSF larvae in integrated waste management and organic fertiliser production systems is therefore essential to optimize its application and promote wider adoption, particularly in developing regions where organic waste accumulation and soil fertility decline remain critical challenges.

Therefore, this study aims to assess the potential of black soldier fly larvae for effective organic waste management and the production of nutrient-rich organic fertiliser. By evaluating waste conversion efficiency, larval biomass production, and the agronomic properties of BSF larvae frass, the study seeks to contribute to sustainable waste recycling strategies and environmentally friendly nutrient management practices.

Materials and Methods

The experiment was carried out at Teaching and Research farm, Obafemi Awolowo University, Ile-Ife, at latitude 7°33'7"N and 7°33'8" N and longitude 4°33'2" E and 4°33'3" E. It involves setting up a BSF experimental farming unit, monitoring the bioconversion process, temperature and pressure {minimum and maximum}, feeding rates, lifespan and analysing the quality of frass (resulting fertiliser). The experimental design was completely randomized design with three replicates. The treatments were BSF larvae, cow dung waste, swine waste, rabbit waste, poultry waste and combined wastes (cow dung+swine+rabbit+poultry wastes in ratio 1:1:1:1). Other materials and equipment used during the research study includes shovel, gloves and protective gears, sieves, thermo-hygrometer, weighing scale/balance, rearing containers, mating net, oviposition stick, buckets, building materials (bamboo sticks, palm fronds, planks, special polythene nylon and sack bags).

Young BSF larvae were introduced into the rearing containers containing different organic substrate/wastes. The larvae were fed with organic

waste and water was added if the waste were dry and clustered wastes were sorted out to aid effective feeding and burrowing. 250 g of larvae was introduced into 25 kg of organic waste, while daily moisture, temperature and larval development were regularly monitored. Harvesting was done between 14 and 21 days. Larvae were harvested and the residue left behind, BSF frass from each of the organic waste treatments, were collected, measured and analysed for total elemental composition using standard laboratory methods. The pH of the frass sample was determined with a standardized digital pH meter in a 1:2 w/v suspension of the samples and 0.01 M CaCl_2 after a 1-hour equilibration period, using the procedure outlined by Jindo *et al.* (2014). The ash content of the frass samples was determined by placing 5 g of the sample in a muffle furnace for two hours at maximum temperature of 500° C. After two hours of ignition, the crucible was removed from the furnace and allowed to cool. The ash content was then estimated in percentage. To determine the basic cations, 1 g of the frass sample from different wastes was digested with 20 ml of concentrated H_2SO_4 for 2 hours and left overnight to cool completely. The digest was transferred into 50 ml volumetric flask, made up to mark with distilled water. The concentrations of Na and K were determined by a flame photometer while Ca, Mg were determined using atomic absorption spectrophotometer (AAS) (Zhang *et al.*, 2002). The K content was converted to K_2O by multiplying K content with 1.21. The total P content was determined using the Vanado-Molybdate method on 0.2 g dry ground sample with 2 ml of concentrated H_2SO_4 (AOAC, 2005). The P content was then converted to P_2O_5 by multiplying the P content with 2.29. Organic carbon was determined on 0.2 g sample using Walkley and Black (1934) method, while the total N was determined on 0.5 g sample using micro-Kjeldahl digestion and distillation procedure (Bremner and Mulvaney, 1982).

Statistical analysis

Data collected were analysed using descriptive statistics (mean, percentage and charts) in Microsoft excel. The data were checked for normality and constant variance using Shapiro and Bartlett tests, respectively, with statistical software version 3.6.0 (R Core Team, 2019). The effectiveness of BSF in

converting waste to organic fertiliser was evaluated based on yield and nutrient component.

Results and Discussion

The Influence of waste types on growth of BSF larvae and frass production

The changes in mass (kg) of organic waste to frass produced and the changes in mass of larvae over 3 weeks period is shown in Table 1. Poultry waste shows the least difference between the inputs provided with the decrease in mass from 25 kg to 19.59 kg frass. However, there was increase in weight gained by larvae from 0.250 kg to 1.1925 kg, indicating the effectiveness of BSF larvae in converting wastes into useful outputs in poultry waste (Xiao *et al.*, 2018). Rabbit waste produced the highest final frass among all the wastes used though, not significantly different from cow waste. The rabbit waste had the lowest larvae output suggesting that the amount of digestible organic matter in the waste is lower than others. The decrease in mass of larvae from 0.25 kg to 0.1149 kg indicates the nature of rabbit waste which can be fibrous due to undigested plant matter, which is harder for larvae to digest, and also suggests that there may be presence of growth inhibitors in the waste.

The final larvae mass from cow, swine and rabbit wastes were significantly lower than the one obtained from poultry waste. In Combined waste, the quantity gained in mass (153.1g) by the larvae was lower than expected, likely due to imbalance of nutrient present in the waste and lower nutritional value as a result of combination of poultry, rabbit, cattle and swine waste. The frass obtained was significantly higher than poultry indicating higher bio-convertible waste in the substrate.

Performance indicators of BSF larvae reared on different organic substrates

The findings in Table 2 show the waste reduction in percentage (%), larvae biomass yield (wet), Feed conversion ratio, bioconversion efficiency (BCE, %) net frass produced (kg), while Table 3 shows the descriptive analysis of the parameters. The highest waste reduction (21.64%) was recorded in poultry frass, while rabbit droppings showed the lowest (5.5%). This suggests that poultry manure provided more

digestible nutrients and structure that seems to promote larval feeding activity. This finding agrees with Meneguz *et al.* (2018), who reported higher waste reduction rates in poultry-based substrates compared to cattle and pig manures due to their higher nitrogen content and palatability. The waste reduction

percentage had a mean value of $13.62\% \pm 5.89$ (Table 3), with the lowest being 5.52% (Rabbit) and the highest 21.64% (Poultry). The relatively high standard deviation showed wide variation in larval consumption efficiency between substrates.

Table 1: The Influence of Waste types on growth of BSF larvae and frass production

Waste Type	Initial Substrate Mass (kg, wet)	Final Frass Mass (kg, wet)	Mass Maggot Input (kg, wet)	Mass Maggot Output (kg, wet)
Poultry	25.00	19.59a	0.250	1.1925e
Rabbit	25.00	23.62c	0.250	0.1149a
Cow	25.00	22.00c	0.250	0.750d
Swine	25.00	21.77b	0.250	0.4136c
Combined	25.00	21.00b	0.250	0.4031b
Means		21.59		0.5748

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$) according to Tukey's Honest Significant Different Test

Table 2: Calculated Performance Indicators of BSF Larvae Reared on Different Organic Substrates

Substrate	Waste Reduction %	Larvae Yield (g)	Biomass Larvae Gained (g)	Biomass FCR	BCE (%)	Net Frass (kg)
Poultry	21.64	1192.5	942.5	26.53	3.77	19.59
Rabbit	5.52	114.9	-135.1	N/A	-0.54	23.62
Cow	12.00	750.0	500.0	50.00	2.00	22.00
Swine	12.92	413.6	163.6	152.81	0.65	21.77
Combined	16.00	403.1	153.1	163.32	0.61	21.00
Means	13.616	574.82	324.82	98.165	1.298	21.596

Table 3: Descriptive Statistics of Waste Reduction, Biomass Yield, Feed Conversion Ratio, Bioconversion Efficiency, and Frass Output of BSF Larvae on Different Substrates

Parameter	Mean	Std. Dev.	Min	25%	Median	75%	Max
Waste Reduction %	13.62	5.89	5.52	12.00	12.92	16.00	21.64
Larvae Biomass Yield (g)	574.82	412.07	114.90	403.10	413.60	750.00	1192.50
Larvae Biomass Gained (g)	324.82	412.07	-135.10	153.10	163.60	500.00	942.50
FCR	98.17	69.96	26.53	44.13	101.41	155.44	163.32
BCE (%)	1.30	1.65	-0.54	0.61	0.65	2.00	3.77
Net Frass (kg)	21.60	1.47	19.59	21.00	21.77	22.00	23.62

Chicken manure produced the highest final biomass yield (1,192.5 g) and net biomass gain (942.5 g), while rabbit droppings recorded a negative gain (-135.1 g), indicating weight loss. Low gains from rabbit droppings may be linked to high fibre and low nutrient availability, which hinder larval metabolism. Similar results were reported by Purnamasari *et al.* (2024), who found that poultry manure supported significantly greater biomass production than other animal manures when rearing BSF larvae. The mean larvae biomass yield was $574.82 \text{ g} \pm 412.07$ as shown in Table 3, indicating large differences across treatments. Chicken manure yielded the highest larvae biomass (1,192.5 g), far exceeding rabbit droppings (114.9 g). This disparity reflects substrate quality, with nutrient-rich poultry manure supporting better larval growth. The high variation (SD = 412 g) also shows that substrate type is a major driver of larval production potential.

The Feed Conversion Ratio (FCR) values were lowest in poultry manure (26.53), indicating more efficient feed-to-biomass conversion. In contrast, swine manure and the combined substrate mixture recorded very high FCR values (>150), reflecting inefficient conversion. Attia *et al.* (2023) also observed that BSF larvae fed on poultry manure achieved better FCR compared to those fed on pig or cattle manure, attributing the difference to nutrient composition and digestibility. Across the four substrates with positive biomass gain as shown in Table 3, the mean FCR was 98.17 ± 69.96 , ranging from 26.53 (Chicken) to 163.32 (Combined substrate). Lower FCR values indicate more efficient feed-to-biomass conversion, thus, chicken manure was the most efficient feed. The high FCR values for swine and combined feeds suggest that large amounts of feed were consumed with relatively low biomass gains, indicating lower digestibility or nutrient utilization.

Poultry manure recorded the highest bioconversion efficiency (BCE) (3.77%), followed by cow dung (2.00%). Rabbit droppings had a negative BCE (-0.54%), suggesting poor performance. BCE values in this study are within the range (2–5%) for manure-based substrates reported by Siddiqui *et al.* (2022) that animal manures are generally less digestible than food waste. The mean BCE was $1.30\% \pm 1.65$ as shown in Table 3, with the highest being

3.77% for poultry manure and the lowest -0.54% for rabbit droppings. These low BCE values are within the typical range for manure-based BSF production (2–5%) but are lower than those reported for food waste (8–20%). The negative BCE in rabbit droppings highlights its inefficiency as a feed source for BSF.

Rabbit droppings produced the highest frass weight (23.62 kg) despite having the lowest larvae yield. This suggests limited consumption of the substrate, leaving more unprocessed residue. Cow dung and swine manure also had high frass output relative to biomass gain. According to Cheng *et al.* (2017), higher frass output often corresponds with substrates that have lower digestibility or where larval feeding activity is reduced. Net frass output averaged $21.60 \text{ kg} \pm 1.47$, with the highest value from rabbit droppings (23.62 kg) and the lowest from chicken manure (19.59 kg). High frass production in rabbit and cow dung treatments likely results from lower larval feeding efficiency, leaving more unprocessed material behind. The lower frass weight in poultry manure is consistent with higher substrate consumption.

The overall implication is that substrate type is a critical determinant of BSF production efficiency. Poultry manure achieved the highest waste reduction and biomass gains, demonstrating that substrates rich in readily available nutrients are better suited for BSF rearing. Rabbit droppings, on the other hand, showed poor utilization (low waste reduction, negative biomass gain), implying that not all animal manures are equally viable without pre-treatment or supplementation. Poultry manure showed superior performance, making it a suitable substrate for large-scale BSF-based bioconversion systems. Substrates with poor performance may not be sustainable for mass rearing but can still play a role in integrated waste management when combined with higher-value feedstocks.

Elemental composition of frass produced by black soldier fly larvae from different organic waste types.

pH value

The pH of frass obtained from different organic waste types ranged from 7.14 in poultry frass to 8.94 in cow waste, with a mean value of approximately 7.94 (Tables 4 and 5). This range indicates that BSF frass is generally neutral to slightly alkaline, which is

considered suitable for most agricultural soils (Li *et al.*, 2011; Beesigamukama *et al.*, 2020). The significant higher pH recorded in cow frass may be attributed to the buffering effects of calcium-rich feed residues (Lalander *et al.*, 2015), whereas the lower pH observed in poultry waste may be attributed to the breakdown of proteinaceous material into ammonium and organic acids during larval digestion. The ideal pH range for

plant growth varies depending on the specific crop but generally falls between 6 and 7 (Azeez *et al.*, 2024). The pH of most frass from different organic wastes determined in this study fell within this pH range, suggesting suitability for growing major arable crops. In addition, the high pH recorded in this study indicates the potential of these frass residues as liming materials for ameliorating soil acidity.

Table 4: Physico-chemical Properties and Nutrient Composition of Various Frass Samples

Parameter	pH	Ash Content	Ca	Mg	Na	K ₂ O	P ₂ O ₅	C	N	C/N
(%)										
Rabbit	7.76b	57.0a	1.62b	1.38c	0.51c	1.51c	2.11c	37.7e	2.08d	18.1b
Combined waste	7.84c	56.2a	0.44a	0.16a	0.04a	0.44a	1.12a	27.7d	0.52a	53.3e
Poultry	7.14a	60.2b	4.18d	0.50b	0.32b	2.13e	4.33e	18.5b	1.28c	11.7a
Cow	8.94e	66.6c	4.58e	2.62d	0.52c	1.59d	1.53b	11.2a	0.54a	20.7c
Swine	8.04d	58.0ab	3.27c	2.07d	0.42bc	1.25b	3.12d	22.6c	0.62b	36.5d
Means	7.94	59.6	2.82	1.35	0.36	1.38	2.44	23.54	1.01	28.06

Means with the same letters in the same column are not significantly different from each other at ($p \leq 0.05$) according to Tukey's Honest Significant Different Test

Table 5: Descriptive statistics of physicochemical properties and nutrient composition of BSF frass samples

Parameter	Mean	Std. Dev.	Min	25%	Median	75%	Max
pH	7.94	0.65	7.14	7.76	7.84	8.04	8.94
Ash Content (%)	59.60	4.19	56.20	57.00	58.00	60.20	66.60
Ca	2.82	1.75	0.44	1.62	3.27	4.18	4.58
Mg	1.35	1.03	0.16	0.50	1.38	2.07	2.62
Na	0.36	0.20	0.04	0.32	0.42	0.51	0.52
K ₂ O	1.38	0.62	0.44	1.25	1.51	1.59	2.13
P ₂ O ₅	2.44	1.30	1.12	1.53	2.11	3.12	4.33
C	23.54	9.95	11.20	18.50	22.60	27.70	37.70
N	1.01	0.68	0.52	0.54	0.62	1.28	2.08
C/N	28.06	16.80	11.70	18.10	20.70	36.50	53.30

The ash content

Ash content, representing the total mineral fraction, was highest in cow frass (66.6%) and lowest in combined waste frass (56.2%). High ash content indicates greater mineral availability for plants. The

high ash content of cattle manure has been well-documented in organic waste management studies (Lalander *et al.*, 2015). Poultry and swine frass also recorded ash contents above 58%, reflecting substantial mineralization during BSF processing. High ash

content generally indicates potential for mineral nutrient supply (Giménez-Berenguer, 2025).

Composition of essential nutrients

Calcium (Ca) was most abundant in cow (4.58%) and poultry (4.18%) frass, reflecting the calcium-rich diets of these animals. Magnesium (Mg) followed a similar trend, with cow (2.62%) and swine (2.07%) having the highest levels. Sodium (Na) concentrations were generally low, suggesting that the frass from different organic wastes is safe as soil amendment. High Na content in soil is not beneficial as it causes soil dispersion and can negatively affect soil structure and plant water uptake (Mohanavelu *et al.*, 2021).

Potassium content in form of K_2O was highest in poultry frass (2.13%), consistent with previous reports that poultry manure-derived frass tends to be potassium-rich (Ahmad-Basri *et al.*, 2022). Phosphorus (P) in form of P_2O_5 was also highest in poultry frass (4.33%), followed by swine frass (3.12%), both exceeding levels observed in cow and rabbit frass. These elevated values suggest poultry and swine wastes are excellent feedstocks for producing frass that can promote root development and flowering. Poultry litter commonly contains **2.2–4.4% P_2O_5** , illustrating its high phosphorus concentration among livestock manures (Sharpley *et al.*, 1998).

Organic carbon (C) was significantly higher in rabbit frass (37.7%) than other wastes used in this study, followed by combined waste (27.7%), indicating a strong potential for improving long-term soil organic matter and C sequestration. However, the C:N ratio determines the rate of nutrient release. Combined waste frass had the highest C:N ratio (53), suggesting slow decomposition and possible nitrogen immobilization (Ma *et al.*, 2025). Poultry frass had the lowest C:N ratio (12), which could promote rapid decomposition of organic wastes with consequent nutrient release for plant uptake. Nitrogen (N) content was highest in rabbit frass (2.08%), followed by poultry (1.28%), supporting their roles as potential nitrogen sources in soil fertility management.

Generally, poultry frass emerges as a balanced organic fertiliser with high P and K contents, a favourable C:N ratio, and optimum pH, making it ideal for viable crop production. Cattle frass offers high ash

and calcium content, making it suitable for correcting soil acidity and calcium deficiencies. These variations in the nutrient present in these frass samples are strongly influenced by the initial waste and the biochemical transformations during BSF digestion (Diener *et al.*, 2011; Beesigamukama *et al.*, 2020). Therefore, waste selection for BSF rearing should align with the intended soil fertility goals and specific crop nutrient requirements. It should be noted that all the frass produced from different wastes in this study possess liming potentials and are suitable as soil amendments for improvement of soil acidity and enhancing soil fertility.

Conclusion

The substrate type is a critical determinant of BSF production efficiency. All the wastes used in this study achieved modest waste reduction and biomass gains, demonstrating that substrates rich in readily available nutrients are better suited for BSF rearing. In terms of waste management, the highest waste reduction was recorded in poultry frass, while rabbit droppings on the other hand, showed poor utilization indicating that not all animal manures are equally viable without pre-treatment or supplementation. Poultry frass emerged as a balanced organic nutrient-rich amendment with high P and K contents, a favourable C:N ratio, and optimum pH, making it ideal and viable for crop production. Cow frass offers high ash and calcium content, making it suitable for correcting soil acidity and calcium deficiencies. It can be inferred from the study that nutrient composition of the BSF larvae-frass could be attributed to initial elemental composition of the waste, and the biochemical transformations during BSF digestion. Therefore, waste selection for BSF rearing should align with the intended soil fertility goals and specific crop nutrient requirements.

References

- Ahmad-Basri, N. E., Mohamed, A. R., and Mohd Zainudin, M. A. (2022). Potential Applications of Frass Derived from Black Soldier Fly Larvae Treatment of Food Waste: A Review. *Foods*, 11(17): 2664. <https://doi.org/10.3390/foods1117-2664>
- Anokye, K. (2025). Black Soldier Fly Larvae as a circular solution for organic waste management

- and sustainable livestock feed in Ghana. *Cleaner Waste Systems*, 12: 100416. <https://doi.org/10.1016/j.clwas.2025.100416>
- AOAC (2005). *Official Methods of Analysis 18th edn*, Association of Official Analytical Chemists, Washington, DC, USA
- Attia, Y. A., Bovera, F., Asiry, K. A., Alqurashi, S., and Alrefaei, M. S. (2023). Fish and Black Soldier Fly Meals as Partial Replacements for Soybean Meal Can Affect Sustainability of Productive Performance, Blood Constituents, Gut Microbiota, and Nutrient Excretion of Broiler Chickens. *Animals*, 13(17): 2759. **Error! Hyperlink reference not valid.**
- Azeez, M. O., Oladipupo, F. A., Jimoh Farinde, A. J. and Oladepo, W. O. (2024). Evaluation of elemental composition and structural analyses of liquid organic fertilizers from rabbit wastes under different feeding regimes. *African Journal of Agricultural Research*, 10(5): 359-364.
- Beesigamukama, D., Mochoge, B., Korir, N.K., Fiaboe, K.K.M., Nakimbugwe, D., Khamis, F.M., Subramanian, S., Dubois, T., Ekesi, S., and Musyoka, M. W. (2020). Exploring the fertiliser value of Black Soldier Fly frass in maize production. *Journal of Insects as Food and Feed*, 6(5): 393–401. <https://doi.org/10.3920/JIFF2019.0047>
- Bremner, J.M. and Mulvaney, C.S. (1982). Nitrogen-total, In: *Methods of Soil Analysis. Part 3. Chemical Methods*, Vol. 5 of Soil Science Society of America Book Series, Ed. By Sarks D.L. *Soil Science Society of America/ American Society of Agronomy*. Madison, WI p1085-1112.
- Cheng, J.Y., Chiu, S. L., and Lo, I. M. (2017). Effects of moisture content of food waste on residue separation, larval growth and larval survival in black soldier fly bioconversion. *Waste Management*, 67: 315-323. <https://doi.org/10.1016/j.wasman.2017.05.046>
- Diener, S., Zurbrugg, C., and Tockner, K. (2011). Conversion of organic material by *Hermetia illucens* larvae: Establishing optimal feeding rates. *Waste Management and Research*, 29(9): 931–935. <https://doi.org/10.1177/0734242X11413376>
- Foscari, A., Dalla Costa, L., Tulli, F., Ubboni, C., and Fellet, G. (2024). Frass from *Tenebrio molitor* as alternative to NPK-mineral fertilization: Results from a germination test and pot experiment on sunflower. *Italian Journal of Agronomy*, 19(2): 100010. <https://doi.org/10.1016/j.ijagro.2024.10-0010>
- Giménez-Berenguer, M., Salicola, S. A., Formenti, C., Giménez, M. J., Mauromicale, G., Zapata, P. J., Lombardo, S., Pandino, G., Giménez-Berenguer, M., Salicola, S. A., Formenti, C., Giménez, M. J., Mauromicale, G., Zapata, P. J., Lombardo, S., and Pandino, G. (2025). Seeds Mineral Profile and Ash Content of Thirteen Different Genotypes of Cultivated and Wild Cardoon over Three Growing Seasons. *Agriculture*, 15(11): 1228 <https://doi.org/10.3390/agriculture15111228>
- Jindo, K., Matsumoto, K., García Izquierdo, C., Sonoki, T. and Sanchez-Monedero, M. A. (2014). Methodological interference of biochar in the determination of extracellular enzyme activities in composting samples, *Solid Earth*, 5: 713–719, <https://doi.org/10.5194/se-5-713-2014>
- Lalander, C.H., Fidjeland, J., Diener, S., Eriksson, S. and Vinneras, B. (2015). High Waste-to-Biomass Conversion and Efficient Salmonella Spp. Reduction Using Black Soldier Fly for Waste Recycling. *Agronomy for Sustainable Development*, 35: 261-271. <https://doi.org/10.1007/s13593-014-0235-4>
- Lawrence, B.T. and Melgar, J.C. (2023). Annual compost amendments can replace synthetic fertilizer, improve soil moisture, and ensure tree performance during peach orchard establishment in a humid subtropical climate. *Frontier in Plant Science*, 8 (14):1172038.
- Li, Q., Zheng, L., Qiu, N., Cai, H., Tomberlin, J. K., and Yu, Z. (2011). Bioconversion of dairy manure by black soldier fly (Diptera: Stratiomyidae) for biodiesel and sugar production. *Waste Management*, 31(6): 1316-1320. <https://doi.org/10.1016/j.wasman.2011.01.005>
- Ma, Y., Wu, Q., Wang, X., Sui, W., and Zhang, X. (2025). Carbon components in organic amendments drive nitrogen metabolism in one-

- year-long anaerobic soil microcosms. *Frontiers in Microbiology*, 16: 1588169. <https://doi.org/10.3389/fmicb.2025.1588169>
- Meneguz, M., Schiavone, A., Gai, F., Dama, A., Lussiana, C., Renna, M. and Gasco, L. (2018). Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (*Hermetia illucens*) larvae. *Journal of the Science of Food and Agriculture*, 98(15): 5776-5784. doi:10.1002/jsfa.9127. Epub 2018 Jun 26. PMID: 29752718.
- Mohanavelu, A., Naganna, S. R., and Al-Ansari, N. (2021). Irrigation induced salinity and sodicity hazards on soil and groundwater: An overview of its causes, impacts and mitigation strategies. *Agriculture*, 11(10): 983. <https://doi.org/10.3390/agriculture11100983>
- Purnamasari, D. K., Syamsuhaidi, S., Sumiati, E., Erwan, and Putra, R. A. (2024). Black Soldier Fly larvae: cultivation and its potential as an alternative protein source for poultry. *Livestock Research for Rural Development*, 36(2), 1-9. <https://www.lrrd.org/lrrd36/2/3617emma.html>
- R Core Team (2019). A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, In., p.275-286.
- Siddiqui, S. A., Ristow, B., Rahayu, T., Putra, N. S., Widya Yuwono, N., Nisa', K., Mategeko, B., Smetana, S., Saki, M., Nawaz, A., and Nagdalian, A. (2022). Black soldier fly larvae (BSFL) and their affinity for organic waste processing. *Waste Management*, 140: 1-13. <https://doi.org/10.1016/j.wasman.2021.12.044>
- Sharpley, A., Meisinger, J., Power, J., and Suarez, D. (1998). Root extraction of nutrients associated with long-term poultry litter applications. *Biology and Fertility of Soils*, 28, 1-7.
- Thomas, C. L., Acquah, G., Whitmore, A. P., McGrath, S. P. and Haefele, S. M. (2019). The Effect of Different Organic Fertilizers on Yield and Soil and Crop Nutrient Concentrations. *Agronomy*, 9 (12): 776. <https://doi.org/10.3390/agronomy9120776>.
- Walkley, A. and Black, C.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science*, 37: 27-38.
- World Bank (2018). *What a waste 2.0: A global snapshot of solid waste management to 2050*. World Bank Publications
- Xiao, X., Mazza, L., Yu, Y., Cai, M., Zheng, L., Tomberlin, J. K., Yu, J., van Huis, A., Yu, Z., Fasulo, S., and Zhang, J. (2018). Efficient co-conversion process of chicken manure into protein feed and organic fertilizer by *Hermetia illucens* L. (Diptera: Stratiomyidae) larvae and functional bacteria. *Journal of Environmental Management*, 217: 668-676. <https://doi.org/10.1016/j.jenvman.2018.03.122>.
- Zhang, F.-S., Yamasaki, S., and Nanzyo, M. (2002). Waste ashes for use in agricultural production: I. Liming effect, contents of plant nutrients and chemical characteristics of some metals. *Science of The Total Environment*, 284(1-3): 215-225. doi:10.1016/s0048-9697(01)00887-7.
- Zhang, Z., Chen, Z., Zhang, J., Liu, Y., Chen, L., Yang, M., Osman, A. I., Farghali, M., Liu, E., Hassan, D., Ihara, I., Lu, K., Rooney, D. W. and Yap, P. (2024). Municipal solid waste management challenges in developing regions: A comprehensive review and future perspectives for Asia and Africa. *Science of The Total Environment*, 930: 172794, <https://doi.org/10.1016/j.scitotenv.2024.172794>.