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Deliverable 5.1

Sustainable production of crickets and black soldier fly

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1. Executive summary

Detailed mapping of agricultural by-products or organic waste for optimal and mass production of black soldier fly (BSF), crickets and mealworm has been completed. Major organic waste streams like market waste (fruit and vegetable waste), animal manure, brewery waste, waste from food processors and others have been characterized and evaluated for their suitability for commercial BSF production. For cricket and mealworm, artificial diet comprising of agricultural by-products particularly weeds have been formulated and validated for large scale production. These diets have demonstrated their effectiveness in enhancing the growth performance, survivorship, and reproductive capacity of these insects. The organic waste recipes for crickets and mealworm were transformed into powder and pelletize forms to maximize and reduce feed intake, thus making them cost-effective and ready for on-site adoption particularly in the eco-hub. The nutritional profile of the insects harvested after feeding on these recipes have been processed and evaluated for further studies for value addition. Consultative arrangements with partners in the target countries interested in edible insect farming have been established and plans for sharing knowledge with other implementing countries have been concluded.

1.1. Production of crickets, black soldier flies and other insects

1.1.1. Mapping organic waste streams locally available in the target sites and establish linkages between the source of waste and BSF farmers

We have completed waste mapping in 8 counties in Kenya. Conducted a waste mapping survey, involving 688 organic waste producers and collectors in Central and Western Kenya (Nairobi, Kiambu, Muranga, Kisii, Homa Bay, Kisumu, Siaya and Busia) counties and assessed factors influencing the knowledge, attitudes, and practices (KAPs) and willingness to use insect-based technologies to recycle organic waste into value-added products (Figure 1). Findings showed that most of the waste is generated from hotels, food markets, food processing industries, abattoirs, and schools, and it is managed by private waste collection companies (Figure 2). More than 71% of the solid wastes generated are decomposable, thus suitable for BSF production. Poultry manure, pig manure, fruits and vegetable waste from horticultural farms are largely generated in Kiambu county, and the wastes are managed privately by farm owners. In rural Kenya, we found that about 284 tonnes of organic wastes are available for BSF production per county. The levels of heavy metals were within allowable limits, indicating safety of the different organic wastes for BSF farming (Table 1). Laboratory analyses revealed that crop wastes contained higher levels of macro nutrients than animal wastes (Table 2). All the wastes had favourable pH and carbon to nitrogen (C/N) ratio and moderate levels of micronutrients for BSF production. Most respondents (80 - 98%) were knowledgeable about the use of insect-based waste recycling, 57% were practicing, and 80 - 88% were willing to adapt. Black soldier fly (BSF) was the most widely used insect in waste recycling. Small scale BSF producers were willing to recycle more than 2 tonnes of waste per day, while large scale entrepreneurs recycle more than 120 tonnes of organic waste daily. We noted that 92 – 97% were willing to acquire training on waste recycling using the BSF. Among the farmers, pig and poultry farmers were the most eager to recycle organic wastes using insects. Majority of the waste producers that were not practicing insect farming were willing to sell their organic waste to insect farmers. However, only 9 – 30% of the respondents practiced waste segregation, consequently, wastes contain plastics, wood, metals and glass, limiting direct use for BSF farming. The ICIPE team and partners have started sensitising waste managers, market vendors and local leaders on the need of segregation of waste at points of production to increase the volumes of sorted decomposable organic wastes available for BSF production. Dissemination activities have commended to sensitise farmers on the availability and suitability of organic wastes for BSF production in target sites.

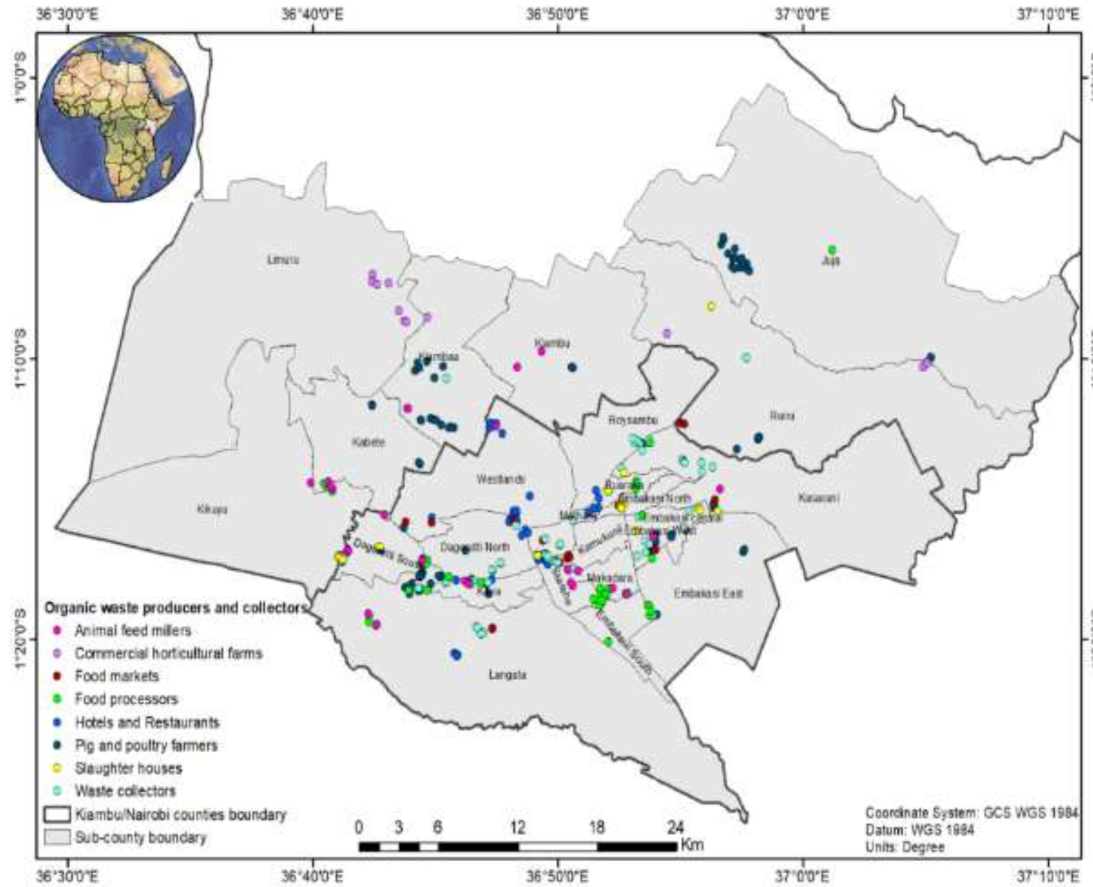

Figure 1: Sources of organic waste in Nairobi and Kiambu counties, Kenya.

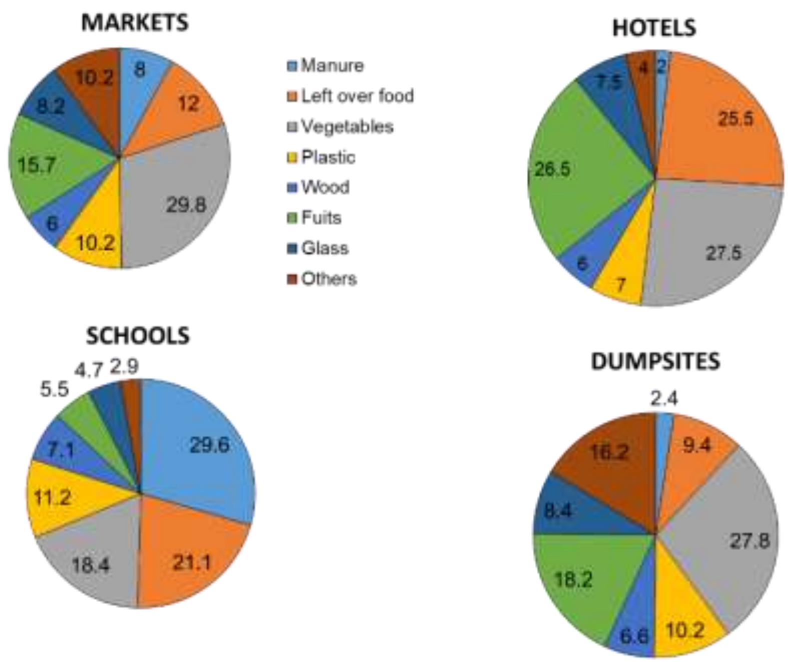

Figure 2: Composition of wastes generated in Central and Western Kenya.

Table 1: Concentrations of heavy metals in organic commonly available organic wastes on dry matter basis.

Waste type	Arsenic	Cadmium	Chromium	Copper	Lead	Iron	Nickel
	(mg/kg)						
Cattle dung	0.33±0.02	0.17±0.01	5.01±0.29	26.3±1.52	2.49±0.15	0.38±0.02	4.48±0.26
Chicken droppings	0.02±0.00	0.39±0.32	2.99±0.20	39.5±1.74	2.04±0.24	0.16±0.01	3.26±0.39
Maize bran	0.02±0.00	0.02±0.00	0.17±0.02	5.81±0.44	0.02±0.00	162.2±5.68	0.60±0.08
Market waste	0.02±0.00	0.02±0.00	5.32±0.31	13.4±0.78	2.10±0.12	0.57±0.03	2.83±0.17

According to the Kenya Standard KS 2290:2011, the maximum permissible concentrations of heavy metals in organic fertilizers are 100 mg/kg for Pb, 3 mg/kg for Cd, 100 mg/kg for total Cr, 50 mg/kg for Ni, 500 mg/kg for Zn, 300 mg/kg for Cu, 10 mg/kg for As, and 2 mg/kg for Hg. Comparison with literature-derived estimates indicates that cow dung, maize bran, and market-derived organic waste generally fall well below these thresholds, whereas poultry manure may approach or exceed the Zn and Cu limits due to feed supplementation practices.

Table 2: Chemical properties of organic wastes available for BSF farming.

Waste type	Dry matter (%)	pH	Electrical conductivity (uS/cm)	Nitrogen (%)	Organic carbon (%)	C/N ratio	Phosphorus (%)	Potassium (%)	Sodium (mg/kg)	Magnesium (%)	Sulphur (mg/kg)	Zinc (mg/kg)	Cobalt (mg/kg)	Manganese (mg/kg)
Cattle dung	88.9±0.20	8.18±0.01	1.49±0.00	4.13±0.01	45.8±0.12	11.1±0.04	0.64±0.04	0.41±0.02	0.05±0.01	0.81±0.06	688.5±40.1	87.9±5.11	0.87±0.05	593.9±34.5
Chicken droppings	85.9±0.04	6.90±0.04	10.4±0.01	3.61±0.01	34.4±0.35	9.51±0.10	1.36±0.11	1.53±0.04	0.18±0.01	0.65±0.05	65.4±3.25	220.3±12.9	1.03±0.12	166.4±10.8
Maize bran	90.5±0.81	6.27±0.01	24.2±1.20	5.07±0.05	56.6±0.39	11.2±0.06	0.76±0.04	0.79±0.01	677.9±48.1	0.29±0.02	25.9±3.30	62.0±4.88	0.02±0.00	19.8±1.00
Market wastes	89.5±0.66	7.23±0.01	4.37±0.02	5.27±0.01	52.5±0.09	9.96±0.04	0.33±0.02	2.87±0.17	0.11±0.01	0.23±0.01	1159±67.4	26.6±1.55	0.65±0.04	94.2±5.48

Assessment of waste distribution in the different waste sites in Siaya County where the ECOHUB will be domiciled yielded vegetable waste and manure as the dominant waste categories in markets and dumpsites, and slaughterhouses, respectively (Figure 3A). From the markets, the dominant waste types included vegetable remains (33.7%) emanating from food sales and preparation. This was followed by fruit waste (16.5%) and food remains (11.3%) constituting significant organic matter. The non-biodegradable waste realized was glass waste (11.4%) and plastics (11.2%) indicating substantial packaging waste. At the slaughterhouse, manure accounted for 97.75% thereby overwhelmingly dominating the waste site, thus highlighting the site's primary function in processing animal by-products. Wood waste (0.75%) and other waste in this case sludge (1.5%) appeared in minimal quantities, while plastics, glass waste, and organic waste were negligible. At dumpsite, vegetable waste (20.9%) was the dominant waste group followed by plastics (19.5%) reflecting the mixed nature of collected waste. Fruit waste (11.2%), glass waste (11.2%), and wood waste (10.9%) also make significant contributions.

An assessment of the waste distribution in Busia, a county adjacent to Siaya county, portrayed dominant proportions of vegetable wastes, manure and food remains in markets and dumpsites, slaughterhouses, and schools, respectively (Figure 3C). The markets were dominated by vegetable waste (24.2%), fruit waste (16.5%), and food remains (15.3%). Non-biodegradable waste such as plastics (12.3%) and glass waste (7.2%) reflected packaging-related waste and different nature of businesses in the markets. Manure (99.4%) overwhelmingly dominated the waste from slaughterhouses because the gastric contents comprise the highest proportion of inedible remains of slaughtered animals. Vegetable waste (20.4%) and fruit waste (14.5%) made up the majority of organic waste in dumpsites. Plastics (18.9%) and glass waste (12.9%) are significant non-biodegradable waste. The food waste (35%) accounted for the highest waste in schools reflecting meal-related organic waste. Vegetable waste (16%) and manure (17%) also contribute significantly to school waste. Manure is from the livestock reared in the school as it is common practice in the schools situated in that region. However, glass waste (8%) and plastics (5%) are moderate contributors.

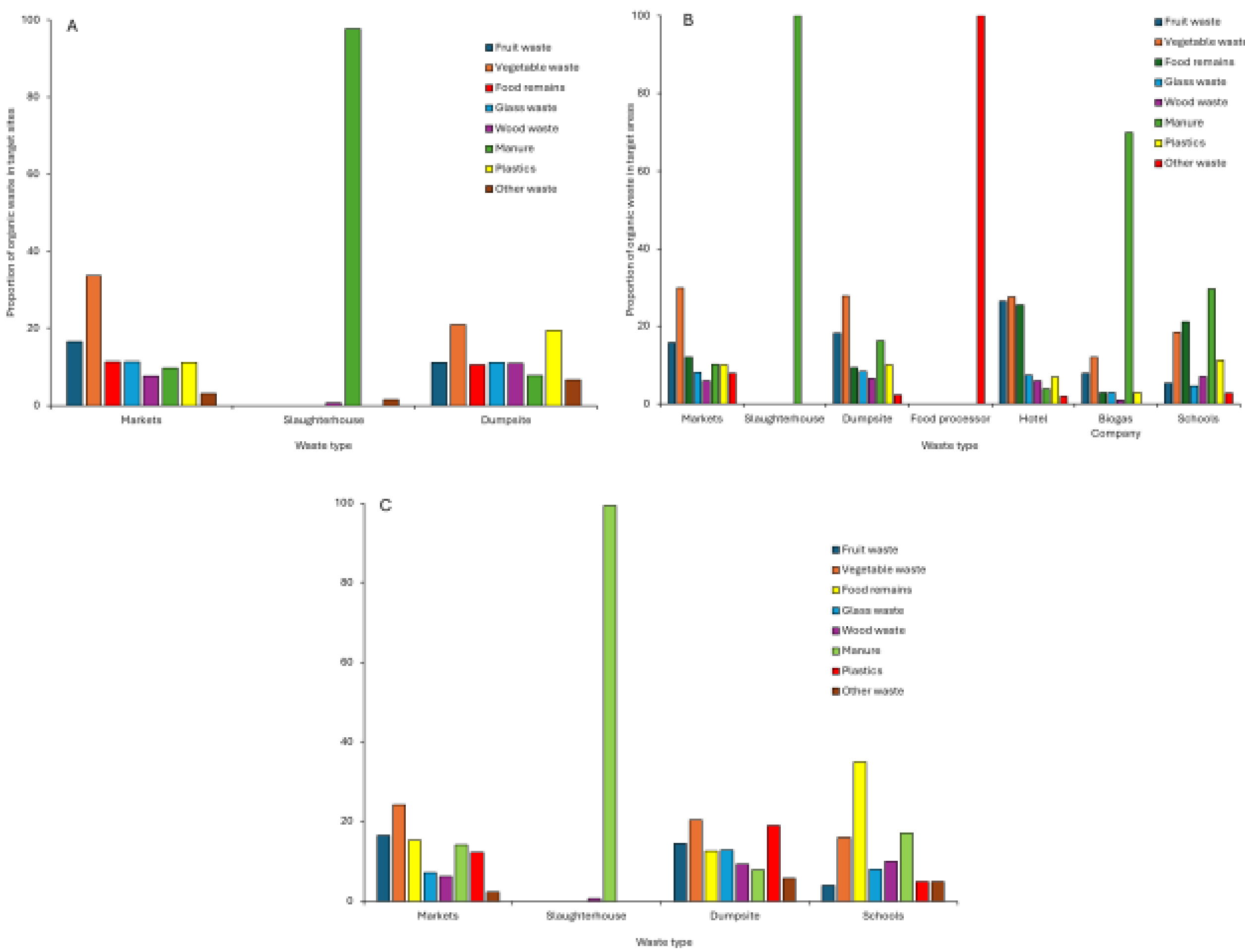

Figure 3: Organic waste distribution in Siaya [A], Busia [B] and Kisumu [C] counties, Kenya.

An assessment of organic waste in Kisumu, a county adjacent to Siaya county revealed dominating proportions of vegetable wastes from the markets, dumpsites and hotels, manures from slaughterhouses, biogas companies and schools, and other wastes from food processors (Figure 3B). Markets produced primarily organic waste (vegetable, fruit, and food remains), accounting for about 57.5% of their waste and a small proportion of non-biodegradable waste (plastics and glass). On the other hand, slaughterhouses waste chiefly comprised of manure. Dumpsite had a balanced distribution of waste types, with vegetable waste (27.8%) and fruit waste (18.2%) being the largest contributors. Manure and plastics also featured notably, indicating that dumpsites act as waste sites for diverse waste streams. Food processors produced only other specialized waste (100%). This was a specialized industry (Rice milling) whose waste, husks, was not classified under the categories. Hotels produced a high percentage of organic waste (fruit waste: 26.5%, vegetable waste: 27.5%, food remains: 25.5%) with minimal non-biodegradable waste (glass, plastics, and wood) indicating efficient waste management practices. For instance, one of the hotels used glass water bottles which are easily reusable to reduce plastic waste. Biogas company dominantly generated manure (70%) since it decomposed animal droppings to generate biofuels. Schools generated a mix of waste types including manure (29.7%) and food remains (21.1%), likely due to livestock farming practices and student meals/feeding.

Generally, waste generation is highly dependent on the waste site type. The slaughterhouse generated mostly organic manure, while markets and dumpsites had a mixture of biodegradable and non-biodegradable waste. Thus, various types of organic waste, including market waste (such as fruit and vegetable scraps), animal manure, brewery waste, and food processing by-products, were analyzed to assess their potential for BSF farming. Waste segregation practices have also been piloted and proven feasible in the region and can be adopted for identified waste sites for collection of organic wastes intended for the BSF rearing in the ECOHUB.

1.1.2. Growth performance and nutritional value of black soldier fly and other wild insects

Bioconversion efficiency of black soldier fly larvae on combined aquaculture sludge and brewers' grains substrates: This study investigated the bioconversion efficiency and nutritional outcomes of black soldier fly (BSF) larvae (*Hermetia illucens*) reared on substrates combining aquaculture sludge (AS) and brewers' spent grains (BG). The objective was to identify the optimal AS inclusion level that maximizes larval growth and nutrient composition, offering a sustainable approach to waste valorization. Frozen aquaculture sludge was thawed at room temperature and thoroughly hand mixed. Five experimental substrates were formulated: [1] Control (C): 100% BG; [2] T1: 25% AS + 75% BG; [3] T2: 50% AS + 50% BG; [4] T3: 75% AS + 25% BG; and [5] T4: 100% AS. Substrate moisture was adjusted to 70% (except for the control) by adding distilled water, aligning with findings by Bekker et al. that optimal BSF larval growth occurs at moisture levels between 65–75%. Larvae were reared under controlled conditions (28 ± 1°C, 70% RH) for 14 days. Growth performance metrics included larval weight gain, survival rate, and development time. Post-harvest, larvae were analyzed for proximate composition: crude protein, lipid, ash, and moisture content. **Results:** Results indicated that T2 (50% AS + 50% BG) achieved the highest larval weight gain (0.45 g/larva), survival rate (95%), and optimal development time (12 days) (Table 3). Proximate analysis revealed that T2 larvae had the highest crude protein (42.5%) and lipid content (28.3%), with moderate ash (8.2%) and moisture levels (10.5%) (Table 4). These findings suggest that a balanced 50:50 ratio of AS and BG provides an optimal nutrient profile and growth environment for BSF larvae. This study demonstrates the potential of integrating aquaculture sludge with brewers' spent grains to enhance BSF larval production, contributing to sustainable waste management and alternative protein sources.

Table 3: Growth performance of BSF larvae on different substrates.

Treatment	Larval weight gain (g/larva)	Survival rate (%)	Development time (days)
C	0.30	85	14
T1	0.38	90	13
T2	0.45	95	12
T3	0.33	88	13
T4	0.25	80	15

Table 4: Proximate composition of BSF larvae (% dry matter).

Treatment	Crude protein (%)	Lipid (%)	Ash (%)	Moisture (%)
C	35.0	20.5	10.0	12.0
T1	38.7	24.0	9.0	11.5
T2	42.5	28.3	8.2	10.5
T3	36.8	22.7	9.5	11.8
T4	32.0	18.0	11.0	13.0

The superior performance of T2 underscores the efficacy of a 50:50 AS and BG substrate in promoting BSF larval growth and nutritional quality, offering a viable strategy for sustainable waste utilization and protein production.

Optimize black soldier fly farming innovations to locally available organic waste substrates: Based on the results obtained from waste mapping, we have conducted five studies aimed at determining the best-best waste combination for improved BSF yield, nutritional quality and high-quality frass fertilizer. The waste streams considered include poultry manure, market waste, potato waste, cattle manure, wheat bran, brewery spent grain, and aquaculture sludge. A chi-square test was applied to evaluate differences in fresh larvae yield and biomass conversion rate among substrates; and an ANOVA was performed to determine the effects of feeding substrate on dry larvae yield, waste reduction efficiency, and frass fertilizer yield. Black soldier fly feeding substrate caused a significant difference in fresh ($\chi2=80.51$, $df=5$, $p<0.001$) and dry ($F=27.45, df=5, p<0.001$) larvae yield (Figure 4a). Similarly, BSF biomass conversion rate ($\chi2=80.23, df=5, p<0.001$) and waste reduction efficiency ($F=11.46, df=5, p<0.001$) were significantly influenced by the feeding substrate (Figure 4 b and c). The BSF feeding substrate also caused a significant difference ($F=11.69, df=5, p<0.001$) in the frass fertilizer yield (Figure 4d). Our findings showed that BSF larvae performed better when reared on combination of more than one organic substrate.

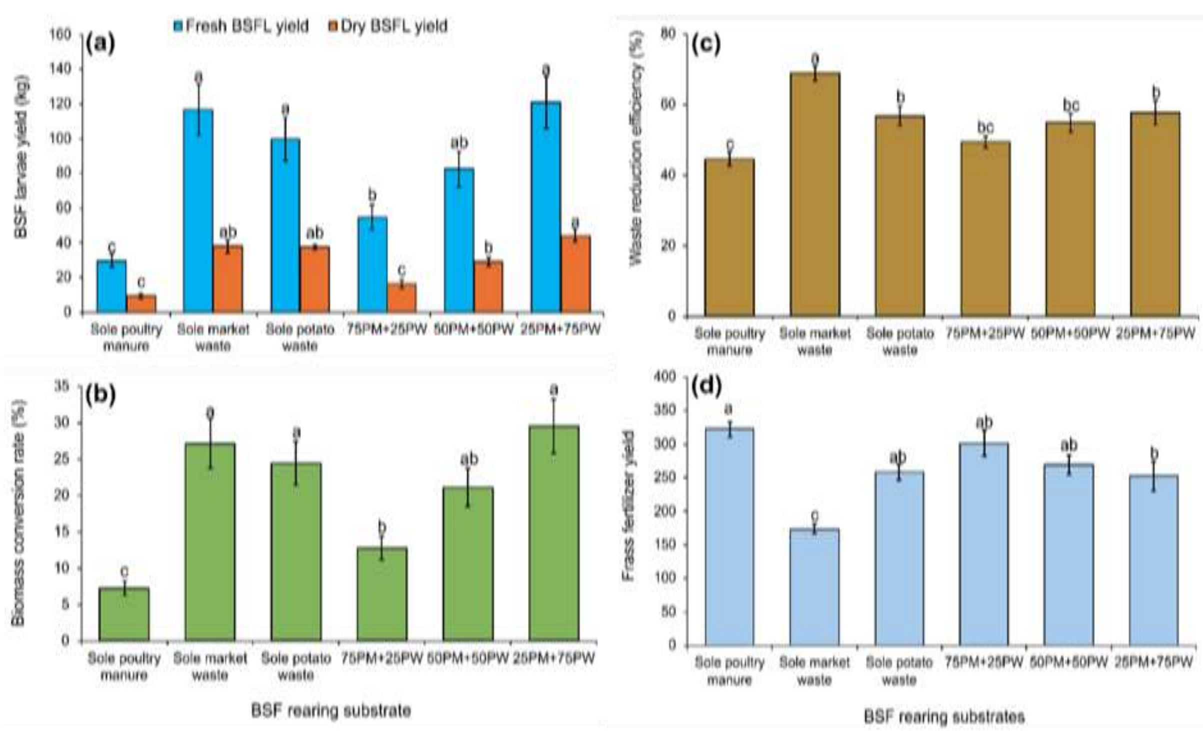

Figure 4: Larval yield (a), bioconversion performance (b) and waste reduction efficiency of black soldier fly (BSF) (c) and frass fertilizer yield (d) obtained from recycling a tonne of different organic wastes. The sequential lowercase letters assigned to each bar indicate statistically significant differences among the samples; bars sharing the same letter are not significantly different, whereas bars with different letters differ significantly.

The BSF larvae fed on market wastes (fruits and vegetables) and a combination of potato waste and poultry manure produced higher larval yield (84% – 306% wet larval yield) and biomass conversion rate, compared to those reared using poultry manure alone. Substrates containing potato waste produced larvae with superior nutritional quality (Figure 5). However, substrates that produced the highest larval yield generated the least frass fertilizer yield, indicating that the choice of substrate will depend on the final product intended. The recycling of one tonne of fresh organic waste produces 29 – 121 kg of fresh BSF larvae and 174 – 322 kg of frass fertilizer. We found that frass derived from a combination of animal and crop wastes had superior concentrations of macronutrients and contained sufficient levels of micronutrients for supporting crop production (Table 5).

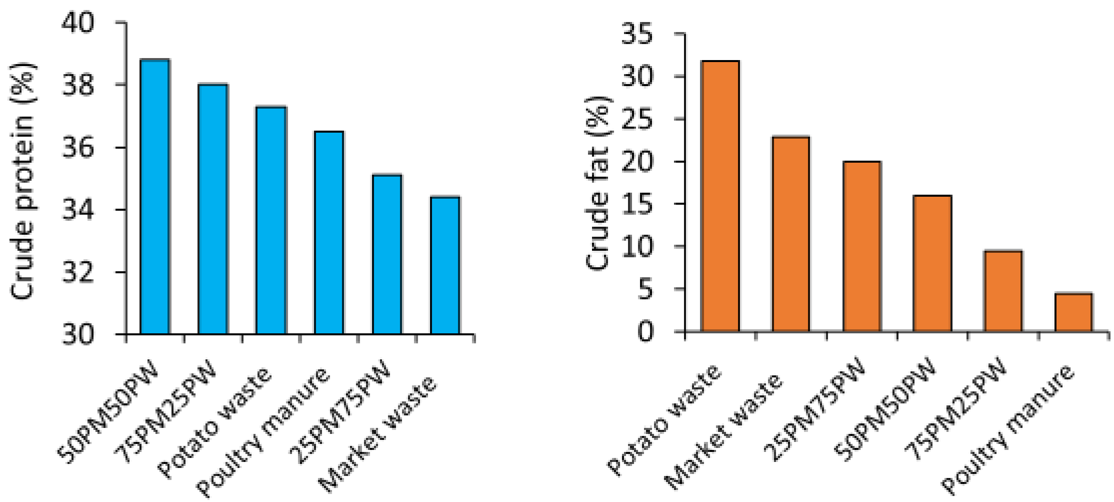

Figure 5: Crude protein and fat levels of BSF larvae reared on different feedstocks.

We are developing low-cost pre-treatment technology for improving nutrient availability and physical properties of cattle dung, a commonly available but considered unsuitable waste for higher BSF growth. Our findings showed that amending cattle dung with dry wheat bran waste and sawdust at 25 – 50% inclusion, coupled with 1 - 2 weeks fermentation enhances nutrient availability, moisture balance, and porosity for BSF production with similar developmental time and survival as other common organic substrates.

Nutritional quality of BSF larva raised on different wheat bran-cattle dung mixtures showed sufficient levels of proteins, fats, carbohydrates and minerals. Assessment of the derived frass fertilizer products is ongoing. We have also explored the potential of artificial intelligence for precision BSF farming with the use of Internet of Things (IoTs) sensors to establish precision production for BSF-based animal feeds and frass fertilizer. The use of Internet of Things (IoTs) sensors highlights the potential to develop decision-support systems for automation of BSF mass production which can attract large-scale private sector investments and increase adoption

Table 5: Chemical properties and concentrations of nutrients in frass fertilizers generated from market waste, potato waste and poultry manure mixtures.

Parameter	Poultry manure (PM)	Potato waste (PW)	Market waste (MW)	75PM25PW	50PM50PW	25PM75PW
pH	8.01a	9.72c	9.80c	8.25ab	8.75abc	9.40bc
Electrical conductivity (uS/cm)	11.65a	21.90bc	25.49c	12.78ab	15.42ab	16.31abc
Carbon (%)	30.89a	46.43c	43.11c	32.10a	33.19a	38.85b
Nitrogen (%)	3.19a	4.28d	3.77c	3.08a	3.23ab	3.54bc
Phosphorus (%)	2.82b	0.46a	0.59a	2.80b	2.55b	1.94b
Potassium (%)	2.00a	3.65c	5.58d	2.36ab	2.56ab	3.12bc
Calcium (%)	8.88e	0.17a	1.28b	8.21e	6.71d	4.05c
Magnesium (%)	1.01d	0.27a	0.46bc	0.97cd	0.86cd	0.68bc
Sulphur (mg/kg)	873.40a	941.83a	1522.70b	980.40a	1069.98ab	1463.89b
Sodium (%)	0.26a	0.50a	0.29a	0.28a	0.31ab	0.37a
Zinc (mg/kg)	251.02d	41.31a	62.19b	257.94d	233.05d	179.01c
Copper (mg/kg)	31.61b	10.32a	12.18a	32.12b	28.39b	24.02b
Iron (mg/kg)	2715.85b	4275.13c	3545.70abc	2993.49ab	3468.34abc	3916.63bc
Boron (mg/kg)	17.01a	9.96a	33.90b	21.42a	15.52a	9.82a
Manganese (mg/kg)	347.01b	151.30a	209.41a	373.70b	359.88b	305.49b

Valorizing waste cow milk as a nutrient supplement for optimizing black soldier fly larval growth:

Black soldier fly larvae (BSFL) are increasingly recognized as a sustainable source of protein for animal feed, with their growth and productivity influenced by the nutritional composition of their rearing substrates. Waste cow milk, a nutrient-dense byproduct often discarded, presents an opportunity for integration into larval substrates, supporting both waste valorization and BSFL production. This study investigated the effects of incorporating varying levels of waste cow milk (0–25%) into a substrate blend of brewer's spent grain (BSG) and potato peels (80:20 ratio) on BSFL growth performance. The results showed that supplementing substrates with 20% and 25% waste cow milk significantly increased BSF larval yield by 40% and 38%, respectively, compared to the control without cow milk. Additionally, the 25% milk supplementation led to a 15% increase in larval length, demonstrating the potential of waste cow milk to enhance larval growth performance effectively. This indicates that higher levels of waste cow milk boost larval growth suggesting that amending substrates with waste cow milk offers balanced nutrition for BSF growth and yield.

Larval performance of black soldier fly reared on various residual organic substrates: In this study, we evaluated the larval yield of BSF reared on twelve different residual organic streams or their combinations to identify suitable substrates for BSF larval biomass production. Preliminary results from the larval yield data suggest notable differences across the substrate combinations (Table 6).

Table 6. Mean larval yield (g) of black soldier fly reared on different organic substrate combinations.

No.	Treatment code	Substrate description	Mean larval yield (g) (n = 3)	Std. Deviation
1	CDSG	Cow dung + spent grain	531.17 g	54.84
2	PMWB	Pig Manure + wheat bran	613.80 g	60.81
3	CMSG	Chicken manure + spent grain	555.79 g	40.11
4	FOWB	Fish offal + wheat bran	255.02 g	43.9
5	PBWB	Pig blood + wheat bran	122.89 g	55.49
6	CM	Chicken manure only	521.05 g	53.47
7	SG	Spent gran only	288.99 g	70.19
8	WB	Wheat bran only	133.75 g	19.6
9	KW	Kitchen waste	244.30 g	67.38
10	MW	Market waste	501.70 g	51.44
11	PW	Potato waste	235.03 g	61.03
12	CF	Chick feed (kienyeji mash)	216.50 g	19.05

Manure-based substrates, particularly pig manure + wheat bran (PMWB), chicken manure + spent grain (CMSG), and cow dung + spent grain (CDSG), showed the highest larval yields, indicating their strong potential for promoting larval growth. Treatments with single components such as wheat bran (WB) or pig blood + wheat bran (PBWB) consistently resulted in the lowest yields, suggesting these may be suboptimal as standalone or primary substrates. While statistical analysis is pending, these initial trends point toward the enhanced performance of mixed organic substrates, especially those combining manure with nutrient-rich bulking agents like spent grain or wheat bran.

Performance of the edible cricket [*Scapsipedus* sp.] on various diets for improved farming: In this study six diets selected such as to vary in protein, carbohydrate and fat content (Table 7) were each provided to 72 newly hatched (~1 h old) individually caged crickets and the influence on their performance were evaluated. The developmental time and survival rate of the different life stages varied considerably on the various diets, with the shortest development and highest survival rate recorded when fed wheat bran diet (Table 8 and Figure 6). Pre-oviposition duration was significantly longer on maize and carrot diets (> 10 days) compared to that recorded on the other diets (< 8 days) (Table 9). We show that body weight and body length were significantly positively correlated in both sexes. Body size was also significantly correlated with longevity of either sex on most of the diets. Females of *Scapsipedus* sp. fed on protein-rich diets (fish offal, soybean and wheat bran) had significantly higher lifetime fecundity and fertility (Table 10) when paired with larger body size male partners, suggesting that male size might have an influence on fecundity. Female-biased sex ratio was recorded on wheat bran, soya bean and carrot diets, whereas it was male-biased on maize and carrot diets. Our results clearly revealed significant differences in the biological performance of *Scapsipedus* sp. when subjected to low quality-protein diets, which indicates the need to formulate nutrient-balanced feeds for efficient production of crickets.

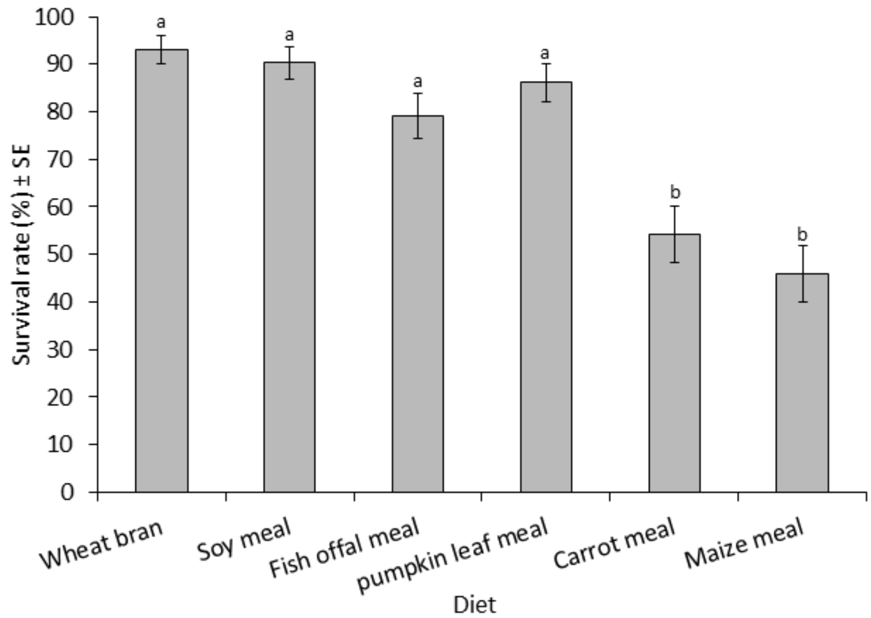

Figure 6: Percent survival of *Scapsipedus* sp. reared on different diets formulated to vary in crude protein and carbohydrates. Means within a pair capped with different letters differ significantly (Student Newman Keul's test: $P < 0.05$).

Table 7. Chemical composition and carbohydrate content of various diets (KJ/kg as fed) of *Scapsipedus icipe* Hugel and Tanga.

Diet	Dry matter (DM) %	Ash	Crude protein (CP)	Crude lipid (CL)	Crude fibre (CF)	Acid detergent fibre (ADF)	Neutral detergent fibre (NDF)	Carbohydrates	Gross energy (KJ/KG)
Wheat bran	88.90±0.16b	4.30±0.18b	16.18±0.03d	5.18±0.35a	38.02±0.01a	15.73±0.08b	53.75±0.08a	25.05±0.01d	20.40±0.01a
Soybean meal	92.85±0.09a	9.51±0.16d	41.13±0.24b	3.78±0.01b	14.19±0.01b	11.49±0.34c	25.68±0.13c	24.25±0.01d	19.74±0.01b
Fish offal meal	87.91±0.14c	11.34±0.02e	55.99±0.19a	4.55±0.01a	12.41±0.01d	7.55±0.40d	19.96±0.28e	3.62±0.01e	20.41±0.01a
Pumpkin leaf meal	81.83±0.27f	13.96±0.02f	24.42±0.11c	3.64±0.10b	13.81±0.01c	8.06±0.38d	21.87±0.08d	26.00±0.58c	17.83±0.01d
Carrot meal	86.02±0.48d	0.78±0.20a	8.24±0.08e	2.91±0.02c	6.48±0.01f	4.24±0.38e	10.72±0.52f	67.61±0.01a	18.85±0.01c
Maize meal	83.11±0.06e	8.77±0.22c	7.41±0.22f	2.01±0.20d	7.67±0.01e	19.13±0.06a	26.80±0.29b	57.24±0.01b	17.16±0.01e

Each value represents the mean ± SE of three determinations on dry matter (DM) basis.

Table 8: Effect of various diets on the developmental attributes of *Scapsipedus icipe* Hugel and Tanga.

Diet type	Developmental duration of various life stage of crickets (days)			
	Pre-adult		Adult	
	Male (N9)	Female (N9)	Male	Female
Wheat bran	7.51±0.14a	7.47±0.13a	65.66±0.36a	65.62±0.28a
Soybean meal	9.08±0.09bc	8.61±0.10b	70.07±0.56b	69.68±0.39b
Fish offal meal	9.93±0.13d	9.86±0.08d	72.36±0.40b	72.29±0.46b
Pumpkin leaf meal	9.41±0.09c	8.76±0.08b	70.72±0.46b	70.07±0.39b
Carrot meal	9.03±0.16bc	8.87±0.17b	103.08±0.32d	102.92±3.25c
Maize meal	9.45±0.17c	10.22±0.10e	106.38±0.90e	107.15±0.46d

Table 9. Pre-oviposition, oviposition and post oviposition duration of *Scapsipedus icipe* Hugel and Tanga reared on various diets.

Diet type	Pre-oviposition (days)	Oviposition (days)	Post oviposition (days)
Wheat bran meal	5.70±0.56a	20.90± 0.72a	24.60±0.72a
Soybean meal	5.50±0.31a	21.10± 1.04a	14.60±0.22b
Fish offal meal	5.10±0.23a	20.60 ± 1.30a	16.40±0.43c
Pumpkin leaves meal	7.70±0.26b	20.50± 0.72a	1.90±0.10 d
Carrot meal	10.40±0.43c	4.40± 0.31b	1.20±0.13d
Maize meal	11.10±0.69c	3.30±0.15b	1.10±0.10 d

Table 10. Fecundity, egg eclosion period, percent egg hatchability and longevity of *Scapsipedus* sp. reared on different diets

Diet type	Fecundity per female	Egg eclosion period (days)	Percent egg hatchability (%)	Adult longevity (days)	
				Male	Female
Wheat bran	1247.72±37.00a	11.70±0.26a	92.00±1.01a	52.37±2.04aA	50.21±1.83aA
Soybean meal	1401.73±25.08a	11.80±0.29a	94.80±0.84a	40.32±3.55bA	40.21±3.47bA
Fish offal meal	1025.2±14.08ab	12.40±0.31b	88.20±1.89ab	42.89±2.01bA	41.11±2.75bA
Pumpkin leaf meal	928.58±24.99b	12.50±0.31b	81.40±1.34b	31.16±2.84cA	30.11±2.41cA
Carrot meal	321.44±23.73c	13.50±0.22b	58.00±2.30c	17.16±1.30dA	15.95±1.95dA
Maize meal	256.20±23.70c	13.80±0.33b	54.00± 1.32c	16.95±1.61dA	15.50±1.46dA

Means within a column followed by same lowercase letter and within row bearing the same uppercase letter are not significantly different (Student-Newman-Keul's test: $P > 0.05$)

Heavy metal accumulation in edible crickets (*Gryllus bimaculatus*): Implications on growth, fecundity, and safety concerns: The study investigated dietary metal concentrations' effect on growth, reproductive performance, nutritional quality, and suitability of edible cricket (*Gryllus bimaculatus*) for human consumption. The crickets were fed on diets containing different concentrations [Below World Health Organization (WHO), at WHO, twice WHO, and three times WHO recommended concentrations] of cadmium (Cd), copper (Cu), iron (Fe), and zinc (Zn). Data on the harvested insects' weight gain, survival, developmental time, egg production, heavy metal accumulation, and proximate and mineral composition were collected. Results showed a reduction of three – seventy-fold in the body weight of crickets raised on diets with metal concentrations three times higher than WHO recommended limits. The highest reduction in weight was recorded in crickets fed on Cu and Cd spiked diets, while Fe and Zn treatments caused the least reduction. The survival rate (Figure 7), weekly weight, and number of eggs laid per female (Figure 8) reduced by up to 79%, 53%, and 58% respectively. It was noted that increasing diet metal concentration by three times caused a 40% increase in crude protein but reduced the fat content by up to 74% and 58% for Cd; 57% and 55% for Cu; 64% and 29% for Fe; and 34% and 69% for Zn for crude fat and free fatty acids, respectively. The Cd accumulation in *G. bimaculatus* tissues was twofold higher than Fe, threefold higher than Cu, and fourfold higher than Zn (Figure 9). Given these findings, we recommend establishing regulatory frameworks for heavy metal concentrations in insect feed materials for optimized survival, reproduction and enhancing safety on the use of *G. bimaculatus* for food.

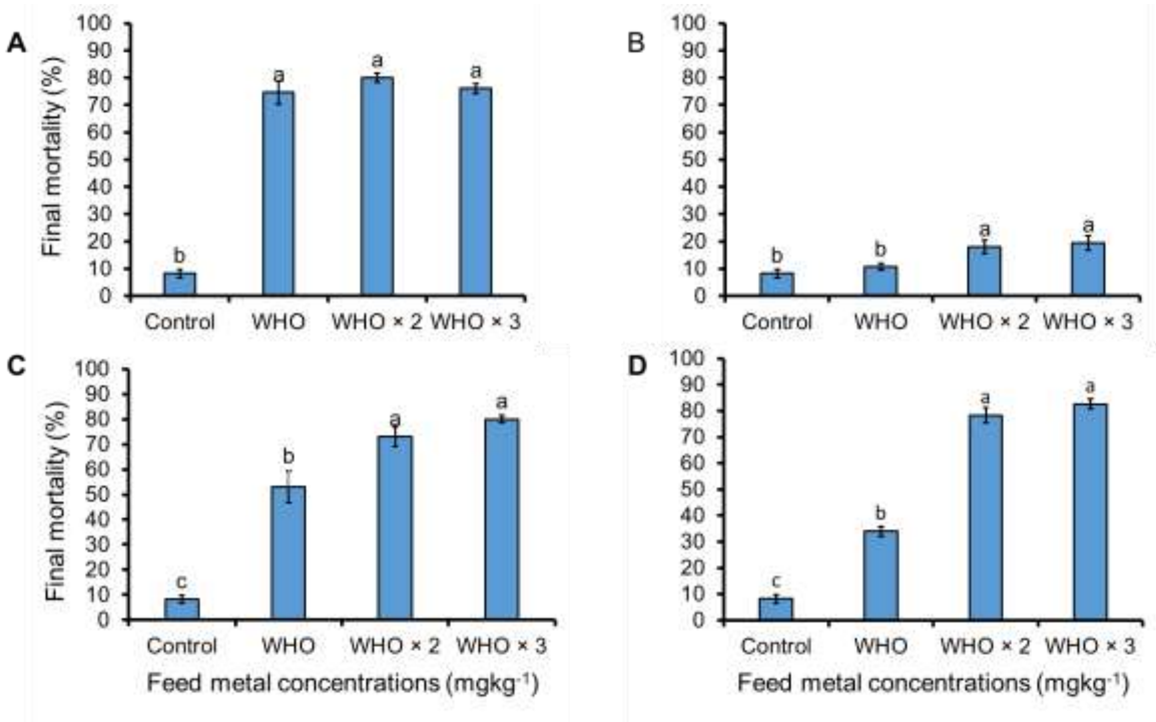

Figure 7: Final percentage mortality of *G. bimaculatus* fed on diets spiked with different levels of heavy metals: (A) Cadmium, (B) Copper, (C) Iron, and (D) Zinc over 49 days. Per panel, means (± standard error) followed by different letters are significantly different at $p \leq 0.05$.

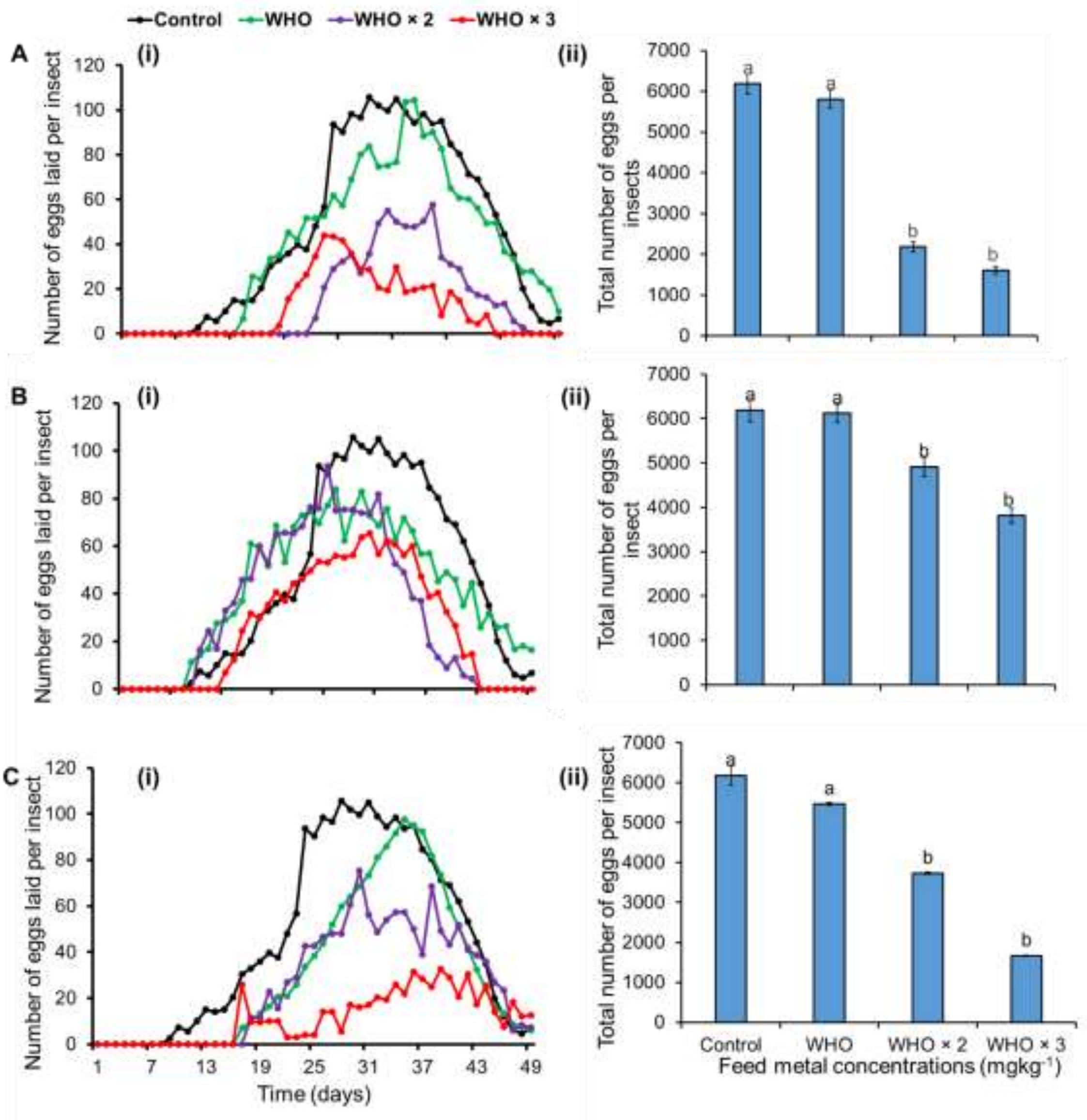

Figure 8: Fecundity of *G. bimaculatus* fed on diets spiked with different levels of heavy metals (i) number of eggs laid per female over time and (ii) total number of eggs laid over 49 days. Per panel, means (± standard error) followed by different letters are significantly different at $p \leq 0.05$.

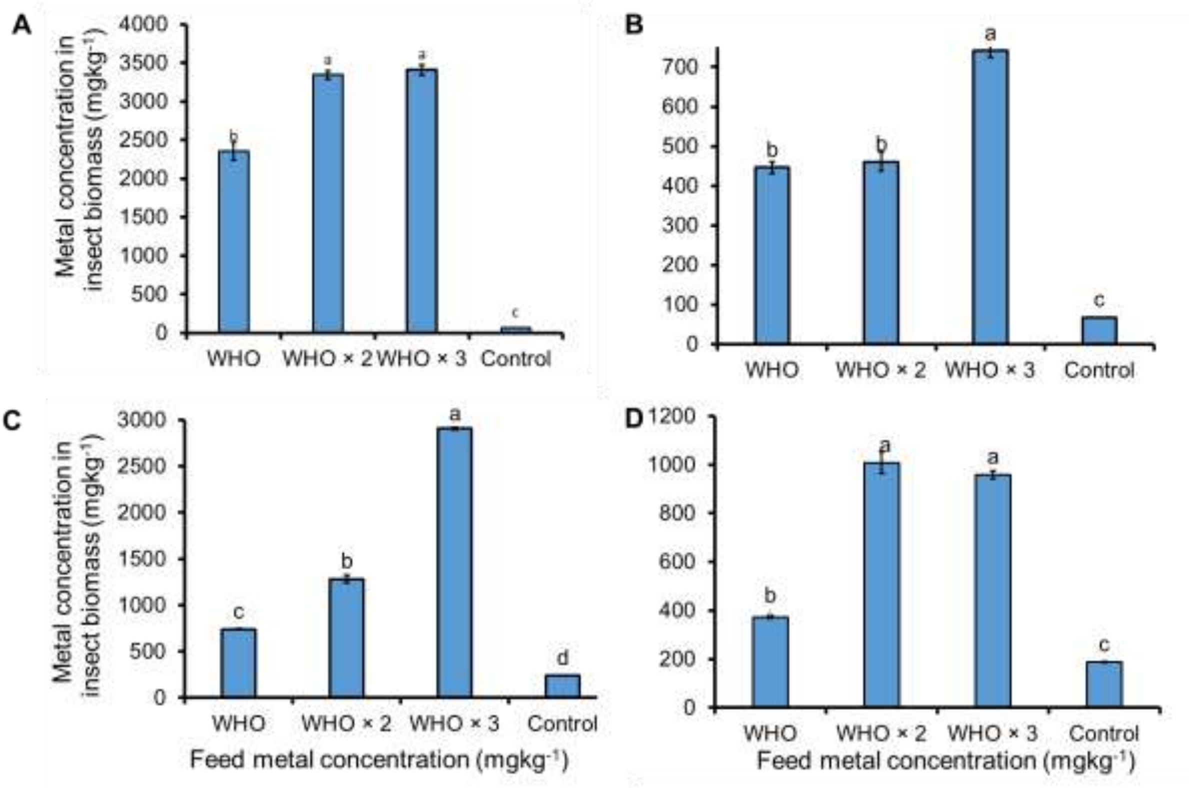

Figure 9: Biomass metals concentrations [cadmium (A), copper (B), iron (C), and zinc (D)] of *G. bimaculatus* fed on diets spiked with different levels of heavy metals. Per panel, means (± standard error) followed by different letters are significantly different at $p \leq 0.05$.

Developing a cost-effective and sustainable diet for mealworm (*Tenebrio* sp.) farming: A study focused on developing a cost-effective and sustainable diet for mealworm (*Tenebrio* sp.) farming in Kenya by utilizing locally available agricultural by-products was conducted. The primary goal was to improve mealworm growth performance, survivorship, bioconversion efficiency, and nutritional composition through the strategic replacement of wheat bran with potato waste, pineapple peels, and cabbage leaves. Two feeding experiments were conducted under controlled conditions using a completely randomized design (CRD), with each treatment replicated four times and 1,000 mealworms per replicate. The mealworms were reared at a temperature of 28.8 ± 2.5 °C, relative humidity of 65 ± 5%, and a 12-hour light/dark cycle. In the first experiment, wheat bran was incrementally replaced with potato waste at levels of 0%, 25%, 50%, 75%, and 100% (Table 11). The second experiment evaluated mealworm performance on diets composed of wheat bran mixed with either cabbage leaves, pineapple peels, or both, in defined ratios. A treatment with wheat bran plus water (via wet cotton wool) was also included to assess the impact of hydration.

Data collected included larval length and weight, survival rate, feed conversion ratio (FCR), efficiency of conversion of ingested feed (ECI), proximate nutrient composition, and amino acid profiles. The results demonstrated that diets containing a mixture of wheat bran and potato waste, especially at 25% inclusion of potato waste, significantly improved mealworm growth, and feed utilization efficiency compared to diets based on wheat bran or potato waste alone. The addition of pineapple peels and cabbage leaves further enhanced growth and bioconversion performance. The study also found that providing water was essential for optimal mealworm development and survival. Mealworms fed on mixed substrates showed higher crude protein content and better amino acid profiles, indicating superior nutritional value.

Table 11: Growth performance of *Tenebrio* sp. reared on wheat bran (WB) with different inclusion levels of potato waste (PW).

Parameter	Diet	Development time (weeks)				
		2	4	6	8	9
Larval length (mm)	WB100 (Control)	6.35 ± 0.04a	8.48 ± 0.06a	12.59 ± 0.10a	15.08 ± 0.10b	16.29 ± 0.11b
	WB75/PW25	6.32 ± 0.04a	8.77 ± 0.06b	14.30 ± 0.11d	16.68 ± 0.10c	**17.81 ± 0.11c**
	WB50/PW50	6.37 ± 0.04a	8.95 ± 0.06b	13.55 ± 0.11c	16.83 ± 0.11c	17.62 ± 0.11c
	WB25/PW75	6.45 ± 0.04a	8.84 ± 0.06b	13.08 ± 0.10b	16.71 ± 0.10c	17.66 ± 0.11c
	PW100	6.45 ± 0.04a	8.92 ± 0.06b	13.21 ± 0.10bc	14.50 ± 0.10a	**15.27 ± 0.09a**
Larval weight (mg)	WB100 (Control)	1.63 ± 0.07a	3.32 ± 0.12a	11.41 ± 0.45a	23.00 ± 0.59a	27.26 ± 0.52b
	WB75/PW25	1.59 ± 0.08a	3.63 ± 0.11a	19.48 ± 0.46c	37.24 ± 0.34b	**40.90 ± 0.37c**
	WB50/PW50	1.53 ± 0.07a	3.84 ± 0.15a	20.17 ± 0.44c	35.32 ± 0.42b	39.77 ± 0.79c
	WB25/PW75	1.75 ± 0.07a	3.84 ± 0.16a	21.85 ± 1.05c	35.65 ± 1.12b	38.70 ± 1.39c
	PW100	1.56 ± 0.10a	3.84 ± 0.16a	16.75 ± 0.25b	22.32 ± 0.55a	**22.86 ± 0.67a**
Survival (%)	WB100 (Control)	100 ± 0.0a	95 ± 0.04a	94.4 ± 0.04a	93.4 ± 0.04a	93.4 ± 0.04a
	WB75/PW25	100 ± 0.0a	95.6 ± 0.03a	93.4 ± 0.04a	93.4 ± 0.04a	**93.1 ± 0.04a**
	WB50/PW50	100 ± 0.0a	95.9 ± 0.03a	94.4 ± 0.04a	94.4 ± 0.04a	93.8 ± 0.04a
	WB25/PW75	100 ± 0.0a	95.3 ± 0.03a	94.1 ± 0.04a	93.8 ± 0.04a	93.4 ± 0.04a
	PW100	100 ± 0.0a	95 ± 0.04a	93.4 ± 0.04a	92.5 ± 0.04a	92.5 ± 0.04a

1.2. Summary of the optimized feed substrates

Serial	Insect type	Best feed substrates for insect performance
1.	Black soldier fly	50% Aquaculture sludge +50% Brewers spent grain
2.	Crickets	Wheat bran
3.	Mealworm (*Tenebrio* sp.)	25% potato waste + 75% wheat bran