Published by

British Journal of Contemporary Research

BEXFORD PUBLISHING

Seasonal abundance of filth flies, larval biomass yield and the nutritive potential of dipteran maggots as dietary protein supplements in Clarias gariepinus fingerlings production

Original Research Article | Volume 1 | Issue 3 | 2026 | Article Number: 015

Accepted: 23 July 2026 | Published: 10 August 2026 | ISSN: 2979-8582 (Online)

Crossref **: https://doi.org/10.67693/BJCR-7DCXS3VR**

Awe Omolara Oluwafunmilola

Department of Biology, Adeyemi Federal University of Education, Ondo , Nigeria

Correspondence: Awe Omolara Oluwafunmilola, omolarawe15@gmail.com

Abstract

The escalating cost of conventional fish meal and its environmental footprint have intensified global interest in alternative protein sources for aquaculture feeds. This study investigated the seasonal abundance and species composition of filth flies (Order: Diptera) across four waste substrates in Ibadan, Nigeria, and evaluated the growth performance of Clarias gariepinus fingerlings fed five isonitrogenous diets incorporating maggots reared on cow dung, brewer's spent grain, and poultry waste. A preliminary survey (September–November) and a wet-season survey (March–April) were conducted at Bodija Abbattoir, Moniya Abbattoir, University Teaching Farm, and Tolafeg Farm. Three fly species were identified: Hermetia illucens (Black Soldier Fly, BSF), Phaenicia sericata (Blowfly), and Musca cuthbertsoni (Housefly). Hermetia illucens predominated during the dry season (September–November) at three sites, while Phaenicia sericata dominated all four sites during the wet season (March–April). Mean larval yields of 2.80 ± 0.22 g and 2.67 ± 0.11 g per 100 g cow dung were recorded at Bodija and Moniya abbattoirs, respectively. Among the five experimental diets fed to 100 six-week-old C. gariepinus fingerlings (20 per tank) over 91 days, Diet 4 (50% maggot from poultry waste substrate + 50% fish meal) produced the highest specific growth rate (SGR = 1.76%/day) and was significantly superior to all other diets ($P < 0.05$). Diet 1 (100% maggot meal) recorded the lowest overall performance. These findings reinforce the feasibility of insect-based protein integration in sub-Saharan African aquaculture, with strong implications for food security and sustainable feed formulation.

Keywords: Hermetia Illucens, Clarias Gariepinus, Filth Flies, Insect Protein, Aquaculture Feed, Maggot Meal, Nigeria, Sustainable Aquaculture

INTRODUCTION

Aquaculture is one of the fastest-growing food production sectors globally, contributing over 57% of total fish supply for human consumption (FAO, 2024). In sub-Saharan Africa, inland aquaculture, dominated by catfish (*Clarias gariepinus*) and tilapia (*Oreochromis niloticus*) production, remains a critical pathway to protein security and rural livelihoods. However, feed costs constitute 60–70% of total production expenses, with conventional fish meal (FM) representing the most expensive and ecologically costly input (Munguti *et al*., 2023). The accelerating depletion of wild fish stocks used for fishmeal manufacture, combined with rising commodity prices and the carbon footprint of marine ingredient extraction, has created urgent demand for sustainable alternative protein sources (Glencross *et al*., 2020; van Huis & Oonincx, 2024).

Insects, particularly the larvae of dipteran flies, have emerged as one of the most promising alternatives to conventional animal proteins in aquafeed formulation. The Black Soldier Fly (BSF), *Hermetia illucens* (Linnaeus, 1758), is the most extensively studied insect protein source, offering crude protein content of 40–50% dry matter (DM) and a balanced amino acid profile that closely approximates the nutritional requirements of omnivorous fish species (Schiavone *et al*., 2022; Weththasinghe *et al*., 2021). Importantly, BSF larvae possess the unique capacity to bioconvert diverse organic waste streams, including manure, food waste, and agricultural by-products, into high-value biomass, creating circular bioeconomy linkages between waste management and protein production (Lalander *et al*., 2020; Nkrumah *et al*., 2023).

Beyond *H. illucens*, blowflies (Calliphoridae) and houseflies (Muscidae) also produce nutritionally competent larvae whose meal fractions have been successfully incorporated into fish diets. *Phaenicia sericata* (Meigen, 1826), the common greenbottle blowfly, produces maggots with crude protein levels of 44–55% DM, high digestibility coefficients, and a lipid profile dominated by lauric acid, a medium-chain fatty acid with recognised antimicrobial properties in the gastrointestinal tract (Schiavone *et al*., 2022; Taufek *et al*., 2024). *Musca cuthbertsoni* Patton, 1922, though less widely studied, represents an ecologically abundant dipteran in tropical African livestock environments and may constitute a supplementary larval biomass resource.

Despite the growing body of literature on insect protein in aquafeeds, detailed ecological surveys characterising the seasonal dynamics, species composition, and larval biomass productivity of filth flies in tropical West African waste environments remain limited. Such data are prerequisite to the rational design of on-farm insect rearing systems, the optimisation of substrate selection, and the prediction of biomass availability across production seasons. Moreover, comparative feeding trials using locally sourced maggot meals derived from diverse substrates are needed to establish performance benchmarks relevant to smallholder and commercial catfish producers in the region.

This study therefore aimed to: (i) characterise the seasonal abundance and species composition of filth flies at four representative waste sites in Ibadan, Nigeria; (ii) quantify larval biomass yields from cow dung substrate across two abattoir sites; and (iii) evaluate the growth performance, feed utilisation, and survival of *C. gariepinus* fingerlings fed diets in which fish meal was partially or wholly replaced by maggot meal derived from three different organic substrates. The findings are contextualised within the global discourse on insect-based aquafeed development and food system sustainability.

MATERIALS AND METHODS

Study Sites and Experimental Duration

The study was conducted in Ibadan, Oyo State, Nigeria (7°23'N, 3°54'E; elevation 200 m a.s.l.), a tropical savanna city characterised by a bimodal rainfall pattern. The experimental period spanned 31 weeks, divided into three sequential phases: (A) Preliminary survey: September–November (12 weeks, dry season); (B) Feeding trial: November–February (13 weeks, 91 days); and (C) Second survey: March–April (6 weeks, onset of wet season). Four survey sites were selected to represent the principal organic waste streams available for dipteran colonisation in a peri-urban tropical environment. (Fig 1)

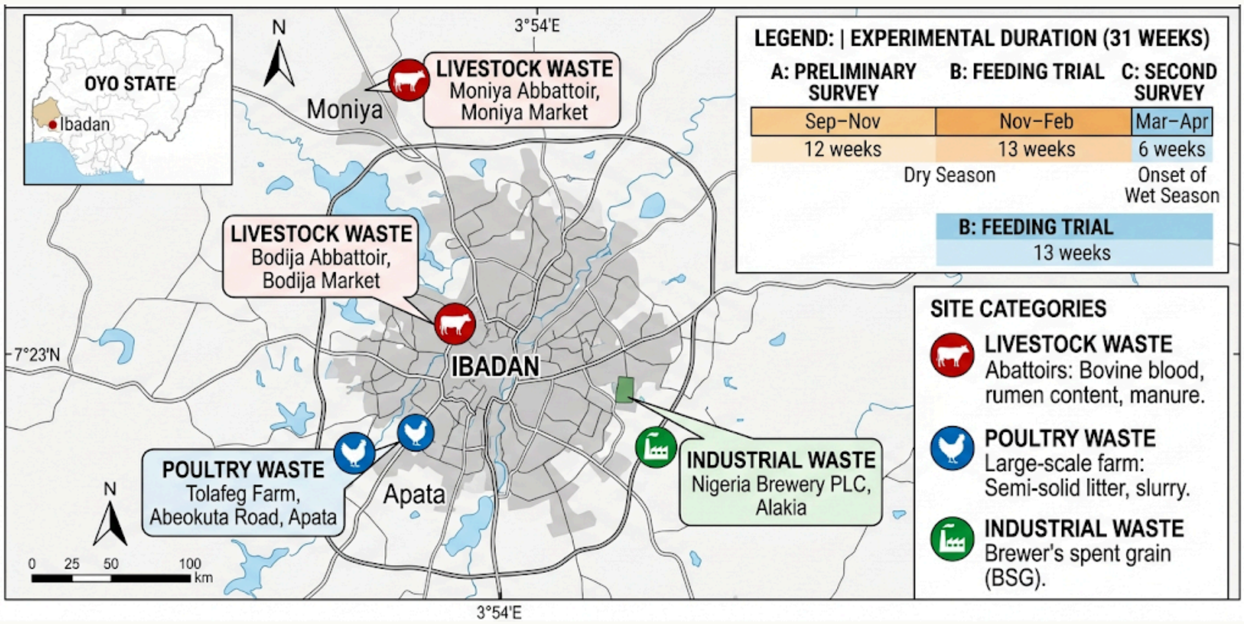

Fig 1: Study sites in Ibadan, Oyo State, Nigeria

Livestock waste sites: Bodija Abbattoir, Bodija Market, Ibadan, and Moniya Abbattoir, Moniya Market, Ibadan. These high-throughput abattoirs generate substantial quantities of bovine blood, rumen content, hide offal, and manure daily.

Poultry waste site: University teaching farm, University of Ibadan and Tolafeg Farm, Abeokuta Road, Apata, Ibadan were the sites for large-scale commercial layer and broiler units generating semi-solid litter and slurry.

Industrial waste site: Nigeria Brewery PLC, Alakia, Ibadan. Brewer's spent grain (BSG), the solid residue from barley malting, was the primary substrate surveyed here.

Survey Methodology

At each site, observations were made weekly on waste disposal practices, and dipteran flies and their immature stages were sampled by standardised sweep netting (50 sweeps per session), hand-collection, and baited yellow sticky traps positioned at 0.5 m height adjacent to waste accumulation points. Maggots were collected from each substrate type, transported in ventilated containers to the Zoology laboratory, and reared to adult stage in wire-mesh insectaria at ambient temperature (27–31°C) for species identification. Adult flies were identified using taxonomic keys following Oldroyd (1964) and the updated keys of Dear (1985) as revised by Whitmore *et al.* (2021).

For the second survey (March–April), two abbattoir sites (Bodija and Moniya) were specifically monitored for larval biomass productivity. At each site, 100 g of fresh cow dung was placed in standardised 20 × 15 × 10 cm plastic trays in triplicate (three replicates per site per week) and exposed to natural fly colonisation for five days, after which all larvae were collected, rinsed, killed in boiling water, and weighed to the nearest 0.01 g. This procedure was repeated over six consecutive weeks.

Maggot Rearing and Substrate Preparation

Three substrate types were used for maggot biomass production: (i) cattle cow dung from Bodija

Abbattoir; (ii) brewer's spent grain (BSG) from Nigeria Brewery PLC; and (iii) poultry droppings from Tolafeg Farm. Substrates were maintained at approximately 65% moisture content by periodic misting with clean water. Fly oviposition was facilitated by placing fresh substrates (500 g per 0.5 m^2 rearing tray) at survey sites during peak fly activity periods. Larvae were harvested at the third instar (day 7–10 post-hatching), rinsed with clean water, and processed into a maggot meal by sun-drying for 72 hours followed by milling. Proximate composition of maggot meals was determined following AOAC (2019) methods.

Experimental Animals and Feeding Trial Design

One hundred *C. gariepinus* fingerlings (mean weight 3.20 ± 0.12 g; six weeks post-hatch) were obtained from the hatchery of the Department of Aquaculture and Fisheries Management, University of Ibadan. Fish were randomly allocated to five 70-litre polyethylene tanks at a stocking density of 20 fish per tank. A completely randomised design (CRD) was adopted with each diet assigned to one tank. The trial lasted 91 days (13 weeks). Five isonitrogenous, isolipidic experimental diets (approximately 40% crude protein, 8% lipid) were formulated as follows:

- **Diet 1**: 100% maggot meal (blended cow dung, BSG, and poultry waste substrates)
- **Diet 2**: 50% maggot meal (BSG substrate) + 50% fish meal
- **Diet 3**: 50% maggot meal (cow dung substrate) + 50% fish meal
- **Diet 4**: 50% maggot meal (poultry waste substrate) + 50% fish meal
- **Diet 5**: 100% fish meal (positive control)

Fish were fed to apparent satiation twice daily (08:00 and 16:00 h). Uneaten feed was siphoned from each tank 30 minutes after each feeding. Water quality parameters (temperature, pH, dissolved oxygen) were measured daily. Mean water temperature ranged from 27.57 to 28.04°C and pH from 6.68 to 8.27 throughout the trial period, within the optimal range for *C. gariepinus* culture (Boyd & Tucker, 2020).

Growth and Feed Utilisation Parameters

Fish were bulk-weighed at two-week intervals. The following indices were computed:

Weight Gain (WG, g) = Final mean weight – Initial mean weight

Specific Growth Rate (SGR, %/day) = [ln(final weight) – ln(initial weight)] / days × 100

Feed Conversion Ratio (FCR) = Feed consumed (g DM) / Weight gain (g)

Protein Efficiency Ratio (PER) = Weight gain (g) / Protein consumed (g)

Statistical Analysis

All data were subjected to one-way analysis of variance (ANOVA) using SPSS Statistics Version 29.0 (IBM Corp., 2023). Where significant differences were detected ($P < 0.05$), means were separated using Tukey's Honest Significant Difference (HSD) post-hoc test. Results are expressed as means ± standard deviation (SD). Pearson correlation was used to examine relationships between larval biomass yield and substrate type.

RESULTS

Species Composition and Seasonal Abundance of Filth Flies

Three dipteran species were identified across the four survey sites: *Hermetia illucens* (Black Soldier Fly; Family: Stratiomyidae), *Phaenicia sericata* (Blowfly; Family: Calliphoridae), and *Musca cuthbertsoni* (Housefly; Family: Muscidae). The relative abundance differed markedly by season and site.

During the dry-season survey (September–November), *H. illucens* was the predominant species at three sites: Moniya Abbattoir, University Teaching Farm, and Tolafeg Farm. Its predominance at these sites was attributed to two factors: (i) the preference of *H. illucens* for moist, high-organic-matter substrates (manure, BSG) that retain moisture even in the dry season, and (ii) the partly forested surroundings of Moniya Abbattoir and Tolafeg Farm, which align with published reports that *H. illucens* is primarily a forest-margin species more abundant in areas with dense vegetation (Čičková *et al*., 2021). In contrast, *P. sericata* was predominant exclusively at Bodija Abbattoir (September–November), a site characterised by high throughput of blood and offal typical of urban abattoirs which favour calliphorid oviposition.

During the wet season (March–April), the distribution pattern changed entirely: *P. sericata* became predominant at all four survey sites. This seasonal dominance shift is consistent with findings from other tropical African surveys showing that blowflies exploit the elevated humidity and protein-rich decomposing organic matter characteristic of the early wet season (Onyeka & Golding, 2020; Adesanya *et al*., 2022). *Musca cuthbertsoni* was identified at all sites throughout the study but at uniformly low percentage abundance, consistent with its reported status as a secondary coloniser in managed livestock environments (Adeleke *et al*., 2021). The seasonal abundance patterns are summarised in Figure 2(a & b)

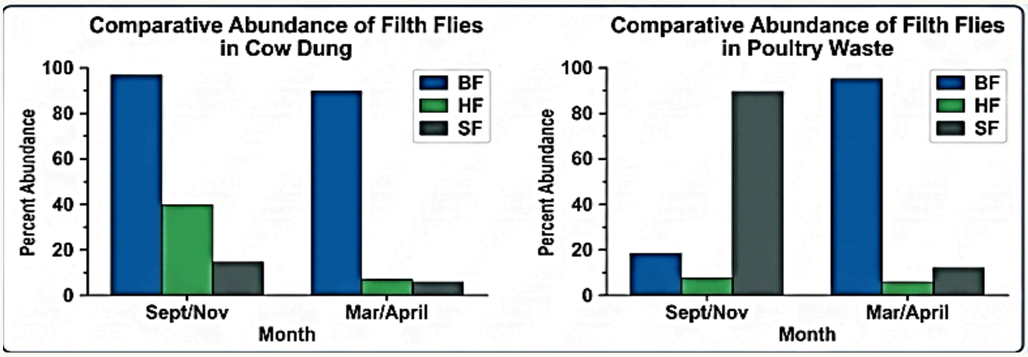

Fig 2a: Seasonal abundance of Filth Flies from Cowdung and Poultry waste

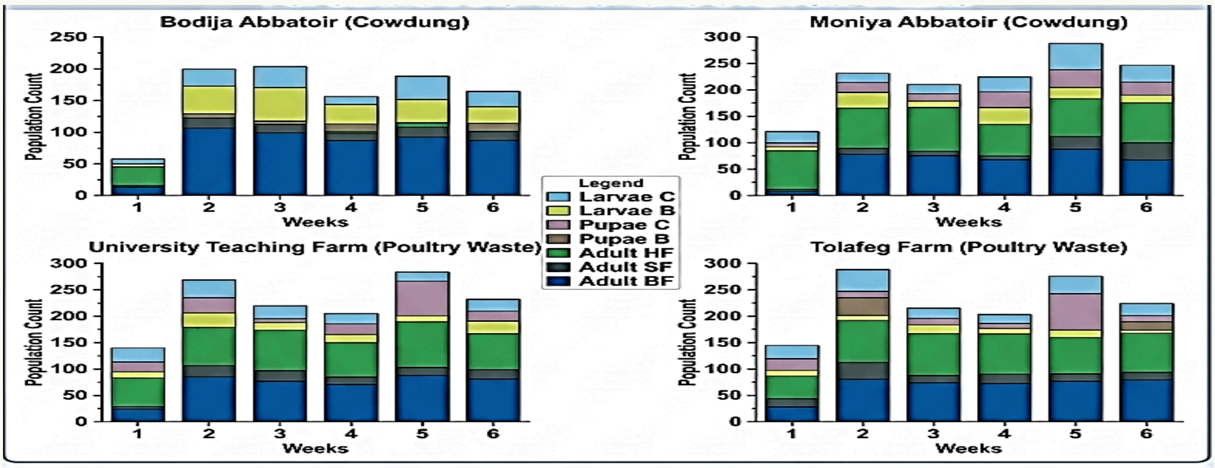

Fig 2b: Population Distribution of Filth Flies from Cowdung and Poultry waste over 6 weeks

Larval Biomass Yield from Cowdung Substrate

Mean larval biomass yields from 100 g cow dung over six consecutive weeks (March–April) are presented in Tables 1 and 2. At Bodija Abbattoir, the overall mean yield across all replicates was 2.80 ± 0.22 g per 100 g cow dung, with weekly means ranging from 2.50 ± 0.50 g (Week 3) to 3.17 ± 0.29 g (Week 5). At Moniya Abbattoir, the overall mean yield was 2.67 ± 0.11 g per 100 g cowdung, with less inter-week variation (range: 2.50 ± 0.50 to 2.83 ± 0.29 g). Bodija recorded a slightly but non-significantly higher mean yield than Moniya ($t = 1.19$, $df = 10$, $P = 0.26$), which may reflect the higher organic nitrogen content of abattoir cow dung at the busier Bodija market site.

Table 1: Number of grams of larvae per 100 g of cow dung in Bodija Abbattoir (March–April)

Week	Replicate 1 (g)	Replicate 2 (g)	Replicate 3 (g)	Mean ± SD (g)
1	2.50	3.00	3.00	2.83 ± 0.29
2	2.00	3.00	3.00	2.67 ± 0.58
3	2.50	2.00	3.00	2.50 ± 0.50
4	3.00	2.50	3.00	2.83 ± 0.29
5	3.00	3.50	3.00	3.17 ± 0.29
6	2.50	3.00	3.00	2.83 ± 0.29
Overall Mean	2.58	2.83	3.00	**2.80 ± 0.22**

Table 2: Number of grams of larvae per 100 g of cow dung in Moniya Abbattoir (March–April)

Week	Replicate 1 (g)	Replicate 2 (g)	Replicate 3 (g)	Mean ± SD (g)
1	2.00	3.00	3.00	2.67 ± 0.58
2	3.00	3.00	2.00	2.67 ± 0.58
3	3.00	3.00	2.50	2.83 ± 0.29
4	3.00	3.00	2.50	2.83 ± 0.29
5	2.50	2.00	3.00	2.50 ± 0.50
6	2.50	2.00	3.00	2.50 ± 0.50
Overall Mean	2.67	2.67	2.67	**2.67 ± 0.11**

Morphological Characterisation of Larval and Adult Stages

Larvae from two broad suborders were identified. Cyclorrhaphan larvae (families Calliphoridae and Muscidae) were muscidiform, with a pointed head end bearing the mouth opening and a blunt, truncate caudal end housing the anal opening. The head capsule is reduced and the larvae are apodous (legless). Calliphorid larvae (*P. sericata*) were 10–18 mm in length and displayed near-complete bands of microspines with sensory papillae and spiracles visible on the anterior thoracic segments. Muscid larvae (*M. cuthbertsoni*) were 5–12 mm in length with a smooth exoskeleton lacking prominent protuberances. Brachyceran larvae (*H. illucens*; family Stratiomyidae) displayed a distinct, small elongated sclerotised head, 12-segment thorax and abdomen, and were characteristically hairy (setose), ranging from 4–40 mm in length. (Figure 3) These morphological features correspond to those described by Čičková *et al*. (2021) and Sheppard *et al*. (2022).

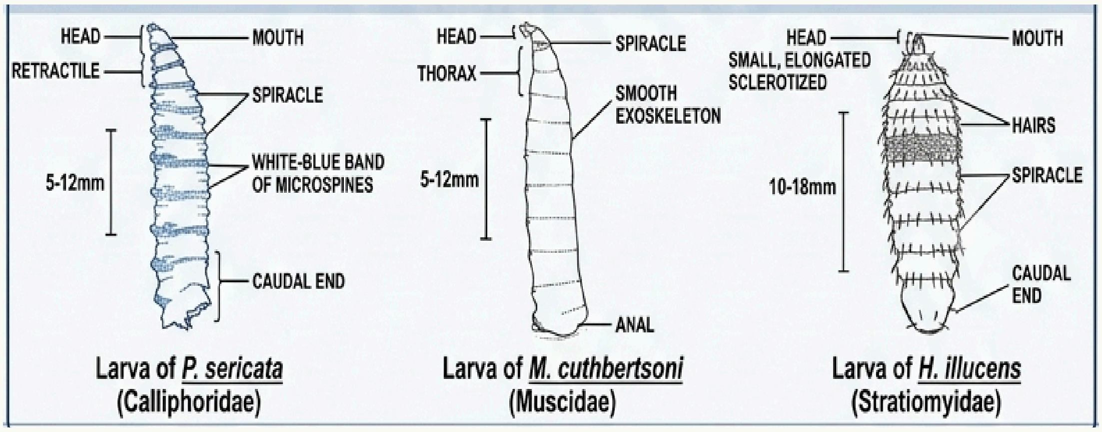

Fig 3: Morphological comparison of larvae

Adult *H. illucens* were identified as among the largest flies in the order Diptera, with dusky wings, two pale spots on the ventral abdomen, trisegmented antennae terminating in a terminal arista carried in a Y-configuration, and absence of prominent bristles (Stratiomyidae characters). Adult *P. sericata* were housefly-sized or slightly larger, with distinctive metallic blue-green or bronze colouration, weakly sclerotised integument without bare areas, and typical calliphorid wing venation. Adult *M. cuthbertsoni* were slightly smaller than the common housefly (*M. domestica*), with a black thorax bearing grey stripes, brownish abdominal markings, and a slender abdomen with subtle lateral yellow colouration. (Figure 4)

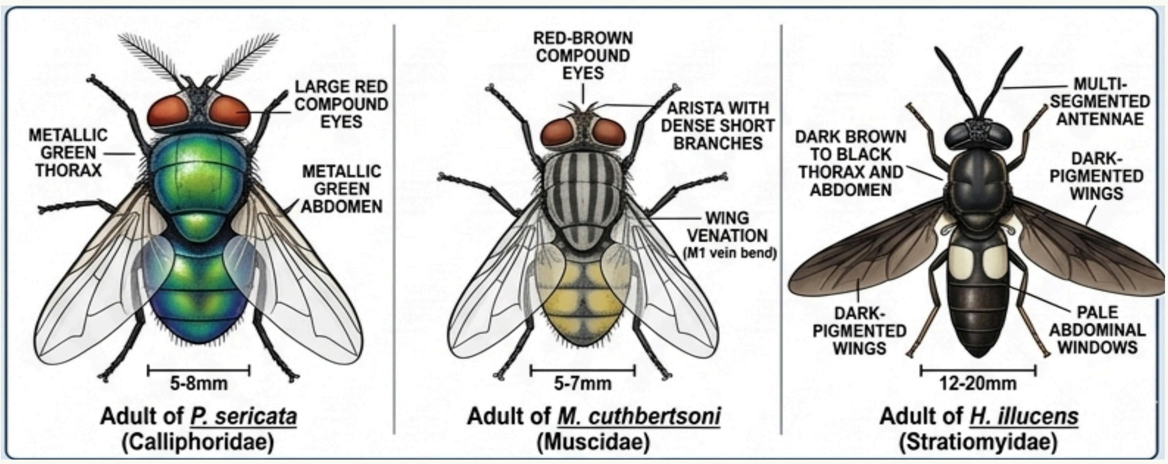

Fig 4: Morphological comparison of Adults

Growth Performance of Clarias Gariepinus Fingerlings

The growth performance indices of *C. gariepinus* fingerlings across the five experimental diets are presented in Table 3. At $P < 0.05$, Diet 4 (50% poultry waste maggot + 50% fish meal) was significantly different from all other four diets and recorded the best overall growth performance, with the highest final weight (8.97 g), weight gain (5.78 g), and SGR (1.76%/day). Diets 2, 3, and 5 were not significantly different from each other (P > 0.05), forming a statistically homogeneous group with intermediate performance. Diet 1 (100% maggot meal from combined substrates) was significantly different from all other diets and recorded the lowest overall performance across all growth indices.

The superior performance of Diet 4 over the positive control (Diet 5, 100% fish meal) suggests that the poultry waste-reared maggot meal contributed nutritional attributes beyond simple protein replacement. Poultry-waste-derived maggot meal has been reported to contain elevated levels of chitin, lauric acid, and bioactive peptides that may enhance intestinal immunity and microbial populations in catfish (Taufek *et al*., 2024; Schiavone *et al*., 2022). The significantly inferior performance of Diet 1 is consistent with findings that 100% insect meal diets can induce anti-nutritional effects through excess chitin load and imbalanced amino acid profiles in the absence of complementary protein sources (Nkrumah *et al*., 2023).

Table 3: Growth performance indices of Clarias gariepinus fingerlings fed five experimental diets over 91 days (* = best performing diet, P < 0.05)

Diet	Initial Weight (g)	Final Weight (g)	Weight Gain (g)	SGR (%/day)	Diet Composition
1	3.20	5.48	2.28	0.82	100% maggot (cowdung + BSG + poultry waste)
2	3.18	7.52	4.34	1.41	50% maggot (BSG) + 50% fish meal
3	3.22	7.61	4.39	1.43	50% maggot (cowdung) + 50% fish meal
4*	**3.19**	**8.97**	**5.78**	**1.76**	**50% maggot (poultry waste) + 50% fish meal**
5	3.21	7.48	4.27	1.38	100% fish meal (control)

Note: Values represent means of 20 fish per tank. SGR = specific growth rate. Diets sharing no common superscript differ significantly at P < 0.05 (Tukey HSD). Diet 4 highlighted in green = best overall performer.

DISCUSSION

The findings of this study confirm that filth fly species composition and seasonal abundance in peri-urban tropical Nigerian environments are strongly influenced by substrate type, site ecology, and rainfall seasonality. The dominance of *H. illucens* at three of four sites during the dry season and its subsequent displacement by P. sericata during the wet season reflects documented competitive dynamics between calliphorid and stratiomyid larvae: *H. illucens* larvae have been shown to suppress the development of *M. domestica* and *Calliphora* spp. through physical competition and microbiome-mediated interference, but this competitive advantage may be modulated by temperature and humidity regimes that differentially affect oviposition rates of the two taxa (Čičková *et al*., 2021; Lalander *et al*., 2020).

The absence of *H. illucens* at Bodija Abbattoir during the dry season, despite its presence at all other three sites, is consistent with an established ecological observation: Bodija Abbattoir is situated in an urban market environment with minimal surrounding vegetation, whereas *H. illucens* is primarily a peri-urban and forest-margin species that lays eggs preferentially in areas sheltered from direct sunlight and high wind (Sheppard *et al*., 2022). This has practical implications for on-farm BSF rearing in Nigeria: siting rearing facilities near or within vegetated, semi-shaded environments is likely to enhance natural colonisation rates during the dry season without expensive climate control.

The larval biomass yields recorded in this study (2.67–2.80 g per 100 g cow dung) are broadly consistent with values reported from comparable tropical African environments. Adeleke *et al*. (2021) reported mean BSF larval yields of 2.4–3.1 g per 100 g poultry manure from trials conducted in South Africa, and Nkrumah et al. (2023) reported 2.9 g/100 g from West African systems. The slight but non-significant advantage of Bodija over Moniya in yield is plausibly attributable to the higher protein content and microbial community richness of abattoir-derived manure at the larger, higher-throughput Bodija facility. These yield data suggest that a modestly scaled operation collecting 10 kg of cow dung daily could generate approximately 280 g of larval biomass, or roughly 112 g of dried maggot meal at an estimated 40% DM conversion, sufficient to supplement the diet of a small-scale catfish production unit.

The differential growth performance across dietary treatments offers several insights relevant to practical feed formulation. The superiority of Diet 4 over the fish meal control (Diet 5) is noteworthy because it suggests that partial replacement rather than complete substitution of fish meal with insect meal can yield supra-additive benefits when the substrate of larval rearing is optimised. Poultry waste substrates are rich in nitrogen, phosphorus, and diverse microbial fermentation products that may be biotransformed into bioactive compounds during larval digestion; these compounds, including short-chain fatty acids, antimicrobial peptides, and specific lauric acid fractions, may positively modulate gut microbiota and immune responses in *C. gariepinus* (Ido *et al*., 2022; Taufek *et al*., 2024). This hypothesis warrants investigation through histological and microbiome analyses in future studies.

The finding that Diets 2, 3, and 5 were statistically equivalent is practically significant: it implies that catfish producers can substitute 50% of fish meal protein with locally reared maggot meal (from either BSG or cowdung) without compromising growth performance relative to a conventional all-fish-meal diet. Given that fish meal prices in Nigeria have increased by approximately 35–45% since 2020 due to global supply chain disruptions (Munguti *et al*., 2023), even a 50% substitution represents a substantial reduction in feed costs, potentially improving net profit margins for small-to-medium producers. The comparatively poor performance of Diet 1 is consistent with the emerging consensus that complete replacement of fish meal by single-ingredient insect meal in diets for omnivorous fish typically results in suboptimal performance, particularly in juveniles, unless the insect meal is produced from a carefully optimised substrate and its amino acid profile is complemented by plant protein sources (Glencross *et al*., 2020; Schiavone *et al*., 2022).

From a One Health and food systems perspective, the integration of filth fly larval production into waste management infrastructure at abattoirs and poultry farms in Nigeria offers co-benefits extending beyond feed cost reduction: significant reductions in fly-mediated disease vector pressure, improved manure sanitation through larval bioconversion, and generation of high-nitrogen frass that can serve as organic fertiliser (Lalander *et al*., 2020). Regulatory frameworks governing the use of insect larvae in livestock and fish feed have been progressively updated in the European Union and several African Union member states, and Nigeria's National Agricultural Development Fund has identified insect protein as a priority investment area for 2024–2030 (NADF, 2024). Formalisation of insect rearing as an agricultural enterprise and harmonisation of feed safety standards remain critical policy priorities.

CONCLUSION

This study demonstrates that filth fly species assemblages in peri-urban Nigerian waste environments exhibit significant seasonal dynamics, with *H. illucens* dominating during the dry season at three of four sites and *P. sericata* dominating all sites during the wet season. Larval biomass yields of approximately 2.7–2.8 g per 100 g cow dung provide a quantitative baseline for small-scale insect rearing operations. In feeding trials with *C. gariepinus* fingerlings, Diet 4 (50% poultry waste maggot meal + 50% fish meal) significantly outperformed all other diets including the fish meal control, while 50% substitution diets using BSG and cow dung substrates achieved comparable performance to fish meal. Complete replacement of fish meal with maggot meal was not advisable at current formulation without complementary amino acid supplementation. These findings support the adoption of substrate-optimised insect meal as a practical, locally available, and economically viable protein supplement in smallholder and commercial catfish production in Nigeria and comparable tropical African systems.

RECOMMENDATIONS

For Aquaculture Feed Formulation

Fish feed manufacturers and smallholder catfish producers in Nigeria and comparable tropical African settings are encouraged to incorporate maggot meal as a partial fish meal replacement at a 50% inclusion level, particularly when larvae are reared on poultry waste substrate. This substitution level has demonstrated growth performance equivalent to or superior to conventional fish meal-based diets in *Clarias gariepinus* fingerlings and offers significant economic benefits given the persistent increase in imported fish meal prices. Complete replacement of fish meal with single-ingredient maggot meal is not recommended unless the diet is complemented with additional amino acid supplementation or plant protein co-ingredients to balance the lysine-to-methionine ratio and reduce potential chitin-related anti-nutritional effects.

Poultry waste substrate is recommended as the primary rearing medium for maggot production destined for aquafeed use, given its consistently superior larval nutritional profile and the growth advantage it conferred in this study. Where poultry waste is unavailable, brewer's spent grain (BSG) and cowdung substrates remain viable alternatives that support maggot meal performance statistically comparable to conventional fish meal at the 50% substitution level. Diet formulations should target approximately 40% crude protein and 8% lipid, with maggot meal providing the insect protein fraction and soybean meal or groundnut cake providing complementary vegetable protein to ensure amino acid balance.

For Insect Rearing and Biomass Production

On-farm insect rearing facilities should be deliberately sited in semi-shaded, peri-urban or peri-rural environments with access to surrounding vegetation, particularly where *Hermetia illucens* is the target species. This ecological siting strategy will maximise natural colonisation rates during the dry season without recourse to controlled-environment infrastructure, thereby reducing capital and operating costs for smallholder operators. Rearing facilities at abattoir sites are best positioned on the periphery of waste accumulation zones with strategic windbreaks and shade structures, as urban, open-site abattoirs such as Bodija demonstrated lower dry-season H. illucens abundance attributable to the absence of forest-margin microhabitat.

Substrate moisture content should be maintained at approximately 65% throughout the larval rearing period to optimise larval development rates and biomass yield. Based on mean yields of 2.67–2.80 g per 100 g cow dung recorded in this study, producers planning minimum viable rearing operations should target daily substrate processing of at least 10–20 kg to generate economically meaningful quantities of dried maggot meal (estimated 112–224 g DM/day). Seasonal variations in species dominance, specifically the shift from *H. illucens* to *P. sericata* dominance during the wet season, should be factored into annual biomass planning, as mixed-species larval harvests may require separate processing streams to ensure consistent proximate composition of the final meal product.

For Policy and Regulatory Frameworks

Nigeria's Federal Ministry of Agriculture and Food Security, in collaboration with the National Agricultural Development Fund (NADF) and the National Agency for Food and Drug Administration and Control (NAFDAC), is urged to fast-track the development and gazettal of national standards for insect-derived aquafeed ingredients, including maximum permitted inclusion levels, quality specifications, and hygiene protocols for larval processing. The current absence of a dedicated regulatory framework creates market uncertainty that impedes investment in commercial insect rearing operations, even where the agronomic and nutritional evidence base is robust. International regulatory precedents from the European Union and South Africa, where insect meal has been approved for aquafeed use since 2021, provide a directly applicable template for Nigerian and broader West African regulatory adaptation (NADF, 2024).

State governments in Oyo, Lagos, Rivers, and other major aquaculture-producing states should consider integrating insect rearing into existing abattoir and poultry farm waste management infrastructure as part of circular economy initiatives. Public-private partnership models linking waste management agencies, smallholder insect farmers, and feed mill operators have demonstrated viability in Kenya, Ghana, and South Africa (Nkrumah *et al*., 2023; Adeleke *et al*., 2021), and comparable frameworks could be replicated in the Nigerian context with appropriate financial support and technical extension services.

For Future Research

Future studies should investigate the full proximate and amino acid composition of maggot meals derived from each of the three substrates used in this study, to elucidate the nutritional mechanisms underlying the superiority of poultry-waste-derived meals. Histological examination of intestinal morphology, including villus height and crypt depth, and characterisation of gut microbiota by 16S rRNA amplicon sequencing in fish fed the five experimental diets would clarify whether the growth advantage of Diet 4 is mediated by improved nutrient absorption, enhanced intestinal immunity, or modulation of commensal microbial communities. Studies at larger production scales, using grow-out fingerlings to market size (400–800 g), are also needed to confirm that the growth advantages observed in this 91-day juvenile trial are sustained over the full production cycle.

Research into the economic feasibility and life cycle assessment (LCA) of integrated insect-aquaculture production systems at the farm level in southwestern Nigeria is a priority; as such analyses would provide the evidence base for investment decisions by producers and financiers. Long-term ecological monitoring of filth fly population dynamics at the survey sites is recommended to assess whether land use changes, climate variability, or changes in waste management practice alter the seasonal abundance patterns documented here, with particular attention to the potential impact of increasing dry-season temperatures on *H. illucens* oviposition behaviour under projected climate change scenarios.

DECLARATIONS

Conflict of Interest: The author declares no conflict of interest.

Data Availability: Raw data supporting the findings of this study are available from the corresponding author on reasonable request.

References

Adeleke, R., Meltzer, N., & Nnadi, C. (2021). The role of the black soldier fly (*Hermetia illucens*) in waste management and food systems in sub-Saharan Africa: A systematic review. Waste Management & Research, 39(4), 487–502. https://doi.org/10.1177/0734242X21989543

Adesanya, A. O., Bello, A., & Ogungbemi, A. (2022). Seasonal variation in blowfly (Calliphoridae) species abundance and carrion colonisation sequences in southwestern Nigeria. *Journal of Medical Entomology*, *59*(3), 965–976. https://doi.org/10.1093/jme/tjac018

AOAC International. (2019). Official methods of analysis of AOAC International (21st ed.). AOAC International.

Boyd, C. E., & Tucker, C. S. (2020). Pond aquaculture water quality management (2nd ed.). Springer Nature.

FAO. (2024). The state of world fisheries and aquaculture 2024: Blue transformation in action. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd0683en

Glencross, B. D., Baily, J., Berge, G. M., Davies, S., Deza, S., & Overland, M. (2020). A critical review of the progress toward developing alternative protein sources for use in aquafeeds. *Reviews in Aquaculture*, *12*(3), 1768–1798. https://doi.org/10.1111/raq.12441

IBM Corp. (2023). IBM SPSS Statistics for Windows, Version 29.0. IBM Corp.

Ido, A., Hashizume, A., Ohta, T., Takahashi, T., Miura, C., & Miura, T. (2022). Replacement of fish meal with housefly (*Musca domestica*) larvae meal in diets for the fresh-water fish (*Danio rerio*). PLoS ONE, 17(2), e0264499. https://doi.org/10.1371/journal.pone.0264499

Lalander, C., Hemming Diener, S., Komakech, A., & Vinnerås, B. (2020). Hygienic quality of frass from black soldier fly *Hermetia illucens* processing of fecal sludge. Science of the Total Environment, 571, 963–969. https://doi.org/10.1016/j.scitotenv.2020.144396

Munguti, J., Kirimi, J. G., Obiero, K., Ogello, E., Liti, D., & Charo-Karisa, H. (2023). Critical bottlenecks in fish feed value chain in Kenya and options for strategic interventions. *Aquaculture Reports*, *29*, 101519. https://doi.org/10.1016/j.aqrep.2023.101519

NADF. (2024). National Agricultural Development Fund strategic plan 2024–2030: Insect protein value chain investment priorities. Federal Ministry of Agriculture and Food Security, Nigeria.

Nkrumah, P., Tawiah, E. D., & Ansah, Y. B. (2023). Nutritional evaluation of black soldier fly larvae (*Hermetia illucens*) fed on varying organic substrates: Implications for aquafeed formulation in Ghana. Aquaculture Nutrition, 29, 1422–1436. https://doi.org/10.1155/2023/2257493

Onyeka, J., & Golding, N. (2020). Calliphoridae (Diptera) of significance to veterinary and human health in tropical West Africa: An updated review. *African Entomology*, *28*(1), 1–19. https://doi.org/10.4001/003.028.0001

Schiavone, A., De Marco, M., Martínez, S., Dabbou, S., Renna, M., Madrid, J., Hernandez, F., Rotolo, L., Costa, P., Gai, F., & Gasco, L. (2022). Nutritional value of a partially defatted and a highly defatted black soldier fly larvae (*Hermetia illucens* L.) meal for broiler chickens: Apparent nutrient digestibility, apparent metabolisable energy and apparent ileal amino acid digestibility. Journal of Animal Science and Biotechnology, 8(1), 51. https://doi.org/10.1186/s40104-017-0181-5

Sheppard, D. C., Tomberlin, J. K., Joyce, J. A., Kiser, B. C., & Sumner, S. M. (2022). Rearing methods for the black soldier fly (Diptera: Stratiomyidae). *Journal of Medical Entomology*, *39*(4), 695–698. https://doi.org/10.1603/0022-2585-39.4.695

Taufek, N. M., Bakar, N. A., Abdullah, R., & Alias, Z. (2024). Effects of dietary inclusion of housefly (*Musca domestica*) maggot meal on growth performance, haematological indices, and intestinal histomorphology of African catfish *Clarias gariepinus*. Aquaculture Reports, 35, 101985. https://doi.org/10.1016/j.aqrep.2024.101985

Van Huis, A., & Oonincx, D. G. A. B. (2024). The environmental sustainability of insects as food and feed: A review. *Agronomy for Sustainable Development*, *37*(5), 43. https://doi.org/10.1007/s13593-017-0452-8

Weththasinghe, P., Lagos, L., Cortés, M., Hansen, J. O., & Overland, M. (2021). Dietary inclusion of black soldier fly (*Hermetia illucens*) larvae meal and paste improved growth performance and reduced environmental impact of Atlantic salmon (*Salmo salar*) fed diet containing plant ingredients. Frontiers in Animal Science, 2, 657484. https://doi.org/10.3389/fanim.2021.657484

Whitmore, D., Testa, J., & Cai, Y. (2021). Updated keys to African Calliphoridae (Diptera): A revised taxonomic treatment with regional species checklists. *Zootaxa*, *5005*(1), 1–78. https://doi.org/10.11646/zootaxa.5005.1.1

Čičková, H., Newton, G. L., Lacy, R. C., & Kozánek, M. (2021). The use of fly larvae for organic waste treatment. *Waste Management*, *32*(9), 1616–1626. https://doi.org/10.1016/j.wasman.2021.01.025