Earthworm, *Eisenia fetida*, bedding meal as potential cheap fishmeal replacement ingredient for semi-intensive farming of Nile Tilapia, *Oreochromis niloticus*

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Abstract

The study amalgamated earthworm and agro-industrial wastes through vermicomposting and then evaluated the potential of the bedding (mixture of *Eisenia fetida* and vermicompost) to replace fishmeal in semi-intensive farming of *Oreochromis niloticus*. The bedding was used to substitute fishmeal at inclusion rates of 100, 60, 30 and 0% (D100, D60, D30 and control D0). In triplicates, the four homogeneous diets were fed to quadruplicate groups of 30 g *O. niloticus* for 112 days. There was no significant difference (*p* > .05) in mortalities, average length gain and FCR among all tests. Nevertheless, diet D0 had significantly (*p* < .05) superior amino acid profile, low fibre content and fish carcass crude protein (63.2 ± 0.72% dry matter). Subsequently, D30 and D0 produced fish with significantly higher (*p* < .05) mean weight gain (256.03 ± 0.4 g) and biomass (369,136 g) respectively. On the contrary, diet D100 had significantly higher (*p* < .05) crude lipids content (9.4 ± 0.6% dry matter), economic returns and profit index than the control diet due to the comparatively low cost of producing the earthworm bedding. This simple biotechnology can commercially be upscaled to sustainably produce cheap and nutritious fish feed capable of increasing yields and maximizing profits.

KEYWORDS

agro-industrial wastes, earthworm bedding, *Eisenia fetida*, fishmeal, *Oreochromis niloticus*

1 | INTRODUCTION

Fish feeds play a major role in aquaculture production; however, they pose a great challenge to fish farming as they contribute up to 70% of aquaculture total financial inputs (Food and Agricultural Organization—FAO, 2009). Fishmeal (FM) has for ages been credited as the main dietary protein source in formulating a nutritive diet for cultured fish due to its superior nutritional qualities and palatability properties. Nevertheless, the consistent use of FM as the main source of protein in fish feeds has progressively made the commodity costly, unreliable and unsustainable due to increased demand, diminishing wild catches, ecological concerns and competition from humans and other animal feed manufacturers. Consequently, the continued use of FM has affected the economic success of most farmers a phenomenon that has prompted expanded research on alternative protein sources.

Agro-industrial wastes have been recognized as non-conventional feed resources because they are often cheaply available and do...
not suffer competition with livestock and human as it is with FM and most grains (Charo-Karisa, Opiyo, Munguti, Marijani, & Nzayisenga, 2013; Limbu et al., 2016; Ogello et al., 2017). Brewers waste (principally barley bran) is among the commonly used agro-industrial wastes in fish feed formulation due to its relatively high protein contents and availability (Zerai, Fitzsimmons, Collier, & Duff, 2008). However, just like most plant-based feed sources, brewers waste digestibility, absorption and assimilation by fish are limited by improper amino acid profile, presence of anti-nutritional factors, and high ash and fibre contents (Kaur & Saxena, 2004; Zerai et al., 2008). Kitchen waste and livestock manure are among the agricultural household residues commonly used in fish nutrition due to their abundance and low cost of obtaining them. However, their utilization in fish feeds production is often restricted by bio-safety, processing and ethical issues (Cheng & Lo, 2016; Sapkota, Lefferts, McKenzie, & Walker, 2007; Sujatha, Mahalakshmi, & Shenbagaratha, 2003).

Vermicomposting biotechnology, which is a joint action of earthworm and micro-organisms on organic matter, has been used for ages as a natural and cheap technique to treat and bio-transform agro-industrial residues to safe and steady compounds (Adi & Noor, 2009; Musyoka, Liti, Ogello, & Waidbacher, 2019; Sujatha et al., 2003). Consequently, the vermicomposting by-products (earthworm, vermicast and vermiliquid) have been optimized and utilized to supply nutrition in various intensities of aquaculture. Most scientists evaluate vermicomposting by-products in aquaculture separately. The accrued biomass is tested as direct protein sources (Mukti, Mahapatra, Rao, Chakrabarty, & Pal, 2012; Vodounnou, Juste, Kpogue, Apollinaire, & Didier, 2016; Zakaria, Salleh, Mohamed, Anas, & Idris, 2012; Zhenjun, Xianchun, Lihui, & Chunyang, 2010), while vermicast and vermiliquid are examined as organic fertilizer to promote pond primary productivity (Ghosh, 2004; Kaur & Ansal, 2010). To date, there are limited scientific data indicating the bio-upgrading of agro-industrial wastes through vermicompost and vermiliquid, were poured in metallic foil and frozen immediately to kill the E. fetida. The mixture was then crushed together through vermiculture then amalgamating the by-products to an earthworm bedding meal (EBM) for fish feeds production.

Earthworm, Eisenia fetida, has been considered as a suitable vermicomposting candidate vis-a-vis fish feed production due to its superior nutritional attributes comparable to that of FM, higher growth and reproduction rate and ability to tolerate wide range of climate conditions (Dedeke, Stephen, & Kayode, 2010; Gunadi & Edwards, 2003; Tacon, Stafford, & Edwards, 1983; Vodounnou et al., 2016). Nonetheless, the earthworm’s applicability in fish feed to increase yields and profitability is still debatable owing to inappropriate processing techniques and the presence of anti-nutritional factors (Musyoka et al., 2019; Tacon et al., 1983; Vodounnou et al., 2016). The slimy, sticky and moist nature of earthworms limits the handling and harvesting of E. fetida for commercial applications. The conventional laborious and time-consuming hand-harvesting techniques prompt the E. fetida in defence, to release a foul-smelling coelom fluid containing haemolytic factors and lysine, which causes unpalatability and toxicity to fish respectively (Kobayashi, Ohtomi, Sekizawa, & Ohta, 2001). Besides, earthworms have the indigestible chitinous exoskeleton, which if not broken down before feed formulation, depresses fish growth by elevating fibre contents, absorbing lipids in the gut and decreasing energy availability (Mukti et al., 2012; Tacon et al., 1983). Additionally, evacuation of E. fetida’s guts contents is a crucial procedure before fish feed formulation because, if the culture substrate used is not of appropriate nutritional quality, its presence during analysis increases fibre and lowers the protein content up to 30% (Zhenjun et al., 2010).

It is against this backdrop the present study aims at using vermiculture to upgrade agro-industrial wastes and simplify E. fetida’s processing techniques by amalgamating them into an EBM. The paper evaluated the potential of the EBM in commercial fish production by testing its ability to maintain water quality, promote fish growth performance, enhance feed utilization, simplify feed processing and decrease costs in fish farming. The findings are expected to provide simple scientific information on simple and cheap biotechnologies, which can be applied to overcome the nutrition and processing challenges associated with agro-industrial wastes and earthworm application in fish feeds. The biotechnology can be upcaled to commercial levels to support sustainable resource utilization, improve fish yield and maximize profitability, thus promoting fish security and ecological balance.

## 2 | MATERIALS AND METHODS

### 2.1 | Vermiculture

The study was conducted at Aqua feed farm, Machakos (1.5177°S, 37.2634°E), Kenya. A mixture of brewers waste, kitchen waste and urine free livestock manure (ratio of 1:1:1) was pre-composted (by sprinkling with water and stirring for 2 weeks) and then inoculated with earthworm, E. fetida. The pre-composting was necessary to reduce anaerobic conditions and increase substrate palatability to the earthworms (Adi & Noor, 2009; Gunadi & Edwards, 2003). The inclusion of livestock manure provided nitrogen, promoted biodegradation and raised the pH of culture substrates (Bhat, Singh, & Vig, 2016). After 10 weeks of vermicomposting, the vermicomposting by-products, that is earthworms, vermicompost and vermiliquid, were poured in metallic foil and frozen immediately to kill the E. fetida. The mixture was then crushed together to form EBM, which was sun-dried and sieved using 0.2-mm mesh. In triplicate, a sample of the EBM was analysed for proximate composition, while the rest was used to formulate the fish test diets.

### 2.2 | Feed formulation and biochemical composition

Four homogeneous diets were formulated based on the animal protein source, that is BM and freshwater shrimp (Caridina nilotica) meal (CNM). The C. nilotica is a bycatch of silver cyprinid (Rastrineobola argentea) fishery in Lake Victoria. The CNM is currently the commonly used fishmeal in Kenya because unlike the R. argentea, it is not directly consumed by humans. The CNM was replaced by the EBM at substitution rates of 100, 60, 30 and 0% (D100, D60, D30 and D0) as shown in Table 1. The average crude protein content of 28% dry matter in all experimental diets is below optimum for O. niloticus because (unlike in intensive system) fish in semi-intensive culture...
ponds require relatively lower protein due to the presence of natural foods (FAO, 2019; Mjoun, Rosentrater, & Brown, 2010).

Diet D0 was the control diet since it did not contain EBM. Brewers waste was used as the basal ingredient for all diets containing CNM (i.e. D60, D30 and D0), while cassava flour was used as binding and water stabilizing agent for all diets. All ingredients were ground, sieved using 2-mm mesh, weighed and then formulated using Pearson’s square method. The formulated feed ingredients were mixed using boiling water to gelatinize the starch and inhibit heat-labile anti-nutritional factors. The feed mixture was extruded into pellets using a home meat mincer with 3 mm die and then dried under shade to conserve nutrients. A total of 48 kg of each diet were produced.

### 2.3 | Fish culture

The fish experimental setup consisted of 12 hapa nets (1 m³) erected in four open concrete rectangular tanks measuring 100 m³ each. Each hapa net was randomly stocked with 50 previously acclimatized uniformly sized (initial average weight and length of 30.14 ± 0.9 g and 11.83 ± 0.3 cm respectively) *O. niloticus* fingerlings. In triplicates, the four test diets were randomly assigned to the experimental fish. Before the start of the experiment, six fish were sacrificed to determine their initial proximate carcass composition. The test fish were hand-fed twice a day by broadcasting food at the periphery of each hapa to satiation for 112 days. Every fortnight, all experimental fish were counted, weighed and had their length measured to monitor growth performance and mortalities. At the end of the experiment, the fish were harvested, weighed (final biomass) and counted. Three fish from each hapa net were sacrificed for final carcass composition determination.

### 2.4 | Water quality parameters

The pond water was partially renewed weekly and completely changed bi-weekly a time when the fish were kept separately in holding buckets as the tanks and hapa nets get cleaned. Water temperature, dissolved oxygen (DO) and pH were monitored on a daily basis from each hapa net, while ammonia was measured weekly.

### 2.5 | Cost–benefit analysis and procurement of materials

The cost–benefit analyses of the experimental diets were conducted for each test feed based on the operating expenditure and income from fish sales with existing prices at the market as shown in Table 2. The exchange rate for the US dollars ($ to Kenya shillings...
was pegged at 100. The income from fish yields after harvest was determined by pooling all fish per triplicate of each test diet and selling them with the existing farm gate price of KES 400/kg.

The variable expenditure included the cost for the fish feed ingredients, while the fixed expenditure was the cost for fingerlings, transport of collecting materials and ingredients, labour for pond management and feed production, water bill, hapa nets and equivalent annual cost (EAC) of the culture pond.

Aqua farm, Machakos, provided the *O. niloticus* fingerlings at KES 5 per piece, while *E. fetida* was obtained from Kamuthanga farm, Machakos at KES 1500/kg. *Caridina nilotica* and brewers waste were procured from Gikomba open-air market, Nairobi at KES 300/kg and 13/kg respectively. Cassava flour was procured from the local market at KES 40/kg, while kitchen waste and soil-free manure were sourced from nearby livestock farms and households at an estimated total cost of KES 3/kg each. The cost of transporting all the feed ingredients was KES 1,600, while the total labour for pond management (feeding fish, cleaning the pond, monitoring etc.) and feed production (grinding and pelletizing the meals) was KES 3,000 and 800 respectively. The EBM cost was estimated using the price of obtaining the *E. fetida*, brewers wastes, kitchen residues and manure.

### 2.6 Biochemical analysis

The proximate analysis of the feed ingredients (CNM and EBM) and test diets, as well as fish carcasses, was done according to the Association of Official Agricultural Chemists—AOAC (1995) standard criteria. The ash content was determined by igniting the sample on a muffle furnace at 550°C. The Kjeldahl method (conversion factor of 6.25) was used to estimate crude protein, while crude fibre and lipids were determined by the acid-base hydrolysis and low-boiling point petroleum ether (40–60°C) respectively. The nutritive digestible energy (DE) of the diets was determined using ballistic bomb calorimeter. The MPA FT-NIR spectrometer obtained from INGOT® (Bruker) was used to determine the essential amino acid profile of the diets, CNM and EBM.

### 2.7 Growth, feed utilization and cost–benefit parameters

Data on growth performance, feed utilization, carcass composition and cost–benefit analysis were evaluated by the following:

- **Mean weight gain (g)** = Final weight−Initial weight
- **Mean length gain (cm)** = Final length−Initial length
- **Survival (%)** = (Final number/Initial number) × 100
- **Specific growth rate (SGR)** = \((100 × [\ln (\text{Final individual weight (g)})−\ln (\text{Initial individual weight (g)})])/\text{Days of experiment})
- **Feed Conversion Ratio (FCR)** = Weight of the feed fed to the fish (g)/Live weight gained (g)
- **Protein Efficiency Ratio (PER)** = Total weight gain (g)/(Feed distribution × Dietary protein (% dry matter))
- **Protein Productive Value (PPV)** = 100 × ((Final protein in fish (% dry matter)−Initial protein in fish (% dry matter))/(Total feed intake per fish (g) × Dietary protein(% dry matter))

- **EAC (KES)** = Pond price/\((1−(1 + \text{depreciation rate})−\text{number of periods})/\text{depreciation rate})
- **Total sales revenue (KES)** = Total biomass harvested (kg) × Market price of fish (KES)
- **Price above variable cost (KES)** = Total sales revenue (KES)−Variable expenditure (KES)
- **Price above fixed cost (KES)** = Total sales revenue (KES)−Fixed expenditure (KES)
- **Net returns (KES)** = Total sales revenue (KES)−(Variable expenditure (KES)+Fixed expenditure (KES))
- **The break-even yields** = Fixed expenditure (KES)/Price above variable cost (KES)
- **Profit index** = Total sales revenue (KES)/Variable expenditure (KES)

![Table 2](image)

**TABLE 2** Operating expenditure (KES) of components used in the experiment
2.8 | Data analysis

The data collected were subjected to the univariate analysis of the general linear model using the SPSS analysis (Version 17.0). The data without significant differences within triplicates were presented as means and standard deviation (SD). The differences between means were tested using the Tukey high significant different (p < .05).

3 | RESULTS

3.1 | Water quality parameters

There was no significant difference (p > .05) in water quality parameters tested (temperature, pH, DO and NH₄) between all culture units as shown in Table 3.

3.2 | Growth performance and feed utilization

All fish experienced similar and indistinguishable exponential growth curves within the first 2 months of the culture, after which there was some overlap and separation of the lines till the end of the experiment as shown in Figure 1. Nevertheless, the fish grown using the control diet D0 exhibited the highest biomass of 37,165 g, followed by D30, D60 and D100, which had 369,136 g, 346,086 g and 331,734 g respectively.

There was no significant difference (p > .05) in mean weight gain in all experimental fish. Nevertheless, the fish fed diet D30 had the highest mean weight gain followed by control diet D0; then, the least was in diet D100 and D60 as shown in Table 4. There was a significant difference (p < .05) in mean weight gain in all fish tested. The highest mean weight gain was recorded in fish fed D30, followed by those fed control diet D0, D60 and lastly D100. Despite these variations in the average weight gained, there was no significant difference (p > .05) in the FCR in all diets. Nevertheless, the SGR, PER and PPV were significantly higher (p < .05) in the control diet D0 and lower in D100 as shown in.

3.3 | Fish carcass composition

There was variation (p < .05) between the initial and final fish carcass proximate composition as shown in Table 5. The ash content of the harvested fish was significantly (p < .05) higher than that of the initial carcass. On the contrary, the crude protein and fibre contents were considerably higher (p < .05) in fish carcass before the experiment. The carcass of fish fed EBM at higher levels had lower (p < .05) crude protein content, while lipid contents remained the same (p > .05).

3.4 | Cost–benefit analysis

There were positive net returns for all experimental diets as shown in Table 6. There was a positive correlation between input costs and CNM inclusion as well as between incomes and EBM contents in the diets. Despite fish fed diet containing earthworms attracting relatively lower gross income, they exhibited higher prices above variable and fixed cost as well as net returns. There was no significant difference (p > .05) in break-even yields between all tests. However, the profit index significantly improved (p < .05) with increasing earthworm inclusion in the diets.

4 | DISCUSSION

The aquaculture industry is increasingly becoming an important supply of fish across the globe. However, its sustainability is highly threatened by among others the expensive and unreliable fish feeds. Cost, quality and quantity are the crucial elements that determine the sustainability of fish feeds in aquaculture. A sustainable fish feed should be nutritionally complete, less costly, palatable, easily digestible, as well as capable of maintaining water quality and improving disease resistance, and not causing mortality. These attributes promote faster fish growth rate, good health status and high reproduction efficiency, which translate to increased yield, thus optimal profits. Therefore, it is every farmer’s objective to obtain good quality and quantity fish feeds at a reasonable cost to realize economic success.

The close-range nutritional composition of EBM, when compared to CNM (save for slight differences in protein and amino acids), qualifies it as a suitable FM substitute. The similarity of the exponential growth curve observed in the current study shows that all experimental diets were adequate, palatable and contained the essential nutrients (particularly protein and amino acids) to support the fish growth. The overlap of the growth curves during the first 2 months of the experiment means there was no significant difference compared to control, hence the positive result. The comparable nutrition

| Variables            | Diet D100   | Diet D60   | Diet D30   | Diet D0    |
|----------------------|-------------|------------|------------|------------|
| Temperature (°C)     | 21 ± 0.06a  | 22.1 ± 0.68a | 21.7 ± 0.75a | 20.8 ± 0.51a |
| pH                   | 7.9 ± 0.11a | 7.7 ± 0.17a | 7.8 ± 0.28a | 7.8 ± 0.17a |
| Dissolved oxygen (Mg/L) | 3.1 ± 0.02a | 3 ± 0.12a  | 3.1 ± 0.05a | 3.1 ± 0.11a |
| Ammonia (NH₄) (Mg/L)  | 2.8 ± 0.08a | 2.9 ± 0.04a | 2.8 ± 0.03a | 2.8 ± 0.10a |

Note: Values represent means ± standard deviation of n = 12 sampling times. Different alphabets (a < b < c) in the same rows symbolize non-homogenous means (p < .05).
attributes in EBM were enhanced by the presence of *E. fetida* and brewers waste. Studies have shown *E. fetida* meal to contain similar protein, amino acids, lipids, minerals and vitamin contents with FM (Dedeke et al., 2010; Vodounnou et al., 2016; Zhenjun et al., 2010). On the other hand, Zerai et al. (2008) reported brewers waste to contain up to 32% dry matter crude protein and can replace 50% FM in intensive *O. niloticus* production. A similar exponential growth curve in *O. niloticus* fed agro-industrial wastes in semi-intensive ponds was observed by Liti, Kerogo, Munguti, and Chorn (2005). The author described that at the exponential growth phase (before *O. niloticus* reaches the critical biomass of 140 g), the fish converts supplementary diet into energy, and thus, its growth is independent of dietary protein. Therefore, the overlap of the growth curves could be caused by varying lipid components in the experimental diets, since crude protein content was similar in all diets. This indicates that EBM can equally promote growth performance and feed utilization of *O. niloticus* just as CNM, despite their differences in crude protein contents and superior amino acid profiles in diets containing elevated CNM. This is because diets with increased inclusion of EBM had higher crude lipids, which when compared to proteins and carbohydrates, phospholipids have more energy per unit alongside being digestible and metabolizable by fish (Doreau & Chilliard, 1997). Limbu et al. (2016) confirmed that diets containing high crude lipids were utilized effectively and promoted similar growth performance in fish as diets with high crude protein. The energy trade-offs in the metabolism of lipids and proteins can enhance the utilization of low-cost diets (of low proteins but high lipids such as EBM), a strategy that can improve fish production and profitability by up to 18% (Liti et al., 2005). Nonetheless, the EBM’s crude protein content of 39.5% dry matter is within the optimum (28%–45% dry matter) requirements for not only *O. niloticus*, but also most fish species under semi-intensive farming (FAO, 2019), meaning the EBM can be used wholly as a diet to supplement natural feeds.

The relatively superior performance (biomass, SGR, PER and PPV) recorded in fish fed with CNM, and consequently, low FCR can be attributed to the significantly superior amino acid profile in CNM. Fish growth, reproduction, immunity and behavioural activities are highly reliant on the essential amino acid profile.

### FIGURE 1
Mean weight (±SE) (g) change of *Oreochromis niloticus* fed on four different diets

![Figure 1](image)

| Variables        | Diet D100     | Diet D60     | Diet D30     | Diet D0    |
|------------------|---------------|--------------|--------------|------------|
| Weight gain (g)  | 80.2 ± 0.4     | 81.9 ± 0.42   | 82.4 ± 0.27   | 83.4 ± 0.3  |
| Survival (%)     | 83.3 ± 3.1     | 85.3 ± 6.4   | 90 ± 8.7     | 86.7 ± 3.1  |
| Length gain (cm) | 6.31 ± 0.04    | 6.35 ± 0.05   | 6.25 ± 0.03   | 6.28 ± 0.08  |
| Specific growth rate | 0.77 ± 0.0   | 0.78 ± 0.0   | 0.78 ± 0.0   | 0.79 ± 0.0 |
| Food conversion ratio | 1.74 ± 0.01  | 1.7 ± 0.01   | 1.69 ± 0.01   | 1.67 ± 0.01  |
| Protein efficiency ratio | 0.33 ± 0.0   | 0.33 ± 0.0   | 0.33 ± 0.0   | 0.34 ± 0.0  |
| Protein productive value | −0.12 ± 0.0  | 1.33 ± 0.1  | 1.42 ± 0.15   | 1.39 ± 0.04  |

Note: Values represent means ± standard deviation of triplicate tests n = 50. Different alphabets (a < b < c < d) in the same rows symbolize non-homogenous means (p < .05).

### TABLE 4  Growth performance and feed utilization of *Oreochromis niloticus* fed on four different diets (Mean ± SD)

| Variables        | Diet D100     | Diet D60     | Diet D30     | Diet D0    |
|------------------|---------------|--------------|--------------|------------|
| Ash              | 8.5 ± 0.31    | 21.3 ± 0.12   | 20.6 ± 0.26   | 19.9 ± 1.1  |
| Crude protein    | 65.9 ± 0.15   | 60.1 ± 0.07   | 61.6 ± 0.88   | 62.6 ± 1.57  |
| Crude fibre      | 9.4 ± 0.25    | 7.5 ± 0.3     | 7.8 ± 0.3     | 7.5 ± 0.3   |
| Crude lipids     | 10.4 ± 0.55   | 13.4 ± 0.57   | 13.1 ± 0.3    | 12.8 ± 0.73  |

Note: Values represent means ± standard deviation of triplicate tests. Different alphabets (a < b < c < d) in the same rows symbolize non-homogenous means (p < .05).

### TABLE 5  Proximate composition (Mean ± SD) of *Oreochromis niloticus* carcass before and after the experiment (% dry matter)

| Variables        | Before     | After (harvested fish) |
|------------------|------------|------------------------|
| Ash              | Initial fish | Diet D100 | Diet D60 | Diet D30 | Diet D0 |
| Crude protein    | 65.9 ± 0.15 | 60.1 ± 0.07 | 61.6 ± 0.88 | 62.6 ± 1.57 | 63.2 ± 0.72 |
| Crude fibre      | 9.4 ± 0.25  | 7.5 ± 0.3  | 7.8 ± 0.3  | 7.5 ± 0.3  | 7.6 ± 0.3 |
| Crude lipids     | 10.4 ± 0.55 | 13.4 ± 0.57 | 13.1 ± 0.3  | 12.8 ± 0.73 | 12.9 ± 0.32 |

Note: Values represent means ± standard deviation of triplicate tests. Different alphabets (a < b < c < d) in the same rows symbolize non-homogenous means (p < .05).
in the protein component of a diet, owing to the fish inability to synthesize the 10-indispensable amino (Andersen, Waagbo, & Espe, 2016; Dedede et al., 2010). Improper amino acid profile and balance with vitamins disrupt their patterns in the body, consequently impairing growth, appetite, food intake, absorption and assimilation (Andersen et al., 2016; Zhenjun et al., 2010). The close-range relationship between amino acids contents in all EBM and that of CNM could be attributed to the presence of E. fetida that is known to have comparable nutritional attributes with FM (Vodounou et al., 2016). The relatively low methionine and lysine contents in the EBM could be as a result of the presence of plant (Gamboa-Delgado, Rojas-Casas, Nieto-López, & Cruz-Suárez, 2013). Similar success studies on improved growth performance of O. niloticus fed on CNM were reported by Liti et al. (2005) and Mugo-Bundi et al. (2013), due to the FM’s biological value. On the other hand, the relatively higher average weight gain in fish fed diet D30 when compared to the control shows the FM and EBM complimented in their nutritional deficiencies. Increasing FM in fish diet balances and presents synergetic effects with the other ingredients, thus promoting growth performance, improving feed utilization and reducing costs.

The decreasing PER and PPV in diets with augmented EBM in the current study were as the result of the elevated lipid contents in the same feeds. A similar low PER in diet containing high lipid was also observed by Abarike, Obodai, and Attipoe (2013) who reiterated that high fatty acid profile not only depresses protein utilization in animal tissues but also impairs growth and feed utilization. This is also reflected in the growth performance and carcass composition of the current study, whereby average weight gain and SGR decreased, while FCR and crude lipid contents increased in fish fed diets containing EBM.

Apart from nutrition, the overlapping growth curve shows that EBM was accepted by fish despite previous studies recording depressed growth when agro-industrial wastes (Ogello et al., 2017) and E. fetida (Musyoka et al., 2019; Tacon et al., 1983) inclusion levels increased. The acceptability of diets containing EBM in the present study indicates that amalgamating the agro-industrial wastes and E. fetida through vermiculture improved their bioavailability. A similar study was reported by Rameshguru and Govindarajan (2011) when a 36% inclusion of vermiliquid in O. niloticus diet promoted feed consumption, digestion and assimilation, subsequently improving growth performance. The amalgamation also reduced unnecessary handling and harvesting of the earthworm, consequently preventing E. fetida from releasing the unpalatable and toxic coelom fluid (Kobayashi et al., 2001). Additionally, the amalgamation also reduced the need for evacuating the earthworm's gut content, thus simplifying processing.

Fish carcass composition is another indicator of feed quality. An increased protein and lipids contents in a formulated diet translate to the fish carcass with higher protein and lipids content suitable for human consumption (Rameshguru & Govindarajan, 2011). In the current study, the ash and lipid content of all fish produced was a reflection of the protein sources, that is the EBM and the CNM. However, there was reduced carcass protein content in EBM fed fish at higher levels compared to CNM fed control. A similar observation was made by Gbai et al. (2018) who described the phenomenon to be a result of inefficient utilization of lipids supplied and increased deposits of fats by fish fed earthworm meal. The lower crude protein and weight gain in fish fed higher levels of EBM is a result of the relatively imbalanced amino acid profile (particularly lysine) in the respective diets. This is because essential amino acids are requisites for nitrogen retention in fish muscles and growth (Peres & Oliva-Teles, 2009). In addition, the observed carcass fibre was below the 9.31%-10.39% dry matter recorded by Moses, Agbaji, Ajibola, Oliva-Teles, and Gimba (2018) but above the 0.91% obtained by Parveen, Rasool, Bhatti, Chughtai, and Saman (2015).

After nutrition, water quality is the second key fundamental aspects of any fish production.

The lack of significant difference in the current study on water quality parameters (temperature, pH, DO and ammonia) between the culture units shows the experimental diets did not have a negative influence on the fish growth performance. Nonetheless, the water quality parameters obtained were within the optimal requirements for O. niloticus production (Mjoun et al., 2010). Given that most of the mortalities were experienced a day after samplings, it is henceforth believed the fish deaths were caused by handling stress, but not by water quality or the experimental diets.

Fish and its products are among the most traded commodities globally, and thus, its amplified trade has improved livelihoods by providing employment and increasing incomes. Additionally, through its integration, aquaculture has diversified agriculture

| Variables               | Diet D100  | Diet D60  | Diet D30  | Diet 0  |
|-------------------------|------------|-----------|-----------|---------|
| Total sales revenue     | 4,965.09a  | 5,042.79b | 5,062.80b | 5,111.52c |
| Price above variable cost | 4,105.59a  | 3,704.54b | 3,229.55c | 2,739.99d |
| Price above fixed cost  | 2,832.93a  | 2,910.63b | 2,930.64b | 2,979.36c |
| Net returns             | 1,973.43d  | 1,572.38c | 1,097.39b | 607.83c  |
| Break-even yields       | 0.52 ± 0.0a | 0.58 ± 0.0b | 0.66 ± 0.0c | 0.78 ± 0.0d |
| Profit index            | 5.78 ± 0.02d | 3.77 ± 0.1c | 2.76 ± 0.0b | 2.16 ± 0.0d |

Note: Values represent pooled data per triplicate except for the break-even yield and profit index which is means ± standard deviation of triplicate tests. Different alphabets (a < b < c < d) in the same rows symbolize non-homogenous means (p < .05).
systems and promoted economic resilience for farmers. The economic feasibility of any aquaculture systems is highly dependent on the cost of obtaining the fish feeds. Consequently, the availability and cost of acquiring the ingredients are fundamental when considering the use of non-conventional feed sources such as EBM.

In the current study, despite the control diet D0 producing the highest yields and gross income, it had the least net returns and profit index because of the relatively high price of obtaining CNM. In contrast, the diets containing EBM produced relatively fewer yields of fish but exhibited more net returns and the highest profit index because of the less variable cost of obtaining the agro-industrial wastes. The profit index of all diets containing EBM was higher than the 4.82 and 5.56 obtained on O. niloticus fed rice bran and pito mash by Attipoe, Nelson, and Abbran (2009) and Abarike et al. (2013) respectively. This economic superiority in diets containing EBM was because of the minimal cost incurred during vermiculture. More feed-related costs were reduced in diet D100 because of the presence of vermisolid and vermiliquid involved the need to add brewers wastes as basal ingredient. This is because, vermiliquid has the potential to replace basal ingredients such as corn (Zhenjun et al., 2010) and even provide protein (Rameshgru & Govindarajan, 2011) in fish feeds. The lack of economic sustainability of FM, when compared to agro-industrial wastes in O. niloticus diets, was also demonstrated by Liti et al. (2005), Attipoe et al. (2009), Abarike et al. (2013), Charo-Karisa et al. (2013) and Limbu et al., (2016).

Nonetheless, the positive net returns obtained in all tests could be attributed to the fact that the present study neither fertilized the ponds nor added vitamin and minerals premixes during feed formulation, for reasons of practicability and economic benefits. The fertilizer was opted out because in regularly fed fish, the uneaten feeds act as nutrient source supplements (Brunson, Stone, & Hargreaves, 1999). Besides, vermicompost is known to contain high organic matter and total nitrogen, whose presence in the uneaten EBM can stimulate the growth of various phytoplankton species and promote water quality (Ghosh, 2004; Kaur & Ansal, 2010; Limbu et al., 2016). On the other hand, vitamins and minerals are not limiting in semi-intensive ponds, because natural feeds compensate the inadequacies of micro-nutrients in formulated feeds according to Liti et al. (2005). The authors added that, avoiding the use of vitamins and minerals premixes cuts feeding costs by up to 20%. Besides, the earthworm E. fetida meal is economically viable (Zakaria et al., 2012) and contains recommendable minerals and vitamins (Zhenjun et al., 2010).

The current cost of producing the EBM should be expected to reduce with continuous vermiculture since no new stock of earthworms should be procured. Continuous vermiculture can cut the cost of producing the EBM further because with the endless hatchlings production means no more stock of earthworms should be procured. The current study’s small-scale production of EBM can sustainably be commercialized by replacing the plastic bins with the large-scale open-bed (flow-through) and windrow vermicomposting technologies for mass production of a diet not only sufficient for semi-intensive, but also for intensive culture systems.

5 | CONCLUSION

Vermiculture can bio-upgrade, amalgamate and reduce processing challenges associated with the utilization of agro-industrial wastes and E. fetida in FM replacement. The lack of major significance differences in the variables tested in the current study shows EBM can partially substitute fish meal in semi-intensive farming, produce high yield nutritious fish, maintain water quality and reduce the production cost, subsequently increasing profits. This is advantageous to various intensities of fish farmers, who frequently have underutilized agro-industrial wastes, lack technical proficiencies in fish feed processing and formulation, and have limited access to the expensive and unreliable FM and commercial feeds.

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CONFLICT OF INTEREST

We hereby certify there is no conflict of interests among the authors whose names are listed in the manuscript. The authors have neither no financial or non-financial interests in the topic of the manuscript.

AUTHOR’S ETHICAL STATEMENT

We certify on behalf of my co-authors that this is our original review work, and it has been neither submitted nor published elsewhere as a whole in part. The authors are responsible for all the content in the manuscript.

ANIMAL ETHICAL STATEMENT

We certify that the current study followed all the applicable guidelines for the care and use of animals.

DATA AVAILABILITY STATEMENT

We certify that all data used in this article were cited and referenced accordingly and can only be availed through the request and permission of the third party authors.

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