INCREASING PRODUCTIVITY OF NILE TILAPIA (*OREOCHROMIS NILOTICUS*) THROUGH ENHANCED FEEDS AND FEEDING PRACTICES

Sustainable Feed Technology and Nutrient Input Systems/Experiment/16SFT03PU

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ABSTRACT

Productivity of farmed fish in Tanzania is low mainly due to poor feeds and feeding practices. Small-scale fish farmers cannot afford the price of fishmeal and soybean meal that are used as protein sources in fish diets. This study was conducted to determine appropriate inclusion levels of substituting fishmeal and soybean meal with a combination of Moringa leaf meal and housefly maggot meal as sources of protein in Nile tilapia diets. In addition, the study aimed at determining the most suitable substrate for production of housefly (*Musca domestica*) maggots and the appropriate feeding strategy for minimizing feed cost in Nile tilapia production. Three experiments were conducted. In the first experiment a total of five substrates (cow dung, chicken manure, pig manure, cattle offal and kitchen leftovers) were tested for production of housefly maggots. Also, the effects of quantity of manure and the age at which housefly maggots are harvested on maggot yields were assessed. In the second experiment a feeding trial was carried out to evaluate the effect of substituting fishmeal and soybean meal with a mixture of Moringa leaf meal and housefly maggot meal on growth performance of sex reversed Nile tilapia (*Oreochromis niloticus*). Eight diets were formulated and each diet contained about 30% crude protein. Diet one (D_1) was a control diet and contained only fishmeal as the source of protein. Diet D_2 was another control diet, but based on soybean meal as the main source of protein. Diets D_3, D_4, D_5, D_6 and D_7 contained various combinations of housefly maggot meal and Moringa leaf meal while diet D_8 contained only housefly maggot meal as sources of protein. The feeding experiment was conducted using 24 plastic tanks, each with capacity of 30 litre, in an indoor semi-recirculation system. Each tank was stocked with 10 Nile tilapia fingerlings with mean initial weight of 1.17 ± 0.04 g. The fish were fed to apparent satiation. Water temperature, pH and dissolved oxygen (DO) were measured weekly. Body weight was measured once per week during the experimental period. The experiment took 56 days. In experiment 3 the best diet identified in experiment 2 was used. Using this diet four feeding strategies were tested i.e. daily feeding at a level of 2.5% of fish weight (T_1), daily feeding at a level 5% of fish weight (T_2), feeding one day at 2.5% followed by one day feeding at 5% of fish weight (T_3) and feeding two days at 2.5% followed by two days feeding at 5% of fish weight (T_4). Nile tilapia fingerlings with average body weight of 10.43 g were stocked in outdoor concrete tanks (each 4.5 m^2 in size and 1 m deep) at a stocking rate of 10 fingerlings per tank. The experiment was conducted for 70 days. Final body weight, weight gain, daily weight gain, specific growth rate, daily feed intake, feed conversion ratio (FCR), protein efficiency ratio, feed costs, revenue and gross margin were computed.

Results show that the type of substrate influenced the yield of maggots ($p \leq 0.05$). The use of cattle offal resulted in significantly higher maggot yield ($p \leq 0.05$) compared to the other substrates. The quantity of maggots produced from chicken manure (40.83 ± 0.67 g/kg) was higher ($p \leq 0.05$) than that obtained from pig manure (27.25 ± 1.29 g/kg), cattle manure (21.57 ± 0.21 g/kg) and kitchen leftovers (27.24 ± 0.33 g/kg). Increasing the quantity manure from 6 to 12 kg increased the yield of maggots from 54.49 ± 1.43 to 74.72 ± 1.43 g/kg of manure. Maggots harvested five days after hatching showed significantly higher yield (72.23 g/kg of manure) than those harvested four and three days after hatching. Fishmeal had the highest crude protein content (60.59%), followed by maggot meal (46.96%). In the second experiment the type of diet had significant effect ($p \leq 0.05$) on body weight gain, average daily weight gain and specific growth rate. Fish fed diet D_1 had the highest body weight gain (3.32 ± 0.25 g), average daily weight gain (0.059 ± 002 g/day) and specific growth rate (2.91%/day), followed by those on D_8 and D_6. Fish fed diet D_5 had the lowest body weight gain (2.07 ± 0.23 g) and average daily weight gain (0.037 g/day). Feed conversion ratio (FCR) was lower on fish fed diet D_1 (2.34 ± 0.06) and D_6 (2.46 ± 0.06), but was higher on those fed diet D_7 (2.84 ± 0.06) and D_4 (2.83 ± 0,06). The type of diet had no significant effect ($p > 0.05$) on protein efficiency ratio. Fish fed diet D_4, D_6, D_7, D_1 and D_8 had significantly higher survival rate compared to those on diet D_2 and D_5.In the third experiment, Nile tilapia reared under T_3 (alternating between feeding levels of 2.5 and 5% of body weight daily) showed higher ($p \leq 0.05$) mean weight gain (93.92 g), average daily gain (1.60 g/day), specific growth rate (5.13%/day), estimated yield (12,969.60 kg/ha/year), revenue (TZS 116,726,499.00 per year) and gross margin (TZS 78,480,026.67 per year) than of those under T_1, T_2 and T_4. The highest feed cost (TZS 25,974,666.67) and total cost (TZS 41,585,77.78) were observed on fish under T_2 (daily feeding at 5% of body weight) while the lowest were found on T_1 (daily feeding at 2.5% of body weight). It is concluded that chicken manure is a better substrate than cattle manure and pig manure for production of maggots. Housefly maggot meal can be used to replace fish meal in the diets without affecting the growth performance of Nile tilapia. Housefly maggot meal has higher protein content and promotes better growth performance than soybean meal. Furthermore, alternating feeding levels of 2.5 and 5% of fish weight daily is the best feeding strategy and can be used to increase the profitability of aquaculture enterprise.

INTRODUCTION

Aquaculture is one of the world's fastest growing animal producing sector with an average growth rate of 8.8%, outpacing capture fisheries (1.2%) and terrestrial farmed meat production (2.8%) (FAO, 2014). Aquaculture accounts for almost half of the world's fish food supply (FAO, 2014). Therefore, aquaculture offers a great potential for food security, poverty alleviation and enhanced trade and economic benefits (ADB, 2005). Aquaculture expansion in Asian countries such as Bangladesh and Thailand has led to enhanced food security among adopters and the population at large (Pant *et al*., 2004; De Silva and Davy, 2010; Jahan *et al*., 2010; Lazard *et al*., 2010). Furthermore, fish are a good source of animal-protein containing essential nutrients of high bioavailability which are found in limiting amounts in most human diets. These nutrients include essential amino acids, essential fatty acids, minerals and vitamins. Fish is a good source of long-chain omega-3 fatty acid docosahexaenoic acid (DHA) that is important for optimal brain and neurodevelopment in children and eicosapentaenoic acid (EPA) that improves cardio-vascular health. Thus, improving fish production from aquaculture will increase the intake of these important nutrients required in a healthy diet and thus reduce the problem of malnutrition.

Despite its potential for improving livelihoods, aquaculture has never developed to a significant extent in Tanzania. Chenyambuga *et al.* (2014) reported tilapia productivity of 5,312 kg ha^{-1} yr^{-1}. This low productivity is mostly attributed to poor feeds and feeding practices. Feeding of fish cultured in ponds of small-scale farmers depends on natural food in the ponds produced by irregular application of inadequate manure. In addition, fish farmers in rural areas provide maize bran, kitchen leftovers and green vegetables/weeds as supplementary feeds. These feeds are of poor quality and when fed as sole diets results into slow growth and low yield of fish at harvest. Elsewhere, it has been shown that with proper feeds and feeding practices, it is possible to attain yields of up to 19,000 kg ha^{-1} yr^{-1} (Hasan and New, 2013). To achieve this high level of production, it is important to develop good quality diets for use in hatcheries, nurseries and grow-out ponds. For many decades, fishmeal and soybean have been used as the main sources of protein in fish feeds due their high quality in terms of amino acid profile and palatability (El-Sayed, 1999; El-Saidy and Gaber, 2002). However, fish farmers in Tanzania cannot afford these two sources essential to meet protein requirement required for high productivity in farmed fish. Thus, there is a need to identify more affordable alternative sources of proteins.

Plant protein sources such as *Moringa oleifera* leaf meal can replace fishmeal, either partially or totally, in practical Nile tilapia diets (Afuang *et al*., 2003). Our previous study showed that a diet containing a mixture of Moringa leaf meal and sunflower seed cake in equal proportions can promote higher growth rate of Nile tilapia, even better than soybean meal (Shigulu, 2012; Kitojo, 2013). Moreover, insects and other invertebrates have been shown to be cheaper sources of animal protein in tilapia diets (Omoyinmi and Olaoye, 2012). These invertebrates are abundantly available because of their short life cycle and ability toproduce large numbers and high biomass within a short time. Our previous study showed that diets containing housefly maggot meal as source of protein promoted higher growth rate of Nile tilapia than cotton seed cake-based diets (Ally, 2015). Thus, the diets based on Moringa leaf meal and maggot meal can be used as alternative to fishmeal and soybean meal as sources of protein, since they have high crude protein content and are abundantly available and affordable to small-scale farmers. However, suitable combination of Moringa leaf meal and maggot meal in Nile tilapia diets have not been established. Likewise, there was a need to determine appropriate feeding practice in terms of feed amount and feeding frequency of fish cultured under semi-intensive production system. Inappropriate feeding practices such as overfeeding can result into feed wastage leading to water quality deterioration and increased production costs (Abdelghany and Ahmad, 2002; Deyab and Husseinm 2015; Ali*et al*., 2016). On the other hand, underfeeding can result into stunted growth and prolonged production cycle, which altogether cause a loss in fish farming enterprise. Therefore, development of appropriate feeding strategies is imperative in order to optimize feed efficiency by reducing feed wastage and deterioration of water quality and ensure profitability. The overall objective of this study was to develop a good quality and cheap diet for Nile tilapia based on Moringa leaf meal and housefly maggot meal. Specifically, the study aimed at determining (1) suitable technique for mass production of housefly maggots, (2) appropriate inclusion levels of a combination of Moringa leaf meal and housefly maggot meal in Nile tilapia diets and (3) appropriate feeding strategy for minimizing feed cost in Nile tilapia production.

METHODOLOGY

Study location and Sampling procedure

The experiment was conducted at Magadu fish farm, Sokoine University of Agriculture (SUA), Morogoro. Sokoine University of Agriculture is located between latitude 6 - 7^{o}S and longitude 37 - 38^{o}E at an altitude of about 500 - 600 m above sea level. The area receives an average annual rainfall of between 600 and 1000 mm. The climate is characterized by bimodal rainfall patterns, with short rains starting in November and ending in December and long rains starting in March and ending in May. The temperature ranges from 25^0 to 30^{0}C.

Experiment 1: Determination of the most suitable substrate for maggot production

This experiment involved designing an appropriate method and determining the most suitable substrate for production of housefly maggots.

Designing of method for production of housefly maggot

Fifteen plastic containers were designed and used for production of maggots. Each had 40 cm diameter and 21.5 cm height (Plate 1). The container consisted of two chambers: the top and the bottom chambers. The top chamber is the culture chamber in which substrates were placed. This chamber was separated from the bottom chamber using a 2 mm plastic mesh to allow dropping of maggots into the harvesting chamber. The dimensions of the culture chamber were 7 cm height and 40 cm diameter. The bottom chamber was the harvesting chamber from which the maggots were collected. The dimensions were 40 cm diameter and 14.5 cm height. The base of this chamber was covered by a lid which can easily be opened during collection of maggots.

Plate 1: The culturing containers

Determining suitable substrate for maggot production

A total of five substrates (cow dung, chicken manure, pig manure, cattle offal and kitchen leftovers) were tested for production of housefly maggots. The experiment was conducted for a period of 21 days. The treatments were cow dung (treatment one - $\mathbf{T_1}$), chicken manure (treatment two - $\mathbf{T_2}$), pig manure (treatment three - $\mathbf{T_3}$), cattle offal (treatment four - $\mathbf{T_4}$) and kitchen leftovers (treatment five - $\mathbf{T_5}$). The treatments were allocated randomly to 15 culture containers shown above and replicated three times. The substrates were put in an air-tight plastic bucket with capacity of ten (10) liters for 24 hours so as to kill fly eggs or maggots if any. A total of 2.5 kg of each substrate (cattle, pig and chicken manures; cattle offal and kitchen leftovers) was put in the culture chamber of the container. Then, 250 g of mixture of blood, small pieces of meat debris and rotten eggs (as housefly attractant) was spread over substrate in each culture chamber. Each culture container was half covered with polythene sheet and a lid, leaving space for houseflies to get in for laying eggs. Substrates were exposed for 7hrs (11:30 am to 05:30 pm) to allow oviposition by the flies. Few perforations were made through the nylon and lids in order to allow aeration. Hatched larva were seen two days after oviposition.

Maggots were dropping from the culture chamber into the harvesting chamber. Harvesting of maggots was done once on the fourth day after oviposition. Prior to harvesting, temperature in each substrate was measured. Collection of maggots, from each harvesting chamber was done by opening the base (lid) of the bottom chamber of the culture container. Collected maggots were thoroughly washed with water and then blanched in hot water at 70 ^{o}C for 10 seconds. Thereafter weighed using digital weighing balance and then dried in oven at 60^{o}C for 48 hours for determination dry matter content.

Another study was conducted to evaluate the effects of quantity of manure and the age at which housefly maggots are harvested on maggot yields. Chicken manure was used as the substrate for culturing the housefly maggots and two levels of manure were used (6 kg and 12 kg), each replicated three times. The manure were spread onto culture chamber and exposed to flies to lay eggs which hatched into maggots. The maggots were harvested at three different ages after hatching i.e. on day three, day four and day five. The harvested maggots were cleaned with water, blanched in hot water at 70^{o}C for 10 sec, weighed and then dried in the oven at 60^{o}C for 48 hours, ground and then subjected to proximate analysis.

Experiment 2: Determination of the appropriate levels of substituting fishmeal and soybean meal with Moringa leaf meal and housefly maggot meal

This experiment involved determination of the appropriate levels of substituting fishmeal and soybean meal with a mixture of Moringa leaf meal and maggot meal. A feeding trial was carried out to evaluate the effect of substituting fishmeal and soybean meal with a mixture of Moringa leaf meal and housefly maggot meal on growth performance of sex reversed Nile tilapia (*Oreochromis niloticus*). Housefly maggots were produced from wet chicken manure as described in experiment 1 above. Harvesting of maggots was done from day 3 to day 5 after oviposition. Harvested maggots were cleaned, blanched with hot water, oven dried at 60°C for 48hrs and ground into powder using a hammer mill to form maggot meal. Moringa leaves were harvested from *Moringa oleifera* tree orchard at Sokoine University of Agriculture. The harvested leaves were soaked in tap water overnight and then boiled at 80°C for 15 minutes to remove water soluble anti-nutritional factors and deactivate trypsin inhibitor. The boiled leaves were oven dried at 60°C for 48 hrs, and then ground into powder using a hammer mill to form Moringa leaf meal. The processed maggot meal and Moringa leaf meal were mixed together with other ingredients to form tilapia diets and in total, eight diets were formulated as shown in Table 1. Proximate analysis was undertaken for fishmeal, soybean meal, maggot meal, Moringa leaf meal and all formulated diets were analyzed according to AOAC (2000). All diets were formulated to contain about 30% crude protein (Table 2). Diet one (D_1) was a control diet and contained only fishmeal as the source of protein. Diet D_2 was another control diet, but based on soybean plus 5% fishmeal as the sources of protein. For the rest of the diets the percentage of fishmeal was fixed at5%, except diet 3 (D_3) which contained 10% fishmeal. Diets D_3, D_4, D_5, D_6 and D_7 contained various combinations of housefly maggot meal and Moringa leaf meal (Table 1) while diet D_8 contained only housefly maggot meal as sources of protein, addition to 5% fishmeal.

The feeding experiment was conducted using 24 plastic tanks, each with capacity of 30 litre, in an indoor recirculation aquaculture system. Each tank was stocked with 10 Nile tilapia fingerlings with mean initial weight of 1.17 ± 0.04 g. The diets were randomly allocated to the plastic tanks and each diet was replicated three times (i.e., each diet was randomly allocated to three plastic tanks). The fish were manually fed to apparent satiation, but not exceeding 5% of their biomass twice a day at 1000 and 1700 hours. The amount of feed provided was adjusted weekly in accordance with the change in fish's body weight. Water temperature, pH and dissolved oxygen (DO) were measured weekly. Body weight was measured before the start of the experiment and then once per week during the experimental period. The experiment took 56 days. After the experiment the following growth performance parameters were computed: weight gain, growth rate, specific growth rate, feed intake, feed conversion ratio, and protein efficiency ratio.

Table 1: Proportion of different ingredients in the experimental diets

Ingredient	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
FM (%)	35.00	5.00	10.00	5.00	5.00	5.00	5.00	5.00
HMM (%)	**0.00**	**0.00**	**15.00**	**25.00**	**30.00**	**35.00**	**40.00**	**45.00**
MLM (%)	**0.00**	**0.00**	**50.00**	**45.00**	**30.00**	**20.00**	**10.00**	**0.00**
SBM (%)	0.00	40.00	0.00	0.00	0.00	0.00	0.00	0.00
MM (%)	57.11	44.21	18.92	19.95	30.56	36.00	41.00	46.00
WM (%)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
SFO (%)	3.89	6.79	2.08	1.05	0.44	0.00	0.00	0.00
Vit/Min (%)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note: D_1 = control diet 1 with only fishmeal, D_2 = control diet 2 with 40% soybean meal, D_3 = test diet 3 with 15%HMM and 50% MLM, D_4 = test diet 4 with 25%HMM and 45% MLM, D_5 = test diet 5 with 30%HMM and 30% HMM, D_6 = test diet 6 with 35%HMM and 20%MLM, D_7 = test diet 7 with 40%HMM and 10%MLM, D_8 = test diet 8 with 45%HMM and0% MLM.
FM = Fishmeal, HMM = Housefly maggot meal, MLM = Moringa leaf meal, SBM = Soybean meal, MM = Maize meal, WM = Wheat meal, SFO = Sunflower oil, Vit/Min = Vitamin/Mineral mix.

Experiment 3: Determination of the appropriate strategy for minimizing feeding cost
This experiment involved determination of the appropriate level and frequency of feeding farmed Nile tilapia. The best diet identified in study 2 was used in this experiment. The experimental diet was formulated to contain about 30% crude protein, and was prepared using housefly maggot meal (45%) as main protein source, fishmeal (5%), maize meal (46%), wheat flour (2%) and vitamin/mineral premix (2%). The chemical composition of the experimental diet is shown in Table 2. Four feeding strategies were tested. These strategies were considered as treatments for this experiment. The treatments were daily feeding at a level of 2.5% of fish weight (T_1), daily feeding at a level of 5% of fish weight (T_2), feeding one day at the level of 2.5% followed by one day feeding at the level of 5% of fish weight (T_3) and feeding two days at the level of 2.5% followed by two days feeding at the level of 5% of fish weight (T_4). The treatments were randomly allocated to 12 round concrete tanks, each with a size of about 4.5 m^2 and 1 m depth. Each treatment was replicated three times. Nile tilapia (*O. niloticus*) fingerlings with average body weight of 10.34 g were stocked in the concrete tanks at a stocking rate of 10 fingerlings per tank. The fingerlings were randomly allotted to the concrete tanks and the experiment was conducted in a completely randomized design. The fish in each treatment were fed twice per day at 1000 and 1700 hours. Each fish was weighed at the start of the experiment and then on every fourteenth day and the amount of feed offered for each treatment was adjusted accordingly. The experiment was conducted for 70 days. Final body weight of each fish was recorded and weight gain, daily weight gain and specific growth rate were computed. Furthermore, the amount of feed provided was recorded daily and feed intake (FI), feed conversion ratio (FCR) and protein efficiency ratio (PER) for the whole experimental period were computed. Death of fish was recorded as it occurred and survival rate at the end of the experiment was calculated. Also feed costs, revenue from sale of fish and gross margin were calculated.

Table 2: Chemical Composition of the Diet

Parameter	Percent (%)
Dry matter (DM)	94.81
Crude protein (CP)	32.33
Crude fibre (CF)	9.17
Ether extract (EE)	5.84
Ash	10.00
Gross energy (GE) (kJ/kg)	17.65

Statistical analysis
Data generated on yield and chemical composition of maggots in experiment 1 and on growth performance (final weight, weight gain, growth rate, specific growth rate) and feed utilization parameters (FI, FCR, and PER) in experiment 2 were analysed using GLM procedure of SAS (2003)in a completely randomized design. In experiment 1, an analysis of variance was carried out to assess the effects of substrate, chicken manure quantity, age of maggots at harvest and interaction of chicken manure quantity and maggot age at harvest on maggot yield. In experiment 2, an analysis of variance was conducted to assess the effects of diet on growth performance and feed utilization of Nile tilapia. In experiment 3, an analysis of variance was conducted to assess the effects of feeding level, feeding frequency, and interaction of feeding level and frequency on growth performance of Nile tilapia. In all treatments Tukey's test was used to determine the significance of the differences between a pair of treatment means.

RESULTS

Experiment 1: Determination of the most suitable substrate for maggot production
Five substrates were tested for their suitability as media for production of housefly maggots. The yield of maggots obtained from the different substrates are shown in Table 3. The results show that the type of substrate significantly influenced the yield of maggots ($p \leq 0.05$) (Table 2). The use of

cattle offal resulted in significantly higher maggot yield ($p \leq 0.05$) compared to other substrates. The quantity of maggots produced from chicken manure was higher ($p \leq 0.05$) than that obtained from pig manure, cattle manure and kitchen leftovers. The lowest yield of maggots was obtained from cattle manure.

Temperature was significantly higher in chicken manure ($p<0.05$) than in other types of substrates. The temperatures observed in cattle manure, pig manure, cattle offal and kitchen leftovers did not differ significantly and ranged from 32.66 ± 3.50°C in cattle manure to 34.86 ± 4.45°C in kitchen leftovers. The results for correlation analysis indicate that there was a weak relationship between temperature and maggot yield ($r = 0.191$).

Table 3: Maggot yield and temperature from different types of substrates

No	Substrate	Yield (g/kg of substrate)	Temperature (°C)
1	Cattle manure	21.57 ± 0.21^{d}	32.66 ± 3.50^{b}
2	Poultry manure	40.83 ± 0.67^{b}	41.60 ± 3.45^{a}
3	Pig manure	27.25 ± 1.29^{c}	34.66 ± 3.25^{b}
4	Cattle offal	50.47 ± 0.43^{a}	33.46 ± 5.05^{b}
5	Kitchen leftovers	27.24 ± 0.33^{c}	34.86 ± 4.45^{b}

The study carried out to evaluate the effect of quantity of chicken manure on maggot yield indicate that the amount of manure used as substrate significantly influenced ($p \leq 0.001$) the yield of maggots (Table 4). On average the increase of the quantity manure from 6 to 12 kg increased the yield of maggots from 54.49 ± 1.43 to 74.72 ± 1.43 g/kg of manure. Also the results shown in Table 3 indicate that the age of maggots at harvest had significant effect on maggot yield. Maggots harvested five days after hatching showed significantly higher yield (72.23 g/kg of manure) than those harvested four days after hatching (65.27 g/kg of manure), which, in turn, had higher yield than those harvested three days after hatching (56.33 g/kg of manure).

Table 4: Effects of manure quantity and age at harvest on yield of housefly maggots (mean ± se) (g/kg of manure)

	Age of maggots at harvest			
Manure mass	**3-days old**	**4-days old**	**5-days old**	**P-Value**
6 kg	47.47 ± 1.41^{c}	55.12 ± 1.38^{b}	60.87 ± 1.41^{a}	0.0001
12 kg	65.18 ± 1.73^{c}	75.41 ± 1.68^{b}	83.58 ± 1.73^{a}	0.0001

^{abc}Means with different superscripts within the same row are significantly different at $p \leq 0.001$.

Table 5 shows the proximate composition of maggots harvested at different ages. On average, maggot meal had crude protein, fat, crude fibre and ash contents of 46.69, 25.92, 6.58 and 9.10%, respectively. The results show that age of maggot at harvest had significant effect ($p \leq 0.05$) on crude protein, ether extract (fat), crude fibre and ash contents. Crude protein content significantly decreased ($p \leq 0.001$) with increase age at harvest of maggot. Fat, crude fibre and ash contents were found to significantly increase ($p \leq 0.05$) with advancement age at harvest of maggot. For increased biomass yield and relatively high protein content it is worth harvesting housefly maggots when they are five days old.

Table 5: Effect of maggot age at harvest on chemical composition of housefly maggot meal

Chemical composition parameter	Age of maggots 3-days	4-days	5-days	P-Value
Crude protein (%)	48.67±0.31^{a}	46.78±0.31^{b}	44.62±0.31^{c}	0.0003
Ether extract (%)	23.06±0.21^{c}	25.39±0.21^{b}	29.30±0.21^{a}	0.0001
Crude fibre (%)	6.24±0.01^{c}	6.35±0.01^{b}	7.15±0.01^{a}	0.0001
Ash (%)	8.88±0.01^{b}	8.90±0.01^{b}	9.52±0.01^{a}	0.0001

^{abc}Means with different superscripts in the same row are significantly different ($p \leq 0.001$).

Experiment 2: Determination of the appropriate levels of substituting fishmeal and soybean meal with Moringa leaf meal and housefly maggot meal

Table 6 shows the chemical composition of maggot meal, Moringa leaf meal, fishmeal, soybean meal and formulated diets used in the experiment. Soybean had the highest dry matter content, followed by maggot meal. Fishmeal had the highest crude protein content (60.59%), followed by maggot meal (46.96%) while Moringa leaf meal had the lowest crude protein content. Crude fat content was highest in maggot meal (23.12%) and lowest in Moringa leaf meal (6.40%). Maggot meal had the highest crude fibre content while fishmeal had the lowest crude fibre content. The highest ash content was observed in fishmeal while the lowest value was found in soybean meal. The formulated diets had almost the same crude protein contents and ranged from 30.15% in diet D_7 to 31.20% in diet D_2. Diet D_6 (14.88%) and D_8 (14.80%) had the highest fat contents while diet D_1 (9.70%) had the lowest. Diet D_1 had the lowest crude fibre content (2.83%) while diet D_6 had the highest value (7.01%). Ash content was highest in diet D_1 (17.7%) and lowest in diet D_2 (11.23%).

Figure 1 shows the growth performance of Nile tilapia fed different dies during the experimental period. Generally fish fed diet D_1 and D_8 showed the highest growth performance while those on diet D_5 had the lowest growth performance throughout the experimental period. The growth performances of fish fed diets D_2, D_3, D_4, D_6 and D_7 did not differ significantly. The analysis of variance revealed that the type of diet had significant effect ($p \leq 0.05$) on final body weight, weight gain, average daily weight gain and specific growth rate. Fish fed diet D_1 had the highest body weight gain, average weight gain and specific growth rate, followed by those on D_8 and D_6 (Table 7). Fish fed diet D_5 had the lowest body weight gain and average daily weight gain. Table 6 also shows that the type of diet significantly influenced ($p \leq 0.05$) feed utilization efficiency. Fish fed diet D_1 and D_8 had higher feed intake values while those fed diet D_5 had lower value than the rest of the diets. Feed conversion ratio (FCR) was lower on fish fed diet D_1 and D_6, but was higher on those fed diet D_7 and D_4. The type of diet had no significant effect ($p > 0.05$) on protein efficiency ratio. However, diets D_1 and D_3 showed slightly higher protein efficiency ratio compared to the other diets. Results on survival rate are shown in Table 6. The results indicate that survival rate differed significantly among the fish fed different diets. Fish fed diet D_4, D_6, D_7, D_1 and D_8 had significantly higher survival rate compared to those on diet D_2 and D_5.

Table 6: Chemical composition of maggot meal, Moringa leaf meal , fishmeal and formulated diets used in the experiment

	Dry matter (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Ash (%)
Maggot meal	94.26	46.96	23.12	10.58	8.51
Moringa leaf meal	93.76	28.60	6.40	9.83	7.14
Fishmeal	93.09	60.59	9.44	0.24	20.74
Soy bean meal	95.12	40.36	14.86	8.42	5.20
D1 (CON 1, FM)	92.46	30.52	9.70	2.83	17.7
D2 (CON 2, SBM)	92.31	31.20	13.32	6.65	11.23
D3 (15%HMM/50%MLM)	92.33	30.83	11.25	6.95	11.72
D4 (25%HMM/45%MLM)	92.68	30.77	12.36	6.75	11.39
D5 (30%HMM/30%MLM)	93.43	30.59	10.32	5.10	12.23
D6 (35%HMM/20%MLM)	92.22	31.13	14.88	7.01	11.93
D7 (40%HMM/10%MLM)	92.60	30.15	11.32	6.83	11.41
D8 (45%HMM/0%MLM)	92.00	30.68	14.80	5.23	11.33

DM = dry matter, FM = fishmeal, SBM = soy bean meal, HMM = housefly maggot meal, MLM = moringa leaf meal, CON 1 = control 1 (FM inclusion), CON 2 = control 2 (SBM inclusion).

Results for water quality parameters, specifically pH, dissolved oxygen (DO) and temperature, during the experimental period are shown in Table 8. Diet had no significant effects on DO and temperature, but significantly influenced water pH. Plastic tanks subject to diet D_4 had higher pH values than those on diet D_6, but the two did not differ significantly from the plastic tanks subjected to the rest of the diets. Generally the values of DO, temperature and pH observed during the whole experimental period were within the range suitable for growth of *O. niloticus*.

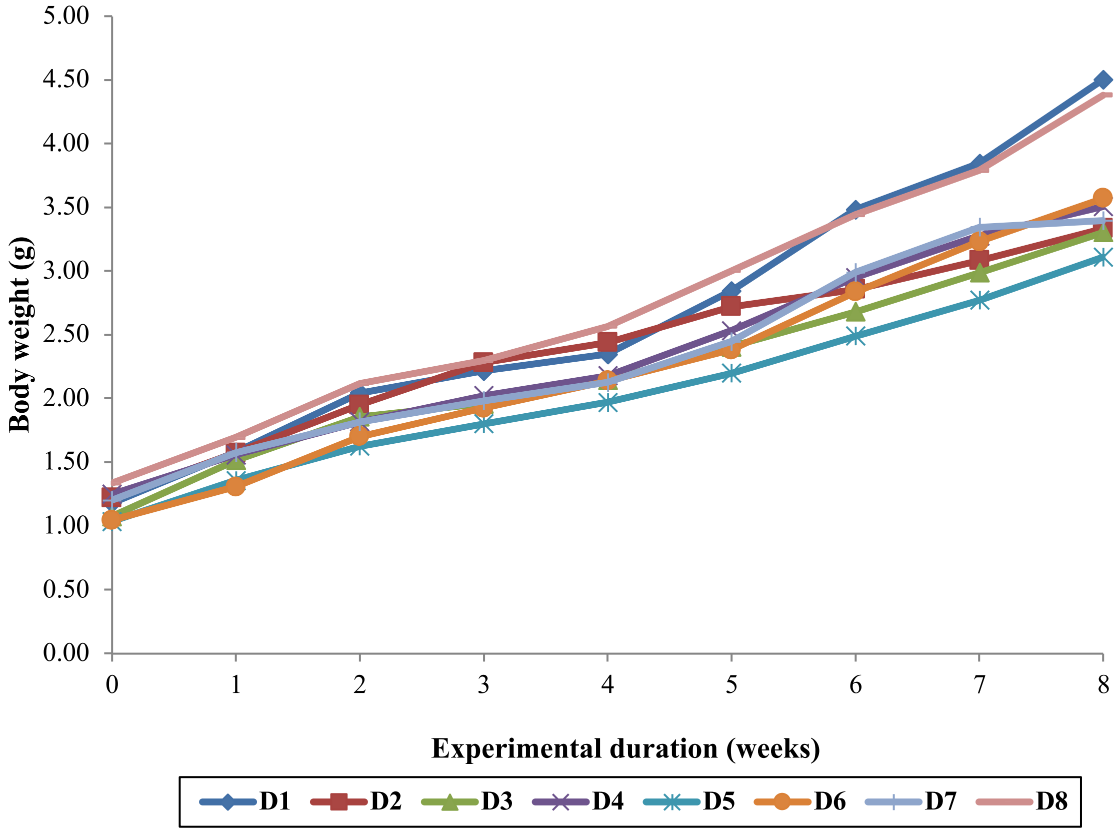

Figure 1: Growth Pattern of Nile Tilapia fed HMM and MLM Diet

Table 6: Growth Performance and Nutrient Utilization of *Oreochromis niloticus* fed diets containing different inclusion levels of housefly maggot meal and Moringa leaf meal

Parameter	D1 (CON 1)	D2 (CON 2)	D3	D4	D5	D6	D7	D8
	0% HMM, 0%MLM	5% FM, 40% SBM	15%HMM, 50%MLM	25%HMM, 45%MLM	30%HMM, 30%MLM	35%HMM, 20%MLM	40%HMM, 10%MLM	45%HMM, 0%MLM
IWT (g)	1.18 ± 0.10	1.22 ± 0.09	1.08 ± 0.10	1.25 ± 0.10	1.04 ± 0.09	1.05±0.09	1.20±0.09	1.34±0.10
FWT (g)	4.50 ± 0.23^{a}	3.3.3 ± 0.22^{bc}	3.30 ± 0.22^{bc}	3.51 ± 0.24^{abc}	3.11 ± 0.21^{c}	3.57 ± 0.21^{abc}	3.40 ± 0.22^{bc}	4.38 ± 0.23^{ab}
WTG (g)	3.32 ± 0.25^{a}	2.11 ± 0.23^{b}	2.23 ± 0.24^{ab}	2.26 ± 0.25^{ab}	2.07 ± 0.23^{b}	2.52±0.23^{ab}	2.19 ± 0.23^{ab}	3.04 ± 0.24^{ab}
ADG (g $fish^{-1}$ day^{-1})	0.059 ± 0.002^{a}	0.037 ± 0.002^{bc}	0.046 ± 0.002^{bc}	0.039 ± 0.002^{c}	0.040 ± 0.002^{c}	0.050 ± 0.002^{c}	0.042 ± 0.002^{c}	0.054 ± 0.002^{ab}
SGR (% day^{-1})	2.91 ± 0.104^{a}	2.54 ± 0.104^{abc}	2.81 ± 0.104^{ab}	2.55 ± 0.104^{c}	2.59 ± 0.104^{abc}	2.69 ± 0.104^{abc}	2.45 ± 0.104^{bc}	2.56 ± 0.104^{abc}
FI (g $fish^{-1}$ day^{-1})	0.12 ± 0.003^{ab}	0.11 ± 0.003^{bc}	0.10 ± 0.003^{cd}	0.11 ± 0.003^{bc}	0.09 ± 0.003^{d}	0.10 ± 0.003^{cd}	0.109 ± 0.003^{bcd}	0.127± 0.003^{a}
FCR	2.34 ± 0.06^{c}	2.73 ± 0.06^{bc}	2.55 ± 0.06^{abc}	2.83 ± 0.06^{a}	2.73 ± 0.06^{bc}	2.46 ± 0.06^{bc}	2.84 ± 0.06^{a}	2.56 ± 0.06^{abc}
PER	1.64 ± 0.08^{a}	1.42 ± 0.08^{a}	1.60 ± 0.08^{a}	1.27 ± 0.08^{a}	1.48 ± 0.08^{a}	1.52 ± 0.08^{a}	1.42 ± 0.08^{a}	1.43 ± 0.08^{a}
Survival (%)	98.33 ± 0.96^{a}	92.08 ± 0.96^{c}	95.41 ± 0.96^{abc}	99.16 ± 0.96^{a}	92.91 ± 0.96^{bc}	98.75 ± 0.96^{a}	98.75 ± 0.96^{ab}	97.91 ± 0.96^{a}

^{abc} Means with different superscript letter in the same row are significantly different at $p<0.05$.
IWT = initial weight, FWT = final weight, ADG = average daily gain, SGR = specific growth rate, FI = fed conversion ratio, FCR = food conversion ratio, PER = protein efficiency ratio. Values represent the mean and standard deviation.

Table 4: Water Environment Parameters During the Feeding Experiment

Diet	Parameter		
	pH	**DO (*ppm*)**	**Temp (°C)**
D1 (CON 1, FM)	6.94 ± 0.07^{ab}	6.26 ± 0.05^{a}	24.00 ± 0.01^{a}
D2 (CON 2, SBM)	6.76 ± 0.07^{b}	6.27 ± 0.05^{a}	24.07 ± 0.01^{a}
D3 (15%HMM/50%MLM)	6.83 ± 0.07^{ab}	6.24 ± 0.05^{a}	24.01 ± 0.01^{a}
D4 (25%HMM/45%MLM)	7.15 ± 0.07^{a}	6.32 ± 0.05^{a}	24.07 ± 0.01^{a}
D5 (30%HMM/30%MLM)	6.92 ± 0.07^{ab}	6.26 ± 0.05^{a}	24.05 ± 0.01^{a}
D6 (35%HMM/20%MLM)	6.75 ± 0.07^{b}	6.16 ± 0.05^{a}	24.03 ± 0.01^{a}
D7 (40%HMM/10%MLM)	6.83 ± 0.07^{ab}	6.31 ± 0.05^{a}	24.07 ± 0.01^{a}
D8 (45%HMM/0%MLM)	6.82 ± 0.07^{ab}	6.11 ± 0.05^{a}	24.02 ± 0.01^{a}

^{abc} Means with different superscript letter in the same column are significantly different at $p<0.05$.
DO = dissolved oxygen, Temp = temperature, FM = fishmeal, SBM soybean meal, CON1 = control 1, CON 2 = control 2.

Experiment 3 - Determination of the appropriate strategy for minimizing feeding cost

Figure 2 shows the growth performance of Nile tilapia reared under different treatments. Fish under treatment T_3 showed higher ($p \leq 0.05$) growth performance than those on T_1, T_2 and T_4. The differences in fish body weight between the fish under T_3 and those under T_1, T_2 and T_4 were obvious just from the second week of the experiment. The results in Table 9 show that the mean final body weight, weight gain, average daily gain and specific growth rate of fish reared under T_3 were significantly higher than of those under T_1, T_2 and T_4. But fish under T_1, T_2 and T_4 did not differ significantly in terms of mean final body weight, weight gain, average daily gain and specific growth rate, though those under T_1 had the lowest values. The highest feed intake was observed on fish under T_2, followed by those under T_3; while those under T_1 had the lowest feed intake. Feed conversion ratio (FCR) of fish under T_1 was significantly lower compared to that of those under T_2, T_3 and T_4. On the other hand, the fish reared under T_2 had significantly higher FCR than those under T_3 and T_4. Fish under T_1 had significantly higher protein efficiency ratio (PER) while those under T_2 had lower PER than those under T_3 and T_4. The survival rate did not differ significantly among the fish reared under different treatments, though the fish under T_2 showed the highest survival rate while those under T_1 had the lowest. The mean ± s.e. values for water quality parameters were: pH = 7.63±0.1, dissolved oxygen (DO) = 7.03±0.3 mg/l and temperature = 26.21±0.32°C.

Table 10 shows estimated yield, feed cost, fingerling cost, labour cost, total variable cost, revenue and gross margin obtained from the fish cultured under different feeding levels and frequencies. Fish cultured under T_3 showed the highest fish yield, revenue and gross margin while those under T_1 showed the lowest fish yield and revenue. The highest feed cost and total variable cost were observed on fish under T_2 while the lowest were found on T_1.

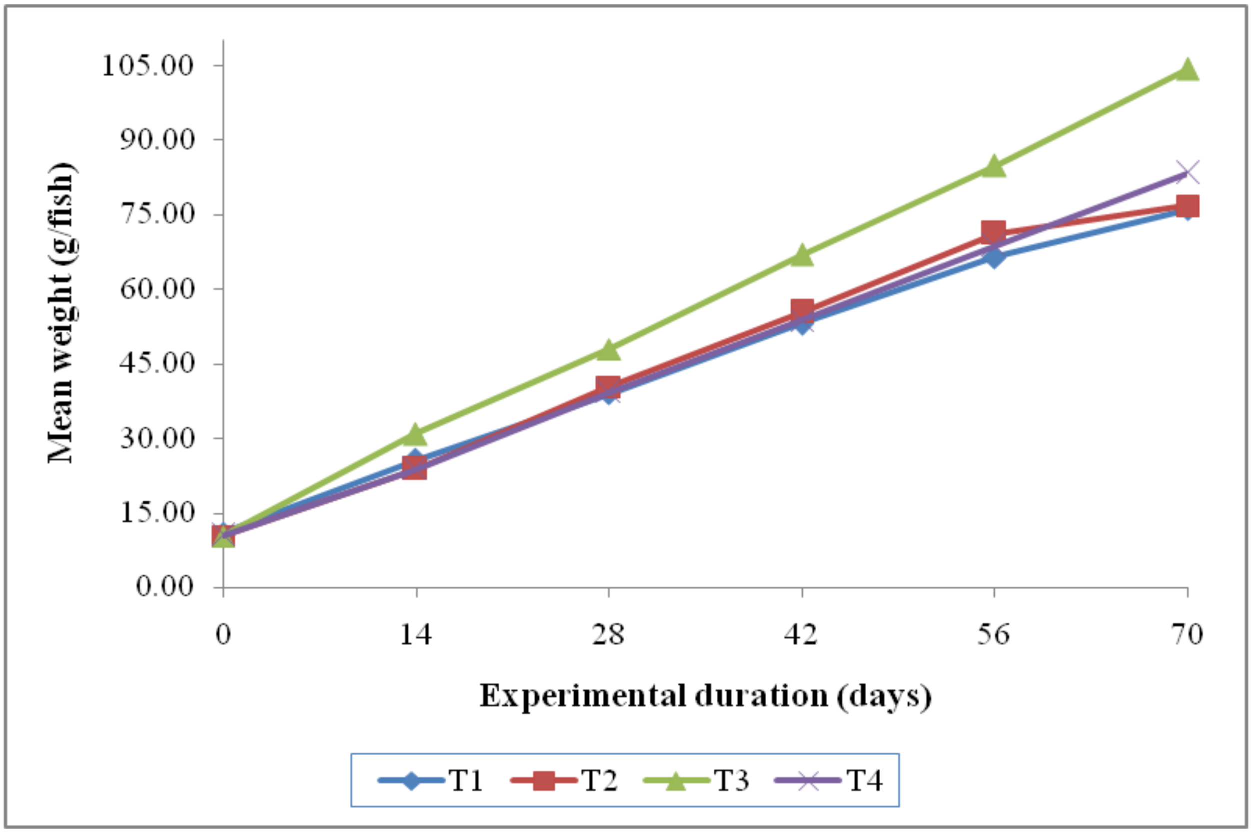

Figure 2: Growth performance of *O. niloticus* subjected to different feeding levels and frequencies

Table 9: Effect of feeding level and frequency on growth performance, feed utilization and survival of *O. niloticus*

Parameter	Treatments					
	T_1	T_2	T_3	T_4	SEM	*P-value*
Initial weight (g)	10.80	10.20	10.29	10.41		-
Final weight (g)	75.96^{b}	76.72^{b}	104.22^{a}	83.33^{b}	3.48	0.0038
Weight gain (g)	65.17^{b}	66.52^{b}	93.92^{a}	72.91^{b}	3.46	0.0036
Average daily gain (g/day)	1.22^{b}	1.26^{b}	1.60^{a}	1.30^{b}	0.07	0.0036
Specific growth rate (%/day)	4.22^{b}	4.39^{b}	5.13^{a}	4.31^{b}	0.13	<0.0001
Feed intake (g/day)	0.90^{c}	1.86^{a}	1.67^{a}	1.36^{b}	0.06	<0.0001
Feed conversion ratio	0.86^{c}	1.68^{a}	1.15^{b}	1.23^{b}	0.04	<0.0001
Protein efficiency ratio	0.84^{a}	0.41^{c}	0.67^{b}	0.58^{b}	0.05	<0.0001
Survival rate (%)	86.66^{a}	96.66^{a}	93.33^{a}	90.00^{a}	5.77	0.6588

[abc] Means with different superscript letter within the same row are significantly different at $p \leq 0.05$.

Table 10: Comparison of feed cost, revenue and gross margin obtained from fish cultured under different feeding levels and frequencies

Variable	Treatment (mean)			
	T_1	T_2	T_3	T_4
Estimated yield (kg/ha/year)	8,777.6	9,888.4	12,969.6	9,999.60.6
Revenue (TZS)	78,998,400.0	88,995,200.0	116,726,400.0	89,996,400.0
Fingerlings costs (TZS)	11,111,111.1	11,111,111.1	11,111,111.1	11,111,111.1
Feed cost (TZS)	11,469,920.0	25,974,666.7	22,635,262.2	17,400,631.1
Labour cost (TZS)	4,500,000.0	4,500,000.0	4,500,000.0	4,500,000.0
Total variable cost (TZS)	27,081,031.1	41,585,777.8	38,246,373.3	33,011,742.22
Gross margin (TZS)	51,917,368.89	47,409,422.2	78,480,026.67	56,984,657.8

DISCUSSION

Determination of the most suitable substrate for maggot production

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Maggot, the larvae of the domestic fly (*Musca domestica*) has ability to grow on a large range of substrates. This study assessed the suitability of five substrates for production of maggots. The results indicate that the highest yield of maggots was obtained from cattle offal, followed by chicken manure. Despite the fact that cattle offal produced higher quantity of maggots than chicken manure, chicken manures seem to be the most suitable substrate for culturing housefly maggots because they are readily available and can be obtained at no cost. The findings in this study agree with Odesanya *et al.* (2011) and Ezewudo *et al.* (2015) who reported that chicken droppings are the most suitable substrate for production of housefly maggots. In the present study the use of chicken manure as attractants for houseflies and substrate for culturing the resulting maggots produced significantly large quantity of maggots, almost double, compared to pig manure, cattle manure and kitchen leftovers. This may be due to higher content of nitrogen in chicken manure compared to cattle and pig manure. The observation in the present study is in agreement with Obeng *et al.* (2015) who reported that poultry waste is a better substrate for production of maggots.

Determination of the appropriate levels of substituting fishmeal and soybean meal with Moringa leaf meal and housefly maggot meal

Maggot meal has been reported to be a promising alternative to the expensive protein sources as it has good nutritional value and cheaper compared to other animal protein sources. The results in this study show that maggot meal had higher crude protein content than soybean meal and Moringa leaf meal, but lower than that of fish meal. This shows that maggot meal is better source of protein than soybean and Moringa leaf meals. The CP content of maggot meal observed in this study is almost similar to the CP values of 47.1 and 48.0% reported by Aniebo *et al.* (2008) and Odesanya *et al.* (2011), respectively, but lower than the CP value of 64.0% reported by Hwangbo *et al.* (2009). The high CP content implies that maggot meal has high nutritive value and can provide the amount of protein required by Nile tilapia for proper growth. The values crude fibre, fat and ash contents obtained in this study are close to that reported by Odesanya *et al.* (2011) and Aniebo *et al.* (2008).

The results of a feeding trial show that fish fed the diet based on maggot meal (D_8) as the main source of protein had body weight gain, growth rate and FCR that were not significantly different from that of fish fed diet based on fishmeal as the source of protein (D_1). This observation is in agreement with the findings of Ogunji *et al.* (2006), who suggested that maggot meal can completely replace fishmeal in the diet of Nile Tilapia (*Oreochromis niloticus*) and can meet the nutrient requirements of this species. Makinde (2015) recommended that the inclusion of maggot meal in fish diets should be limited to 25-30% as performance tends to decrease when higher inclusion levels are used. In the present study the percentage of maggot meal was increased from 0, 15, 25, 30, 35, 40 to 45% of the diet and growth performance and FCR were better at the inclusion level of 45%, almost comparable to the control diet based on fish meal. At inclusion level of 45%, fishmeal was replaced with maggot meal in diet D_8 by about 86% and the growth performance and survival did not differ significantly from that of the diet containing 100% fishmeal. This demonstrates that maggot meal is an ideal protein source and can completely substitute fishmeal. Sogbesan *et al*. (2006) evaluating the use of maggot meal in the diet of *Heterobranchus longifilis* x *Clarias gariepinus* hybrids concluded that 100% replacement of fishmeal with maggot meal is an economically viable option.

Soybean has been identified as most attractive plant protein source, palatable to most fish species and can successfully replace fishmeal up to 75% (El-Sayed, 1999). When comparison is made between maggot meal and soybean meal in the current study, fish fed the diet based on maggot meal (D_8) as the source of protein had higher growth performance and better FCR than those fed the soybean meal based diet (D_2). Maggot meal had higher crude protein content than soybean meal, thus fish fed diets based on maggot meal showed faster growth. This indicates that maggot meal is a better source of protein than soybean meal and can be used to replace fishmeal in fish diets.
The present study evaluated the effects of including different combination levels of Moringa leaf meal and maggot meal in Nile tilapia diets. Despite its high nutritional quality, inclusion of Moringa leaf meal in the diet significantly reduced the growth performance and feed utilization. The lower growth performance of the fish fed diets containing Moringa leaf meal may due to the relatively low protein content as the CP content of Moringa leaf meal was significantly lower than that of fishmeal, soybean meal and maggot meal. This could be indicate ineffectiveness of method used to remove inherent anti-nutritional factors namely tannins, trypsin and amylase inhibitors, lectins, cyanogenic glucosides, saponins, phenols and phytic acid. These are known to reduce palatability, intake and nutrient bioavailability from Moringa leaf meal (Makkar and Becker, 1996; Makkar and Becker, 1997; Afuang *et al*., 2003).Richter *et al*. (2003) showed that saponins and tannins can reduce growth in *Oreochromis niloticus*. Thus, there is a need to devise more effective methods of removing inherent anti-nutritional factors to enable its use as a protein source in tilapia diets.

Determination of the appropriate strategy for minimizing feeding cost
Feed is the highest variable cost in aquaculture enterprise. Therefore, it is important to establish a strategy for using appropriate amount of feed in order to reduce waste and increase profit (Ali *et al*., 2016). This study compared the growth performance, feed cost and gross of margin of fish reared under the treatments of daily feeding at 2.5% of fish weight (T_1), daily feeding at 5% of fish weight (T_2), one day alternating feeding at 2.5 and 5% of fish weight (T_3), two days alternating feeding at 2.5 and 5% of fish weight. The results indicate that fish cultured under T_3 showed better growth, feed utilization and gross margin compared to fish under other treatments. Thus alternating the feeding levels of 2.5 and 5% of fish body weight in consecutive days is the appropriate feeding strategy for minimizing cost. Feeding level of 5% of body weight daily was probably excessive and resulted in most of the feed being left uneaten. This uneaten feed decayed and polluted the water and thus retarded growth. On the other hand, daily feeding at 2.5% of the body weight resulted into inadequate feeding. It appears that at the feeding level of 2.5% of body weight, a large proportion of nutrient in the diet was used to meet maintenance requirements, and only a small proportion was available for growth and this retarded growth of the fish. The relatively lower (better) FCR obtained on fish under T_3 confirms that alternating the feeding levels of 2.5 and 5% of fish body weight for one day is the best feeding strategy. This agrees with Dwyer *et al*. (2002) who said that feed efficiency and growth are decreased when fish are either inadequately or over fed. The findings of the current study contradict the findings of Deyab and Hussein (2015) who suggested that feeding rate of 5% of body weight daily significantly enhances fish growth and feed utilization and can be considered as the optimal feeding rate for red tilapia fingerlings. Also the findings of this study disagrees with the findings of Abdelghany and Ahmad (2002) who reported that feeding to apparent satiation (feed amount of equivalent to 2.67% of fish body weight per day) supports higher fish production, income and net profit and hence, it is the appropriate optimal feeding level.

Although feed cost was significantly lower for the fish cultured under T_1, gross margin was higher in fish under daily alternate feeding of 2.5 and 5% of body weight than those fed daily on either 2.5 or 5% of body weight. According to Bolivar and Jimenez (2006) alternate day feeding reduces production costs of tilapia without significantly affecting performance as it uses almost 50% less feed compared to fixed daily feed ration. In the present study, alternating the feeding rate between 2.5 and 5% of body weight every two days, though lowered feed cost, it negatively affected growth and subsequently yield at harvest. This led to lower revenue and profit than alternating daily feeding of the two levels. Therefore, this study has found that daily alternating feeding levels of 2.5 and 5% of body weight daily is a better feeding strategy for cost minimization and profit maximization.

CONCLUSIONS

Generally, fish fed fishmeal based diet (D_1) showed the highest growth performance, followed by those fed housefly maggot meal based diet (D_8) while those fed the diet containing 30% housefly maggot meal and 30% Moringa leaf meal had poor performance. The study has demonstrated that housefly maggot meal alone can replace fish meal as the source of protein in the diets for Nile tilapia. The lack of significant difference in protein efficiency ratio values between the diets containing fishmeal and maggot meal implies that maggot meal has biological value almost equivalent to fishmeal. Furthermore, this study has demonstrated that alternating feeding levels of 2.5 and 5% of fish weight (T_3) daily is the best feeding strategy and can be used to increase the profitability of aquaculture enterprise. Based on the results from this study, the following conclusions can be made:-

i. Chicken manure is a better substrate than both cattle manure and pig manure for production of housefly maggots.
ii. Increasing the quantity of chicken manure in the facilities for production of maggots can increase significantly the yield of maggots.
iii. Housefly maggot meal has higher protein content and promotes better growth performance than soybean meal.
iv. Housefly maggot meal alone can be used to replace fish meal in the diets without affecting the growth performance of Nile tilapia.
v. Mixture of housefly maggot meal and Moringa leaf meal gives better growth performance compared to soybean meal, hence, can be used in tilapia diets instead of soybean meal.
vi. Alternating feeding levels of 2.5 and 5% of body weight on consecutive days is the most appropriate feeding strategy for Nile tilapia compared to continuous daily feeding at either 2.5 or 5% of body weight.

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