A comparative study of the effects of pelleted and extruded feed on growth, financial revenue and nutrient loading of Nile tilapia (*Oreochromis niloticus* L.) cage culture in a lacustrine environment

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ABSTRACT

We compared the benefits of using extruded feed (EF), against pelleted feed (PF) to guide cage culture investments in Great Lakes. Three out of six cages in the same farm had fish that were fed EF and the other half, belonging to a different farm had fish that were fed PF. The diets were similar in crude protein, lipid and energy content. However, the fiber content in PF was 4 times higher than that of EF. The fish fed on EF grew better (438.0 ± 7.4 g) than the fish fed on PF (220.8 ± 2.9 g). The cost of production for EF was about 26% lower than for PF, primarily because of better feed utilization. The load of P and N for PF diet was 59% and 29% higher, respectively, than when EF was used. Therefore, EF feed delivered better economic gains with lower environmental impact than PF feed.

KEYWORDS: Cage culture; Nile tilapia (*Oreochromis niloticus*); cost of production; market channels; pellet stability; nutrient load.

Introduction

In recent years, open cage culture has increased in African freshwater lakes and reservoirs (Blow and Leonard 2007; Gondwe et al. 2011; Musinguzi et al. 2019; Hamilton et al. 2020). In Lake Victoria, the total number of cages, primarily in the Kenyan portion, increased from 1663 to 4357 between 2018 and 2019 and further growth is expected (Njiru and Aura 2019; Hamilton et al. 2020). The main species produced is Nile tilapia *Oreochromis niloticus* (Aura et al. 2018; Njiru et al. 2018), grown in small (8 m^3) cages. The grow-out period takes 6-8 months and most farmers have only one production cycle per year, since turnover in the lake, occurring between August and October, may cause heavy mortalities (KMFRI 2016). The preferred market size of Nile tilapia around the L. Victoria basin is >400 g, with sales prices per kilogram of fish varying between market sections (KMAP 2016).

As is common practice in Africa, most of the cage fish production is bought by agents who transport the fish, chilled, to retailers in major cities (KMAP 2016; Awuor et al. 2019). Many farmers prefer this route to market because the agents pay cash immediately. A second sales channel is through wholesalers who resell the fish to retailers and/or directly to consumers at the local markets. Here, the wholesaler pays for the fish up to a week later. Finally, a small fraction of the production is bought directly by consumers at the landing site. The farmgate price for tilapia in sub-Saharan Africa is relatively low, due to the limited purchasing power of the local buyers and because of competition with cheaper frozen tilapia imported from China (Awuor et al. 2019). Since there is little direct contact between farmers and consumers the price is determined primarily by the intermediaries. As a result, profit margins of fish farms are narrow.

Globally, aquaculture practices and studies have shown feed costs to represent half or more of production costs and are, therefore, an important factor in determining the economic outcome for fish farms (Watanabe 2002; El-Sayed 2006; Cheng et al. 2010; Khalil et al. 2019; Allam et al. 2020; Musa, Aura and Okechi 2021). However, there is limited information available on the production cost of cage aquaculture in the Great Lakes region. Most fish farmers in the developing countries and in the Great Lake region rely on locally made pelleted feed (PF) rather than more expensive factory made extruded feed (EF) (Charo-Karisa et al. 2013; Aura et al. 2018). However, low-cost feeds may not be the most economically viable when growth rate and feed conversion are taken into account. A number of studies have addressed feed development for tilapia in the developing countries (e.g. Liti et al. 2005; 2006; Munguti et al. 2006; Munguti et al. 2009; Mugo-Bundi et al. 2015; Kubiriza et al. 2017; Opiyo et al. 2019; Kirimi et al. 2021; Chepkirui, 2021). However, none of these compared the growth performance of tilapia and the effect on farm economics when either PF or EF were used in cage culture. In the absence of a scientific study to compare the two types of commercially produced pellets under cage culture conditions, there is scant information for tilapia producers within the Great Lakes region on which feedstuff they should use and producers normally buy the affordable pelleted feed available in the market. Whether pelleted or extruded feed types provide better culture performance and cost efficiency when *O. niloticus* is reared in net cages remains to be validated.

Feed quality can also affect the environmental impact of cage aquaculture (Wu et al. 1999; Musinguzi et al. 2019). Pellets that disintegrate quickly can increase water turbidity, and nitrogen (N) and phosphorus (P) released from uneaten feed and faeces (Brinker and Rosch 2005) causes eutrophication problems. There is a paucity of information on the environmental impact of cage aquaculture in eutrophic, freshwater lakes such as Lake Victoria. Thus, the objective of this study was to compare the revenue, performance, stability and nutrient loads when using PF and EF in cage aquaculture.

Materials and methods

Study Area

The study was conducted at four commercial fish farms at Anyanga beach, Kadimo Bay in the Nyanza Gulf, northern Lake Victoria, Kenya (Fig. 1) from December 2018 to July 2019. Kadimo Bay was chosen for the study as it is one of the main centers of aquaculture in Lake Victoria (Aura et al. 2018; Hamilton et al. 2020). The farms are under separate ownership but are managed by a single company until harvest, with the same people feeding and looking after the fish in all farms. Therefore, we assumed that management practices were similar in all farms, except for the feed used. The farms had fish in 600 cages (2 m × 2 m × 2 m) and each cage was stocked with 2000 tilapia (average initial body mass 15 g). The juveniles for all of the farms were sourced from the Lakeview fisheries hatchery in Homa-bay county. Out of the 600 cages, 402 cages were fed on EF and 198 cages fed on PF. Throughout the culture period, all groups were hand-fed to near satiation twice a day. Due to limitations of financial and capital resources, three cages feeding on PF and three fed EF were randomly selected for growth, feed use and nutrient loading monitoring. However, harvest and sales data were collected from all of the cages at the study site.

The PF was obtained from local artisanal feed producers while the EF was produced by a feed mill, with all of the farms using EF or PF relying on the same source throughout the production cycle. All pellets were 3 mm in diameter. The crude protein of the two diets was similar even though the ingredients varied (Table 1). Data for ingredients and formulations used for EF and PF production was obtained by interviewing the investors of the various companies, while the costs of ingredients was set according to market prices at the time of the survey.

Proximate composition of feeds

The proximate composition of the diets was analyzed using standard methods (AOAC 1995). Crude protein (CP) was estimated as N × 6.25, after determining nitrogen (N) content of the samples using micro-Kjeldahl analysis (AOAC 1995). Lipids were extracted using a Soxhlet apparatus (Soxtec T 2050 Avanti Extraction Unit). Moisture was determined by drying samples in an oven at 105 °C for 24 hours and ashing them by combustion for 8 hours in a muffle furnace at 550 °C. Crude fiber was quantified by alkaline/acid digestion followed by ashing at 550 °C in a muffle furnace for 4 hours. Soluble carbohydrates (Nitrogen Free Extract; NFE) of the feed was calculated in grams as: NFE = DM – (Ether extract (EE)+CP+CF+ash). Gross energy of the diets was determined using an adiabatic bomb calorimeter (1241, Parr Instrument Company, Moline Illinois-USA) and was calculated in terms of the energy content of nutrients: EE 39.5; CP 23.6; CF and NFE 17.3 MJ kg^{-1} respectively (Halver and Barrows 1972). For amino acid determination, samples were hydrolyzed with 6 M HCl at 110 °C for 24 hours. Sulphur-containing amino acids (cysteine and methionine) were oxidized using performic acid before acid hydrolysis. Amino acids were separated using reverse phase HPLC and quantified following post-column derivatization within ninhydrin. All analyses were performed in triplicate.

Sampling, growth assessment, survival and feed efficiency

At the beginning of the experiment, fish were randomly sampled with a scoop net, 90 fish per cage. The fish were individually weighed and measured. Identical measurements were performed on days 90 and 180. Feed use was weighed and recorded daily and feed intake was calculated as grammes of feed per fish. Mean weight gain (g), specific growth rate (SGR), survival and apparent food conversion ratio (AFCR) were estimated as follows:

WG = Final mean body mass – initial mean body mass

$$SGR(\%\ day^{-1}) = 100 \cdot \frac{\ln W_f - \ln W_i}{d}$$

Where W_i and W_f are the mean initial and final body mass respectively, d is the number of days between measurements and ln is the natural logarithm.

$$Survival\ (\%) = 100 \cdot \frac{Final\ number\ of\ fish}{Initial\ number\ of\ fish}$$

$$AFCR = \frac{Weight\ of\ feed\ presented}{Increase\ in\ body\ mass}$$

Protein Efficiency Ratio (PER) was calculated by dividing the fish weight gain by the total amount of protein ingested during the experiment. Total protein ingested was estimated from the daily feed ration multiplied by the protein content of the diet

$$PER = \frac{Wet\ weight\ gain\ (g)}{Total\ protein\ ingested\ (g)}$$

Protein productive value (PPV) was calculated using the following formula:

$$PPV\ (\%) = 100x\,\frac{protein\ gain\ (g)}{protein\ intake\ (g)}$$

Gross and net fish yields were calculated using the following formulae:

$$Gross\ yield = Number\ of\ survivors\ x\ average\ final\ weight\ of\ fish$$

$$Net\ yield = Total\ biomass\ at\ harvest - total\ biomass\ at\ stocking$$

Cost of production

The cost of each diet was estimated using ingredient costs and inclusion levels (Table 1). Furthermore, feed cost per kilogramme of fish produced was computed as follows:

$$Feed\ cost\ (USD \cdot kg^{-1} fish) = \frac{Cost\ of\ feed\ presented}{Increase\ in\ biomass}$$

The economic analysis of cage culture with the two different feeds followed the methods described in Shang (1985). The owners answered a structured questionnaire to establish the costs of capital (cage and equipment), material (seed, feed, etc.) and labour. Based on a survey carried out on all the establishments at Anyanga Beach, the average cost of a 2 m × 2 m × 2 m cage equipped with nets was estimated at USD 162.5. Given a depreciation period of 10 crops, the amortized cage cost was USD 16.25 per cage/per crop. Cage farms need basic equipment and tools (weighing balance, feeding accessories, life jacket) worth about USD 50 per cage. Given a depreciation period of 10 crops, the amortized cost of equipment and tools is estimated at USD 5 per cage per crop. The average price of juveniles was USD 0.05 each but a discount is given on large seed consignments with the price of juveniles being set at USD 0.03 each. The average market price of feed was USD 0.80 kg^{-1} and USD 1.1 kg^{-1} for the PF and EF, respectively. However, large feed consignments received discounts of up to 30% on feed costs. The discounted cost of management was USD 3 $cage^{-1}$ $month^{-1}$. Due to close proximity of the cages to the shoreline (< 150 m), the owners paddle their boats to the cages and, hence, they do not incur any fuel cost in most cases, however, fuel cost is part of management costs. Economic analysis was carried out for one production round per cage for EF and PF.

Feed stability

To measure the stability of feed in water, ten pellets of each feed type were weighed and placed in a 50 mL conical bottom centrifuge tube containing 40 mL of water. The tubes were placed horizontally in a shaking (about 72 cycles min^{-1}) water bath (Magni Whirl, Blue M, Blue Island, IL, USA). After 2 hours, the content of each tube was filtered using a standard 8-mesh sieve and the feed material retained by the sieve was placed in a pre-weighed aluminum dish, dried in a forced air oven at 100 °C for 4 h and then weighed. The relative difference in dry mass before and after 2 h soaking and shaking compared to the original sample dry mass was calculated as percent solid loss as indicated below:

$$Solid\ loss\ (\%) = 100 \cdot \frac{dry\ mass\ of\ feed\ before\ soaking - dry\ mass\ of\ feed\ after\ soaking}{dry\ mass\ of\ feed\ after\ soaking}$$

Estimation of the nitrogen (N) and phosphorus (P) waste from cage culture of Nile tilapia using EF and PF

The amount of N and P released from fish production was estimated based on the difference between the amount of N and P in the feed provided and what was retained in the fish. The body composition of the Nile tilapia was determined from the processing and analysis of five fish per cage from two cages for each feed type with a slaughter weight similar to the final average weight. The analyses were performed in triplicate. The fish were removed alive from the growth site, anaesthetized, placed in a container with ice and transported to the laboratory. The whole fish (including viscera, blood, skin and scales) were homogenized, and the body composition determined by proximate chemical analyses, according to the Association of Official Analytical Chemists (AOAC 2012).

Estimation of nutrient loads in wastes of cage culture

The P concentrations (as a percentage of wet weight) of feed and fish was determined by the molybdate-ascorbic acid method after persulfate digestion of ashed samples (Stainton et al. 1977). The nutrient loads in the wastes from production of Nile tilapia grown in cages was estimated according to the methodology described by Ackefors and Enell (1994). To quantify the amount of waste generated by cage culture, mass balance was calculated to estimate the approximate level of P and N added to the environment for every ton of fish produced based on actual FCR and the N and P contents of the feeds and fish. The total nutrient load was calculated as the difference between the amount N and P in feeds and the nutrient retention in fish at harvest. The following parameters were analyzed according to the equations:

$$\text{N load (kg N)} = [(\text{Feed x Feed}_N) - (\text{Fish x Fish}_N)]$$

$$\text{P load (kg P)} = [(\text{Feed x Feed}_P) - (\text{Fish x Fish}_P)]$$

Where:

Feed = Total feed used during the experiment

Fish = Wet weight of fish produced per harvest

Feed_N = N content of the feed

Feed_P = P content of the feed expressed as the percentage of dry weight

Fish_N = N content in fish

$Fish_P$ = P content of the fish expressed as the percentage of wet weight.

N and P loading from the production of 1 ton of fish = [(Total feed used during the experiment) x ($Feed_{N\ or\ P}$)] – [(1ton fish x $Fish_{N\ or\ P}$)]

Statistical analysis

The program STATISTICA version 8.0 was used for statistical analyses. The effect of experimental diets on growth (using average fish weight for each cage), survival and FCR were compared using analysis of variance (One-way ANOVA). Values throughout the text are expressed as mean ± standard error. The fiducial limits for accepted significance were $P < 0.05$.

Results

Proximate composition of feeds

The quoted crude protein content (CP) of the EF and PF by the producers were similar (32%). However, for both diets, the analyzed CP was lower than the values quoted, 28.2% for the PF and 30.1% for the EF (Table 2), but the difference between the two feed types was not significant ($P = 0.243$) (Table 2). Furthermore, there was no significant difference in the energy and lipid contents of the two diets (Table 2). For the most part, both diets appear to have met the essential amino acid requirements (NRC 2011) of tilapia except for methionine which was 19% and 4% below recommended levels in the PF and EF diets respectively (Table 3). The PF diet was also 5-6% deficient in lysine, phenylalanine and valine. The crude fiber content of the PF diet was four times higher than that of the EF.

Growth, survival and feed efficiency

At the end of the six-month grow-out period, the mean weight and weight gain of the fish fed EF was more than double ($P < 0.0001$) that of the fish fed PF (Table 4, Fig. 2). Similarly, the SGR of the fish fed EF was 1.9 times higher than for the fish fed PF ($P < 0.001$). The fish fed EF grew well during the entire period while the growth rate of the fish fed PF declined during the second half of the experiment (Fig. 2). The average survival rate was 95% for the fish fed EF and 91% for fish fed PF but the difference between the two groups was not statistically significant ($P = 0.134$) (Table 4). The AFCR of fish fed EF was 43% lower ($P < 0.001$) than that of the fish fed PF. Feed intake was significantly higher ($P < 0.001$) for fish fed EF than for fish fed PF (Table 4). Notably, PER, PPV were highest ($P < 0.0001$) in EF as compared to PF. Gross and Net yield were significantly higher ($P < 0.0001$) in groups fed EF than fish fed PF (Fig. 3).

Cost of production

The price of raw materials for EF (per kg) was 34.3% higher than that for PF and, similarly, the market price of EF was 37.5% higher than that of the latter (Table 5). However, the AFCR of PF fish was 75% higher than that of EF fish (Table 4) and, as a result, feed cost (per kg of fish produced) was 18.5% lower than for the PF fish (Table 5). Due to smaller final size, the seed cost was more than double (per kg) when using PF than with using EF. The feed and juvenile costs were the largest components of the production costs and, combined, they were 28% higher when using PF compared to EF (Table 5). The total cost shown in Table 5 is the minimum, since cost items such as the labour contributed by the owner and financial costs are omitted. The latter may be significant since the interest rates in Kenya are almost 10%.

The estimated fixed costs of running one 8 m^3 cage through one production cycle are USD 46.16 (Table 6). This includes the cost of feeding and managing the production and harvesting, both of which are charged per cage and, therefore, counted within the fixed costs. The total production per cage was 401 kg and 861 kg for PF and EF fish, respectively. Therefore, fixed costs add 0.12 and 0.05 USD per kg to the production costs for PF and EF, respectively. The total production costs were 34% higher when PF was used compared with EF (Table 5).

Agents were the main buyers of farmed tilapia (82%; n = 600). The average farm gate price paid by the agents was 1.55 USD kg^{-1} which is below the production cost when fish are fed PF. However, there may be a narrow profit margin when EF is used. The second largest group of buyers were wholesalers (12%) which paid 1.57 USD kg^{-1} at the farm-gate. This is not enough to cover production costs when PF is used, although farmers using EF may generate a narrow profit margin. Only 5% of the fish were sold directly to retailers and 1% to consumers who paid 2.57 and 3.07 USD kg^{-1}, respectively, at the farm-gate. Both of these market channels should return a profit, albeit higher for EF than PF.

Feed stability

The EF pellets floated better and were more stable in water than PF pellets (Fig. 4). The solid loss of PF (82%) was four times higher than EF ($P < 0.001$) after 2 hours of soaking and shaking.

Estimation of the N and P waste from cage culture of Nile tilapia

Although the composition of the feeds was similar, more N (126.0±1.0) and P (30.8±1.8) was provided through the feed (as kg ton^{-1} fish produced) when the fish were fed PF than EF diets (Table 7). Although the proximate composition of the fish fed either PF or EF was similar, the protein content of EF fish was higher (17.0%) and the lipid content lower (4.5%) than that of the PF fish (Table 8). More N (27.2 ± 0.5) and P (8.5 ± 0.6) was retained in EF (as kg ton^{-1}

fish produced) than in PF fish (Table 7). As a result, about double the amount of N (83.3%) and triple the amount of P (74.7%) were released into the environment when the fish were fed the PF.

Discussion

Insight into the economics and environmental impacts of the growing cage aquaculture have received unprecedented views globally. The evaluation in the use of extruded verses pelleted feeds has drawn a major debate on costs, quality and performance. For example, extruded floating feeds have been shown to exhibit better growth performance in several species (Ammar 2008; Chebbaki et al. 2010; Aba et al. 2012; Hematzade et al. 2013; Lee et al. 2016) but have shown no significant difference in some species (Misra et al. 2002; Limbu 2015; Muyot et al. 2018). Whether extrude or pelleted feed types provide better culture performance and cost efficiency on *O. niloticus* reared in net cages remains to be validated. Therefore, most farmers are hesitating on using extruded feeds due to cost implication. In the absence of a scientific study to compare the two types of commercially produced pellets for cage culture, tilapia producers in the Great Lakes region do not know which one to use and are normally inclined to buy the cheaper pelleted feed that are available in the market. Thus, the results of this study provide evidence-based data on the hidden cost of pelleted feed to guide the cage farmers and policy intervention in the Great Lakes region.

Growth and feed intake

The final size of the fish fed EF was about twice (453.0 ± 3.6 g) that of fish fed PF and the former maintained good growth rate during the entire growth cycle whereas the growth rate of the latter slowed down during the second half of the growth period (Fig. 2). This is interesting because the reported and measured proximate composition of the two diets were similar (Table 1,2). The dietary protein requirement for Nile tilapia is size dependent and the recommended CP levels for juveniles larger than 10 g is 25-35% (Balarin and Haller 1982; Tacon 1987; El-Sayed and Teshima 1991; Khattab et al. 2000). Both diets had CP (PF: 28%, EF: 30%) within this range (Table 2) and, similarly, the lipid content of both feeds (4.8%) was also in accordance with recommended levels (<10%) (Jauncey 2000). There was no difference in gross energy content (analyzed) of the two diets. Thus, with respect to energy content, CP and lipids both diets appeared to be suitable for tilapia. However, the difference in growth rate suggests that the quality of PF was inferior to that of EF and, indeed, there were differences between the diets. The high fiber content in PF was due to the greater inclusion of plant ingredients, which is in accordance with previous studies (Neto and Ostrensky 2014, Hueze et al. 2019). Sunflower seed, maize bran and wheat bran have been reported to have high fiber content (El-Sayed 2013; Oliveira et al. 2017); these ingredients formed the bulk of the plant protein in PF. Fiber content above 8-

12% is undesirable in fish feed because it reduces digestibility (De Silva and Anderson 1995; Leal et al. 2010) and this may have reduced the digestibility of the PF diet resulting in a lower growth rate. Digestibility of the diets was not measured directly in this experiment. However, the low NFE in PF indicates that the diet had less soluble carbohydrates and, therefore, lower accessible energy content than the EF diet.

Methionine is usually the first limiting AA in plant-based fish feeds (Furuya et al. 2004; Goff and Gatlin 2004; Belghit et al. 2014). Inclusion of soybean protein in both diets could have contributed to the methionine deficiency (Sadiku and Jauncey 1995) although less so in the EF as this was supplemented with methionine. An imbalanced AA composition in PF could have resulted in reduced protein synthesis, causing reduced growth of fish (Wilson and Halver 1986; Carter and Hauler 2000; Lupatsch et al. 2001; Silva et al. 2009; Belghit et al. 2014; Figueiredo-Silva et al. 2015) and higher FCR (Halver and Barrows 1972). Therefore, the decreased growth observed in fish fed PF could, in part, be due to methionine deficiency (Michelato et al. 2017).

The EF was supplemented with vitamins and minerals and this may have contributed to better growth performance (Halver and Barrows 1972; Kaushik and Seiliez 2010). Earlier studies suggest that supplementing diets with vitamins or minerals may not always improve the growth of Nile tilapia (Tacon et al. 1984; Liti et al. 2005). However, those studies were conducted in semi-intensive pond culture where fish rely partly on natural food rich in vitamins and minerals, which may compensate for inadequacies of micronutrients in the formulated feeds. Natural food also contains an abundance of high-quality protein, 55-60% on a dry weight basis (De Silva 1993). In cage culture, most, if not all, nutritional requirements must be met by the feed as there is little natural food available. Therefore, supplementing diets with vitamins, minerals and essential amino acids may be more important in cage than in pond culture.

The fish fed EF appear to use the feed more efficiently than those fed PF. The AFCR of fish fed EF was 43% lower than that of fish fed PF. The FCR in both groups (1.6 and 2.8) was within the range of those observed in other studies on Nile tilapia in pond culture (1.4-4.4) (Elsayed 1998; Al-Hafedh 1999; Liti et al. 2005, 2006; Kubiriza et al., 2017) and in tanks (1.2-2.03) (Liti et al. 2006) and (1.19-2.03) (Mugo-Bundi et al. 2015). Several factors could have contributed to this difference in AFCR including differences in the physical qualities of the feeds. In addition to deactivating anti-nutritional factors (Allan and Booth 2004; Barrows et al. 2007; Delgado and Reyes-Jaquez 2018), the extrusion process enhances the water stability and the floatation quality of EF (Fig. 3) and, therefore, this will have enhanced the accessibility of the pellets for the fish. This may in turn have reduced the AFCR (Barrows et al. 2007) of the EF fish and improved their growth (Hilton et al. 1981; Barrows et al. 2007). Another factor contributing to the difference in growth may have been differences in digestible energy although the crude energy content of the feed was the same. The high heat used in producing the EF diet, may have made carbohydrates more digestible and increased bioavailability of nutrients in general (Hilton et al. 1981; Barrows and Hardy 2000, Barrows et al. 2007; Venou et al. 2009). As a result, the digestible energy may have been higher in the EF than the PF diet (Barrows and Hardy 2000). These results suggest that, although the crude energy and protein content of both feeds were similar, the EF is superior to the PF and that the better quality of the EF diet results in superior growth. Variability in feed quality is another factor that was not taken into account in this study. Some of the differences between the quoted and analyzed CP in both diets could have been a result of variability in the quality or inaccuracy in chemical composition information provided for the ingredients used. For example, the CP of *Rastrineobola argentea*, which was used in both diets, may range between 530 and 700 g kg^{-1} and appears to vary with time of year and processing methods (Mugo-Bundi et al. 2015; Kubiriza et al. 2017). The local artisanal feed manufactures do not have the facilities to monitor the composition of the raw materials and do not adjust for variation in quality. Therefore, the composition of EF may be more consistent while the artisanal feed may vary more. The high feed intake recorded for fish fed EF could, most likely, be because these fish grew faster and consumed more feed. It could also be due to availability of feed for a longer period of time, thus increasing intake and reducing wastes (Barrows and Hardy, 2000). The PER of fish fed EF was higher than two, indicating efficient protein utilization due to increased levels of digestibility as a result of extrusion. A comparatively higher gross, as well as net, yield of tilapia in groups fed EF might be due to relatively higher consumption of feeds. This could also have been influenced by their significantly higher individual harvesting weight, individual weight gain, specific growth rate and survival. Optimum yields of 150 kg m^{-3} have been achieved in small cages (Schmittou 1991), an indication that all of the cages under investigation were operating below their optimum capacity, more so for the cages utilizing PF.

Cost of production

Many fish farmers in sub-Saharan Africa justify using artisanal feeds because they are less expensive than extruded feeds. However, the results of this study show that the production costs are lower when EF is used (Table 4). This is because feed conversion is better with EF, resulting in feed costs that are 18% lower (per kg fish produced) than when PF is used. Secondly, the final size of the fish fed PF was only half that of that fed EF. Therefore, juvenile costs are higher and minimum variable production costs are about 28% higher when PF is used compared to EF. The variable costs listed represent minimum costs since they neither include interest rates, which are high in Kenya (9% per year), nor labour costs. We have included labour costs with fixed costs (Table 5) since they are included in the management costs and are charged per cage. Due to the smaller final size of the fish fed PF, the fixed costs (Table 5) are assumed to be about twice as high for farms using PF. This is because twice as many cages are required for the same level of production because the PF fish are only half as big when harvested even though the cages are stocked with the same number of juveniles. The estimation of fixed costs is based on assumptions about fish density, and fish density could be higher in cages where PF is used. However, the fixed costs of cage culture are relatively small, constituting <7% of the total production cost. Variation in fixed costs will have minimal effect on the total production costs. The total production cost was 34% higher for farms using PF than those using EF. This is an important finding because the majority of fish farms use artisanal feed.

As expected, feed costs were the largest production cost factor and constituted 85% and 91% of total costs for PF and EF, respectively. The proportion of feed costs in the current study was higher than those reported previously for tilapia where feed costs accounted for 60-70 % of the total production cost (Bolivar et al. 2006; El-Sayed 2006; Watanabe 2002; Cheng et al. 2010). However, most of these studies were conducted in pond systems where the feed offered is supplementary and a significant proportion of the nutrition comes from natural food organisms (Schroeder 1978). In the absence of natural food, feed costs in cage culture will be proportionately higher than in pond culture. This difference may put cage culture at a disadvantage compared to pond culture.

The profit margins in cage aquaculture in the Great Lakes region are low and the economic outcome of the companies involved is sensitive to the sales prices of fish (Musa, Aura and Okechi 2021). Farm gate prices when selling to agents is 1.55 USD kg^{-1}, which is not enough to cover the production costs when PF is used. However, with EF, the profit margin could be up to 15%. Even the farm-gate price to wholesalers (1.57 USD kg^{-1}) is not enough to cover the production costs of farms using PF, which can only be profitable when farmers sell directly to retailers or consumers, a niche that is only about 6% of the market. The farm gate price of fish is similar to the market price of frozen, tilapia imported from China (\$1.6-1.7·kg^{-1}), for fish of 200-400g in size (Awuor et al. 2019). With current production practices, farmed tilapia in the Great Lakes region may never compete in price with those from China. However, consumers appear to be willing to buy fresh fish produced locally at a higher price rather than frozen imports.

As is common in most parts of Africa, the majority of cage farmers in Kenya appear to be losing money, but still they persevere. There may be several reasons for this. First, it is possible that fish farmers do not fully understand the benefits of record keeping and, hence, may not even be aware that they are losing money. However, it may be possible to continue farming because of various forms of subsidies from government and other agencies. To increase food production and bridge the widening gap between fish demand and supply, fish farmers in most developing countries have, and continue to receive, support and subsidies from local and federal governments to cover the cost of inputs and start-up investment (Orina et al. 2018). Although, support for start-up fish farms may promote the growth of aquaculture, it is of little value if the business is not sustainable and/or conducive to good business practices (Guillen et al., 2019).

Environmental impact of EF and PF

In addition to being more economical, EF also appears to have less environmental impact. The retention of N and P by fish fed EF was higher than those fed PF. As a result, the environmental loading of P and N per kg of tilapia produced was more than twice as high when PF was used compared to EF (Table 7). The high loading of N and P was due to poorer feed conversion of fish fed PF. The high loads of N and P to the environment from fish fed with PF are of concern and will further exacerbate the eutrophication of L. Victoria.

One of the most important quality parameters of fish feeds is water stability. With high water stability, less nutrients will leach from the feed into the water before the fish consume the feed. The water stability of the EF was much more than that of the PF with 82% of the solids leaching from the latter diet over 2 hours while only 15% were lost from the EF (Fig. 4). Several factors may have contributed to this difference in stability. The high fibre content of the PF may have reduced the binding capacity of the pellets (Barrows et al. 2007). Moreover, gelatinization occurring during the extrusion process of the EF diet increases stability (Barrows and Hardy 2000; Misra et al. 2002; Brown et al. 2015). Therefore, it is not unexpected that that extruded feed was more stable in water than the pelleted feed. The poor water stability of PF could have contributed to the high nutrient loading (Table 7). Notably, assimilation of N and P in PF may not have been efficient due to the high fibre content, so these elements were excreted into the water (Kong et al., 2020).

Conclusion and recommendations

The use of extruded commercial feed in the cage culture of tilapia is preferential to using artisanal feed as it produced better growth and FCR with less environmental impact. The EF is more expensive than the PF, however, the EF gives much better growth and feed conversion than the PF. Therefore, the cost of production is lower when EF is used. Most fish farmers in sub-Saharan Africa sell their production to agents who bring the fish to market. The cost of producing fish with PF is higher than the farm gate price of tilapia paid by the middlemen. In contrast, the use of EF may yield a modest profit margin regardless of market channel. Finally, the environmental impact (N and P loading) is lower when EF is used. Therefore, EF should be used for farming tilapia in cages for economic and environmental reasons. Future studies should monitor antioxidants, and immunity response of fish fed either EF or PF.

Acknowledgements

This study was funded by the GRO Fisheries Training Programme, a UNESCO Category 2 Centre in Iceland in collaboration with Kenya Marine and Fisheries Research Institute (KMFRI). Helgi Thorarensen was a visiting scholar at the University of South Eastern Norway while working on the manuscript. We thank Dr. Linda May, UKCEH, for improving the English of the manuscript.

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical approval: All applicable international, national, and/or institutional guidelines for the care and use of animals were followed by the authors

References

Aba, M., Driss, B., Khadija, E., Mohammed, B., and M. Aziz. 2012. Effects of Pressed and Extruded Foods on Growth Performance and Body Composition of Rainbow Trout (*Oncorhynchus mykiss*). *Pakistan Journal of Nutrition* 11(2): 104-109.

Ackefors, H., and M. Enell. 1994. The release of nutrients and organic matter from aquaculture systems in Nordic countries. *Journal of Applied Ichthyology* 10:225–241.

Allam, B.W., Khalil, H.S., Mansour, A.T, Srour, T.M., Omar, E.A., and A.A. Nour. 2020. Impact of substitution of fish meal by high protein distillers dried grains on growth performance, plasma protein and economic benefit of striped catfish (*Pangasianodon hypophthalmus*). *Aquaculture* doi:10.1016/j.aquaculture.2019.734792

Allan, G.L., and M.A. Booth. 2004. Effects of extrusion processing on digestibility of peas, lupins, canola meal and soybean meal in silver perch *Bidyanus bidyanus* (Mithchell) diets. *Aquaculture Research* 35:981-991.

Al-Hafedh, Y. 1999. Effects of dietary protein on growth and body composition of Nile tilapia, *Oreochromis niloticus* L. *Aquaculture Research* 30:385–393.

Ammar, A.A., Abd-Elgawad, A.S., and A.A. Salama. 2008. Effect of extruded and non-extruded fish pellet on growth performance and total production of Nile tilapia and grey mullet fingerlings reared in a polyculture system in earthen ponds. 8th International Symposium on Tilapia in Aquaculture 2008. 823-835 p.

AOAC. 1995. Official methods of analysis of official analytical chemists international, in: association of official analytical chemists. Arlington, VA, USA: Association of Official Analytical Chemists.

AOAC. 2012. Official methods of analysis of official analytical chemists international, in: association of official analytical chemists. Arlington, VA, USA: Association of Official Analytical Chemists.

Aura, M.C., S. Musa, E. Yongo, J. Okechi, J.M. Njiru, Z. Ogari, R. Wanyama, H. Charo-Harrison, H. Mbugua, S. Kidera, V. Ombwa, and J. Abwao. 2018. Integration of mapping and socio-economic status of cage culture: Towards balancing lake-use and culture fisheries in Lake Victoria, Kenya. *Aquaculture Research* 49(1):532-545. https://doi.org/10.1111/are.13484.

Awuor, J., K. Obiero, J. Munguti, J. Oginga, D. Kyule, M. Opiyo, P. Odote, E. Yongo, H. Owiti, and J. Ochiewo. 2019 Market linkages and distribution channels of cultured, captured and imported fish in Kenya. *Aquaculture studies* 19(1):1-11.

Balarin, J.D., and R.D. Haller. 1982. The intensive culture of tilapia in tanks, raceways and cages. In: Muir J.F., Roberts, R.J., (Ed.), Recent Advances in Aquaculture. pp. 265– 356. Croom Helm, London.

Barrows, F.T., and R.W. Hardy. 2000. Feed manufacturing technology. R.R. Stickney (Eds.), Encyclopedia of aquaculture, John Wiley and Sons Inc, New York, NY, pp 354-359.

Barrows, F.T., D.A.J. Stone and R.W. Hardy. 2007. The effects of extrusion conditions on the nutritional value of soybean meal for rainbow trout (*Oncorhynchus mykiss*). *Aquaculture* 265:244-252.

Belghit, I., S. Skiba-Cassy, I. Geurden, K. Dias, A. Surget, S. Kaushik, S. Panserat, and I. Seiliez. 2014. Dietary methionine availability affects the main factors involved in muscle protein turnover in rainbow trout (*Oncorhynchus mykiss*). *British Journal of Nutrition* 112:493–503.

Blow, P., and S. Leonard. 2007. A review of cage aquaculture: sub-Saharan Africa. In M. Halwart, D. Soto and J.R. Arthur (Eds). Cage aquaculture – Regional reviews and global overview, pp. 188–207. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 192 – 206 pp.

Bolivar, R.B., E.B.T. Jimenez, and C.L. Brown. 2006. Alternate-day feeding strategy for Nile tilapia grow-out in the Philippines: marginal cost-revenue analysis. *North American Journal of Aquaculture* 68:192-197.

Brinker, A., and R. Rösch. 2005. Factors determining the size of suspended solids in flow-through fish farms. *Aquaculture Engineering* 32:1-19.

Brown, M.L., K. Fallahi, P. Mathukumarappan, and S. Sindelar. 2015. A comparative study of the effect of non-starch polysaccharide gums on the physical properties of single-screw extruded aquafeed. *Food processing and technology* 6:457-465.

Carter, C.G., and R.C. Hauler. 2000. Fish meal replacement by plant meals in extruded feeds for Atlantic salmon (*Salmo salar* L.). *Aquaculture* 185:299–311.

Charo-Karisa, H., M. Opiyo, J. Munguti, E. Marijani, and L. Nzayisenga. 2013. Cost-benefit analysis of pelleted and unpelleted on-farm feed on African catfish (*Clarias gariepinus* Burchell, 1822) in earthen pond. African *Journal of Food, Agriculture, Nutrition and Development* 13:8019-8033.

Chebbaki, K., Akharbach, H., Talbaoui, E., Abrehouch, A., Ait ali, A., Sedki, S., Ben Bani, A., and M. Idaomar. 2010. Effect of fish meal replacement by protein sources on the extruded and pressed diet of European sea bass juvenile (*Dicentrarchus labrax*). *Agriculture and Biology Journal of North America* 1(4): 704-710.

Cheng, Z., Q. Ai, K. Mai, W. Xu, H. Ma, Y. Li, and J. Zhang. 2010. Effects of dietary canola meal on growth performance, digeston and metabolism of Japanese seabass, *Lateolabrax japonicus*. Aquaculture 305:102–108. doi:10.1016/j. *Aquaculture* 2010.03.031.

Chepkirui, M., Orina, P.S., Opiyo, M., Muendo, P., Mbogo, K., and R. Omondi. 2021. Fatty acids composition of Nile tilapia (*Oreochromis niloticus*) fingerlings fed diets containing different levels of water spinach (*Ipomoea aquatica*). *Journal of Agriculture and Food Research* 5:100156.

Delgado, E, and D. Reyes-Jaquez. 2018. Extruded Aquaculture Feed: A Review, Extrusion of Metals, Polymers, and Food Products Sayyad Zahid Qamar, Intech Open [Internet]. [cited 2018 Apr 15]. Available from https://intechopen.com. DOI:10.5772/intechopen.69021.

De Silva, S.S. 1993. Supplementary feeding in semi-intensive aquaculture systems. Pages 24-60. In: New, M.B., Tacon, A.G.J., Csavas, I., (Eds.), Farm-made Aquafeeds. Proceedings of the FAO/AADCP Regional Expert Consultation on Farm-Made Aquafeeds. Bangkok, FAO-RAPA/AADCP.

De Silva, S.S., and T.A. Anderson. 1995. Fish Nutrition in Aquaculture. Chapman & Hall Aquaculture Series, London, 319 pp.

El-Sayed, A.F.M. 2013 Tilapia feed management practices in sub-Saharan Africa. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture*. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 377–405.

El-Sayed, A.F.M. 2006. Tilapia culture. Wallingford, GB, England: CABI Publishing.

El-Sayed, A.F.M. 1998. Total replacement of fishmeal with animal protein sources in Nile tilapia *Oreochromis nilotcus* (L.) feeds. *Aquaculture Research* 29:275–280. doi:10.1046/j.1365- 2109.1998.00199.x.

El-Sayed, A.F.M., and S. Teshima. 1991. Tilapia nutrition in aquaculture. *Reviews in Aquaculture Science* 5:247–265.

Figueiredo-Silva, C., A. Lemme, D. Sangsue, and S. Kiriratnikom. 2015. Effect of DL methionine supplementation on the success of almost total replacement of fish meal with soybean meal in diets for hybrid tilapia (*Oreochromis niloticus* and *Oreochromis mossambicus*). *Aquaculture Nutrition* 21:234–241. doi:10.1111/anu.12150.

Furuya, W.M., L.E. Pezzato, M.M. Barros, A.C. Pezzato, V.R.B. Furuya, and E.C. Miranda. 2004. Use of ideal protein concept for precision formulation of amino acid levels in fishmeal-free diets for juvenile Nile tilapia (*Oreochromis niloticus* L.). *Aquaculture Research* 35:1110–1116.

Goff, J.B., and D.M. Gatlin. 2004. Evaluation of different sulfur amino acid compounds in the diet of red drum, *Sciaenops ocellatus* and sparing value of cystine for methionine. *Aquaculture* 241:465–477.

Gondwe, M., S. Guildford, and R. Hecky. 2011 Physico-chemical measurements in the water column along a transect through a tilapia cage fish farm in Lake Malawi, Africa. *Journal of Great Lakes Research* 37, 102-113.

Guillen, J., Asche, F., Carvalho, N., Polanco, J.M., Llorente, I., Nielsen, R., Nielsen, M., and S. Villasante. 2019. Aquaculture subsidies in the European Union: Evolution, impact and future potential for growth. *Marine policy* 104, 19-28.

Halver, J.E., and F.T. Barrows. 1972. Fish Nutrition. Academic Press. Amsterdam Boston London New York Oxford Paris San Diego San Francisco Singapore Sydney Tokyo.

Hamilton, S.E., S.M. Gallo, N. Krach, C.S. Nyamwea, J.K. Okechi, C.M. Aura, Z. Ogari, P.M. Roberts, and L. Kaufman. 2020. The use of unmanned aircraft systems and high-resolution satellite imagery to monitor tilapia fish cage aquaculture expansion in Lake Victoria, Kenya. *Bulletin of Marine Science* 96 (1): 71-93.

Hematzade, A., Taati, M.M., and M. Raissy. 2013. Effects of extrusion of diet on growth parameters of rainbow trout (*Oncorhyncus mykiss*). *ABAH Bioflux* 5 (2): 127-131.

Heuzé, V., G. Tran, P. Hassoun, M. Lessire, and F. Lebas. 2019. *Sunflower meal*. Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/732.

Hilton, J.W., C.Y. Cho, and S.J. Slinger. 1981. Effect of extrusion processing and steam pelleting diets on pellet stability, pellet water absorption, and the physiological response of rainbow trout (*Salmo gairdneri* R). *Aquaculture* 25: 185-194.

Jauncey, K. 2000. Nutritional requirements. In Malcolm, C.M., J. Beveridge, and K. McAndrew (Eds.). Tilapias: Biology and exploitation. Fish and fish series, Vol. 25.

Kaushik, S.J., and I. Seiliez. 2010. Protein and amino acid nutrition and metabolism in fish: current knowledge and future needs. *Aquaculture Research* 41:322–332.

Kenya Market-Led Aquaculture Programme (KMAP). 2016. Report on market study of the aquaculture market in Kenya. (2016). Luttice Consulting. 76 pp.

Khalil, H.S., Mansour, A.T., Goda, A.M.A., and E.A., Omar. 2019. Effect of selenium yeast supplementation on growth performance, feed utilization, lipid profile, liver and intestine histological changes, and economic benefit in meagre, Argyrosomus regius, fingerlings. *Aquaculture Nutrition* 501, 135–143. https://doi.org/10.1016/j.aquaculture.2018.11.018.

Khattab, Y., M. Ahmad, A. Shalaby, and M. Abdel-Tawwab. 2000. Response of Nile tilapia (*Oreochromis niloticu*s L.) from different locations to different dietary protein levels. *Egypt Journal of Aquatic Biology and Fisheries* 4:295–311.

Kirimi, J.G., Musalia, L.M., Magana, A., and J.M. Munguti. 2021. Enzyme assay to determine optimum crude papain level on plant protein diets for Nile tilapia (O*reochromis niloticus*). *International Journal of Life Sciences Research* 7:40-48.

KMFRI. 2016. Fish Kills in Cages off Beaches in Lake Victoria, Kenya: Imprinting the Possible Causes. Technical Report for Kenya Marine and Fisheries Research Institute (KMFRI) Kisumu. 12 pp.

Kong, W., S. Huang, Z. Yang, F. shi, Y. Feng, and Z. Khatoon. 2020. Fish Feed Quality Is a Key Factor in Impacting Aquaculture Water Environment: Evidence from Incubator Experiments. *Science Report* **10,** 187. https://doi.org/10.1038/s41598-019-57063-w.

Kubiriza, G.K., A.M. Akol, J. Arnason, S. Snorrason, T. Tómasson, and H. Thorarensen. 2017. Practical feeds for juvenile Nile tilapia (*Oreochromis nilotcus*) prepared by replacing *Rastrineobola argentea* fishmeal with freshwater shrimp (*Caridina nilotca*) and mung bean (*Vigna radiata*) meals. *Aquaculture nutrition*. 00:1–8.

Leal, A.L.G., P.F. de Castro, J.P.V. de Lima, E. Correia, and R. Bezerra. 2010. Use of shrimp protein hydrolysate in Nile tilapia (Oreochromis niloticus, L.) feeds. *Aquaculture International* 18:635–646. DOI 10.1007/s10499-009-9284-0.

Lee, S., Moniruzzaman, M., Yun, H., Park, Y., and J. Mann Bai SC. 2016. Comparative studies on effects of extruded pellets and dough type diets on growth, body composition, hematology and gut histology of juvenile Japanese eel, Anguilla japonica (Temminck et Schlegel*). J. Fish. Aquat. Sci.* [Internet]. [cited 2018 Apr 15]; 11(5). Available from: https://www.research gate.net/ publication/304396857. DOI: 103923/jfas.2016.

Limbu, S.M. 2015. The effect of floating and sinking diets on growth performance, feed conversion efficiency, yield and cost-effectiveness of African sharptooth catfsh, *Clarias gariepinus* reared in earthen ponds*. International Journal of Fisheries and Aquatic Studies* 2(5): 253-259.

Liti, D., L. Cherop, J. Munguti, and L. Chhorn. 2005. Growth and economic performance of Nile tilapia (*Oreochromis niloticus* L.) fed on two formulated diets and two locally available feeds in fertilized ponds. *Aquaculture Research* 36:746-752.

Liti, D.M., H. Waidbacher, M. Straif, R.K. Mbaluka, J.M. Munguti and M.M. Kyenze. 2006. Effects of partial and complete replacement of freshwater shrimp meal (*Caridina niloticus* Roux) with a mixture of plant protein sources on growth performance of Nile tilapia (*Oreochromis niloticus* L.) in fertilized ponds. *Aquaculture Research* 37: 477–483. doi:10.1111/j.1365- 2109.2006.01450.x.

Lupatsch, G., W.M. Kissil, D. Sklan, and E. Pfeffer. 2001. Effects of varying dietary protein and energy supply on growth, body composition and protein utilization in gilthead seabream (*Sparus aurata* L.). *Aquaculture Nutrition* 7:71–80.

Michelato, M., W.M. Furuya, D.M. Gatlin. 2017. Metabolic responses of Nile tilapia *Oreochromis niloticus* to methionine and taurine supplementation. *Aquaculture*. doi:10.1016/ j.aquaculture.2017.11.003.

Misra, C.K., N.P. Sahu, K.K. Jain. 2002. Effect of extrusion processing and steam pelleting diets on pellet durability, water absorption and physical response of *Macrobrachium rosenbergii*. *Asian-Australian Journal of Animal Science* 15:1354-1358.

Mugo-Bundi, J., E. Oyoo-Okoth, C.C. Ngugi, D. Manguya-Lusega, J. Rasowo, V. Chepkirui-Boit, and J. Njiru. 2015. Utilization of *Caridina nilotica* (Roux) meal as a protein ingredient in feeds for Nile tilapia (*Oreochromis niloticus*). *Aquaculture Research* 46:346–357. doi:10.1111/are.12181.

Munguti, J.M., D.M. Liti, H. Waidbacher, M. Straif, and W.J. Zollitsch. 2006. Proximate composition of selected potential feedstuffs for Nile tilapia (*Oreochromis niloticus* Linnaeus) Production in Kenya. Die Bodenkultur – Austrian Journal of Agricultural Research 57:123-133.

Munguti, J.M., H. Waidbacher, D.M. Liti, M. Straif, and W.J. Zollitsch. 2009. Effects of substitution of freshwater shrimp meal (*Caridina nilotica* Roux) with hydrolyzed feather meal on growth performance and apparent digestibility in Nile tilapia (*Oreochromis niloticus* L.) under different culture conditions. *Livestock Research for Rural Development* 21 (8):2-13.

Musa, S., C.M. Aura, and J. Okechi. 2021. Economic analysis of tilapia cage culture in Lake Victoria using different cage volumes, *Journal of Applied Aquaculture*. DOI: 10.1080/10454438.2021.1884632.

Musinguzi, L., J. Lugya, P. Rwezaula, A. Kamya, C. Nuwahereza, J. Halafo, S. Kamondo, F. Njaya, C. Aura, A.P. Shoko, R. Osinde, V. Natugonza, and R. Ogutu-Ohwayo. 2019. The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters. *Journal of Great Lakes Research* https://doi:10.1016/j.jglr.2019.09.011.

Muyot, F.B., Mutia, M.T., and Caunan, P.J. 2018. Growth performance and cost efficiency of tilapia (*Oreochromis niloticus*) and milkfsh (*Chanos chanos*) fed extruded floating and non-floating feeds reared in net cages in Taal Lake. The Philippine Journal of Fisheries 25(2): 41-56.

Neto, R.M., and Ostrensky, A. 2014. Evaluation of commercial feeds intended for the Brazilian production of Nile tilapia (*Oreochromis niloticus* L.): Nutritional and environmental implications. *Aquaculture Nutrition*. 1-10.

Njiru, J.M., C.M. Aura, J.K. Okechi. 2018. Cage fishing culture in Lake Victoria: A boon or disaster in waiting? *Fisheries Management and Ecology* Review Article: 1 – 9.

Njiru, J., and C.M. Aura. 2019. Cage farming can protect Lake Victoria's fish. But regulations need tightening. The Conversation. https://theconversation.com/cage-farming-can-protectlake-victorias-fish-but-regulations-need-tightening-112641. Accessed 20 March 2019.

NRC (National Research Council). 2011. Nutrient requirements of fish and shrimp, 1st ed. Washington, DC, USA: National Academy Press.

Orina, P.S., E. Ogello, E. Kembenya, C. Githukia, S. Musa, V. Ombwa, V.M. Mwainge, J. Abwao, R.N. Ondiba, and J.K. Okechi. 2018. State of Cage Culture in Lake Victoria, Kenya. Laxpress Services, Nairobi, Kenya. 62 pp.

Oliveira, V. L., X.T. Orlandi, M.L. Batista, M. Mariana, M.E .Nunes, and F.W. Massamitu. 2017. Apparent digestibility of wheat and coproducts in extruded diets for the Nile tilapia, *Oreochromis niloticus*. Revista Brasileira de Saúde e Produção Animal v.18, n.3, p.479-491.

Opiyo, M.A., Jumbe, J., Ngugi, C.C., and Charo-Karisa, H. 2019. Different levels of probiotics affect growth, survival and body composition of Nile tilapia (*Oreochromis niloticus*) cultured in low input ponds. *Scientific African* 4:e00103.

Schroeder, G.L. 1978. Autotrophic and heterotrophic production of micro-organisms m intensively-manured fish ponds and related fish yields. *Aquaculture* 14: 303-325.

Sadiku, S.O.E., and K. Jauncey 1995. Digestibility, apparent amino acid availability and waste generation potential of soybean flour: poultry meat meal blend-based diets for tilapia, Oreochromis niloticus (L.), fingerlings. *Aquaculture Research* 26:651–657.

Shang, Y.C. 1985. Aquaculture economics: An overview. *Geo-Journal* 10 (3) :299-305.

Silva, J.M.G., M. Espe, L.E.C Conceicao, J. Dias, and L.M.P. Valente. 2009. Senegalese sole juveniles (*Solea senegalensis* Kaup, 1858) grow equally well on diets devoid of fish meal provided the amino acids are balanced. *Aquaculture* 296:309–317.

Stainton, M.P., M.J. Capel, and F.A.J. Armstrong. 1977. The Chemical Analysis of Freshwater, 2nd Ed.: Can. Fish Marine Services Miscellaneous Special Publication 25.

Tacon, A.G.J., K. Jauncey, A. Falaye, M, Pantha, I. McGowen, and E. Stafford. 1984. The use of meat and bone meal, hydrolyzed feather meal and soyabean meal in practical fry and fingerling diets for *Oreochromis niloticus*. In: Fishelson, L., Yaron, Z. (Eds.), Proceedings of the First International Symposium on Tilapia in Aquaculture, Tel Aviv University Press, Tel Aviv, Israel, pp. 356-365.

Tacon, A.D.J. 1987. The nutrition and feeding of farmed fish and shrimp - a training manual. 2. Nutrient sources and composition. GCP/RLA/075/ITA, Field Document 5/E. FAO, Rome, Italy, 129 pp.

Venou, B., M.N. Alexis, E. Fountoulaki, and J. Haralabous 2009. Performance factors, body composition and digestion characteristics of gilthead sea bream (*Sparus aurata*) fed pelleted or extruded diets. *Aquaculture Nutrition* 15:390-401.

Watanabe, T. 2002. Strategies for further development of aquatic feeds. *Fisheries Science* 68:242–252. doi:10.1046/j.1444- 2906.2002.00418.x.

Wilson, R.P., and J.E. Halver. 1986. Protein and amino acids requirements of fishes. *Annual Review of Nutrition* Vol. 6:225-244 https://doi.org/10.1146/annurev.nu.06.070186.001301.

Wu, R.S.S., P.K.S. Shin, D.W. MacKay, M. Mollowney, D. Johnson. 1999. Management of marine fish farming in the sub-tropical environment: a modelling approach. *Aquaculture* 174:279–298.

FIGURES

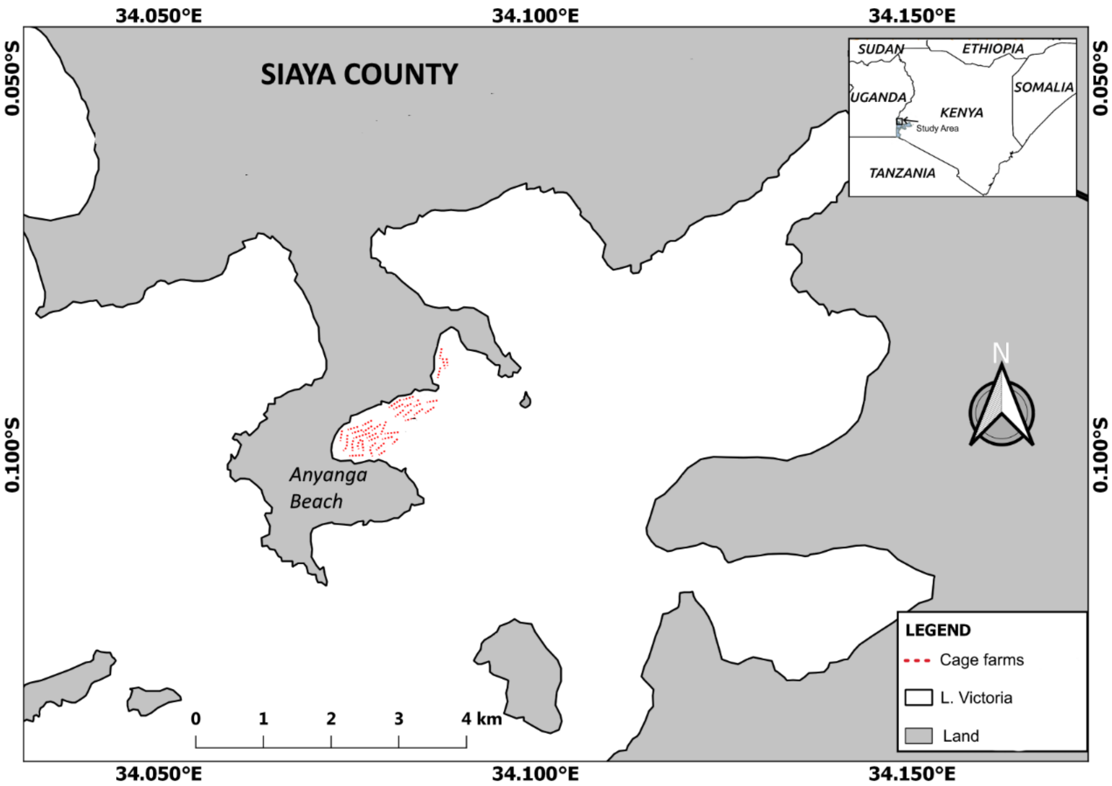

Figure 1. Location of Nyanza Gulf and the study site at Kadimo Bay, Anyanga Beach, Lake Victoria, Kenya.

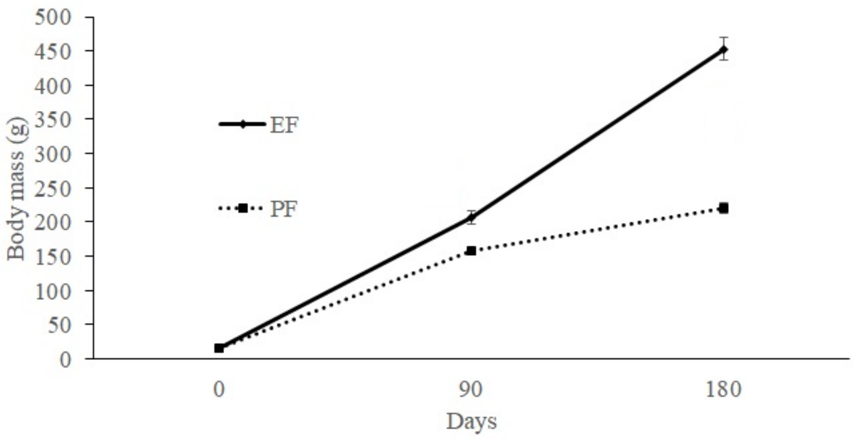

Figure 2. Mean body mass (± SEM) of Nile tilapia reared on extrude (EF) or Pelleted feed (PF) for 180 days in cage culture in Lake Victoria, Kenya.

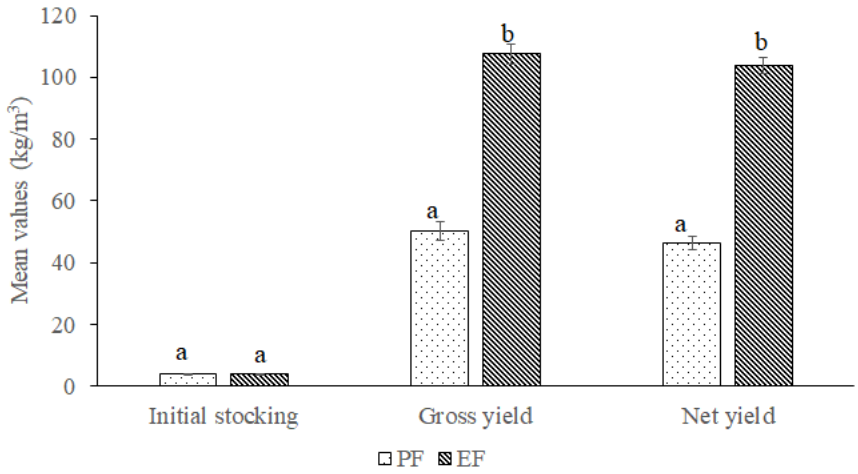

Figure 3. Mean values (± SEM) of initial numbers of fish, gross and net yield for Nile tilapia fed PF and EF for 180 days in cage culture in Lake Victoria, Kenya.

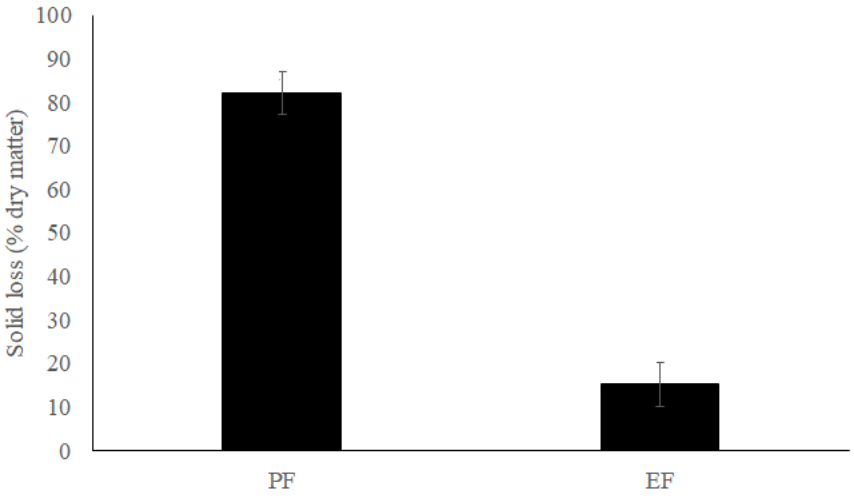

Figure 4. Mean mass loss (± SEM) of PF and EF after 2 hours of soaking and shaking.

TABLES

Table 1. Ingredients, crude protein content and formulations of the pelleted (PF) and extruded feeds (EF) used in the study. The inclusion level of each ingredient (g kg^{-1}) in the diets is shown in the last two columns (PF and EF).

Ingredients	**CP content (g kg^{-1})**	**PF**	**EF**
Sardine fishmeal	521	-	98
Shrimp meal (*Caridina nilotica*)	594	235	108
Soybean meal	383	235	110
Wheat pollard	181	129	321
Wheat bran	162	130	-
Sunflowerseed meal	195	129	306
Maize bran	102	133	-
Toxin binder		-	13
Vitamin premix*		10	20
Mineral premix‡		-	20
Methionine		-	4

*Vitamins (mg kg^{-1} of diet): thiamine, 1200; pyridoxine, 1000; retinol, 1000; riboflavin, 2000; cyanocobalamine, 200; choline chloride, 1600; ascorbic acid (Stay C), 5000; cholecalciferol, 2400; nicotinic acid, 1800; a tocopherol, 1000; pantothenic acid, 400; paraminobenzoic acid, 3200 folic acid, 2500; biotin, 1200; inositol, 3000.

‡Minerals (mg kg^{-1} of diet): Iodine, 1600; manganese, 4000; cobalt, 400; copper, 2100; iron, 2000; zinc, 2000; selenium, 400.

Table 2. Proximate analyses of chemical composition (g kg^{-1} ± SEM) of the diets tested.

Feed component	PF	EF
Dry matter	947.8 ± 3.4	948.0 ± 1.5
Crude protein	282.0 ± 2.1	301.0 ± 0.3
Ash	84.3 ± 0.2 [a]	72.4 ± 1.1[b]
Crude fiber	168.2 ± 0.32 [a]	42.1 ± 0.4 [b]
Crude lipid	47.8 ± 0.1	48.0 ± 0.2
Calculated Nitrogen Free Extract	365.5	487.7
Gross energy (kJ g^{-1})	16.8± 0.1	17.2± 3.2

Different superscripts within a row indicate significant differences among means ($P < 0.05$).

Table 3. Analyzed essential amino acid (EAA) composition of the test diets used (g kg^{-1} of diet) and NRC recommended threshold content for *Oreochromis niloticus*.

Amino acids	***NRC, 2011**	**PF**	**EF**
Arginine	12	15.2	22.2
Histidine	10	10.4	11.9
Isoleucine	10	11.2	13.5
Leucine	19	21	24.6
Lysine	16	15	15.2
Methionine	7	5.7	6.7
Phenylalanine	11	10.4	13.5
Threonine	11	11.9	13.2
Tryptophan	3	3.3	3.8
Valine	15	14.2	15.5

*****NRC (2011) - recommended amino acid content for *Oreochromis* spp.

Table 4. Growth indices (mean ± SEM) and survival of Nile tilapia reared on pelleted (PF) and extruded (EF) feed for 180 days in cages. The means are based on samples of 90 fish from each treatment.

Parameter	**PF**	**EF**
Initial mean weight (g)	15.3 ± 0.2	15.2 ± 0.2
Final mean weight (g)	220.8 ± 2.9[a]	453.0 ± 3.6[b]
WG (g)	205.8 ± 4.8[a]	438.0 ± 7.4[b]
SGR (%day^{-1})	1.3 ± 0.2[a]	2.5 ± 0.1[b]
Survival (%)	90.8 ± 1.0	95.0 ± 2.1
AFCR	2.8 ± 0.2 [a]	1.6 ± 0.1 [b]
Feed intake (g fish^{-1})	576.0 ± 23.1[a]	700.8 ± 40.7[b]
Protein efficiency ratio (PER)	1.2 ± 0.1[a]	2.8 ± 0.2[b]
Productive protein values (PPV; %)	14.3 ± 1.2[a]	28.4 ± 2.2[b]

Different superscripts within a row indicate significant differences among means (ANOVA test, $P < 0.05$).

Table 5. Feed costs and minimum estimated variable production costs of Nile tilapia in cages fed either pelleted (PF) and extruded feeds (EF). USD 1 = Kshs 100.

Parameter	PF	EF
Estimated cost of raw materials (US$·$kg^{-1}$)	0.35	0.47
Market price of feed (US$·$kg^{-1}$)	0.56	0.77
Feed price per kg of fish produced (US$·$kg^{-1}$)	1.46	1.19
Cost of juveniles per kg fish produced (US$·$kg^{-1}$)	0.15	0.07
Total minimum variable production costs (US$·$kg^{-1}$)	1.73	1.31
Fixed production costs	0.12	0.05
Total minimum production costs	1.84	1.37

Table 6. Fixed costs for one cage (2 m x 2 m x 2 m) for one production cycle of Nile tilapia in Lake Victoria, Kenya. Cost and price information are in US$*.

Parameters	
Amortized cage cost	16.25
Amortized equipment and tools	5.00
Interests*	1.91
Management	18.00
Harvest	5.00
Total fixed cost	46.16

*Annual interest rates = 9 %; 1 US$ = 100 Kshs

Table 7. The nitrogen (N) and phosphorus (P) content (mean ± SEM) of feed and fish and the environmental load of producing Nile tilapia using either extruded feed (EF) and or pelleted artisanal feed (PF) in cages in Lake Victoria, Kenya.

	N		P	
	PF	EF	PF	EF
Amount in feed (kg·ton^{-1})	126.0±1.0^{a}	76.8±1.4^{b}	30.8±1.8^{a}	16.0±0.9^{b}
Retained in fish (kg·ton^{-1})	21.0 ± 0.5^{a}	27.2±0.5^{b}	7.8±0.0^{a}	8.5±0.6^{b}
Released (kg·ton^{-1})	105.0±1.1^{a}	49.6±1.5^{b}	23.0±1.8^{a}	7.5±1.1^{b}
Released (%)	83.3±0.6^{a}	64.6±1.1^{b}	74.7±1.2^{a}	46.9±4.5^{b}

All values are expressed in g·kg^{-1} of production. Significant differences are indicated with superscripts (ANOVA test, $P < 0.05$).

Table 8. Carcass proximate composition (%) of Nile tilapia (g 100 g^{-1} wet weight basis) reared under pelleted and extruded feed in cage culture in Lake Victoria, Kenya.

Parameters (%)	Initial value	PF	EF
Moisture	78.3 ± 3.1	74.2 ± 5.4	74.0 ± 3.4
Protein	10.1 ± 1.1	13.1 ± 0.2[a]	17.0 ± 0.3[b]
Lipids	4.3 ± 0.3	5.4 ± 0.3[a]	4.5 + 1.1[b]
Ash	3.1 ± 0.1	3.2 ± 0.2	3.3 ± 0.1
Fiber	4.4 ± 0.2	5.3 ± 0.3[a]	3.8 ± 0.4[b]

Different superscripts within a row indicate significant differences among means ($P < 0.05$). Comparisons were made between dietary treatments and excluded the initial values. n = 5.