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Growth performance of three strains of Nile tilapia (*Oreochromis niloticus*) on four different feeds in Western and Central Kenya

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A B S T R A C T

The growth performance of three commercially available strains of Nile tilapia (*Oreochromis niloticus*) fed one of four different commercially available feeds during nursery and grow-out was assessed in Kenya. Each of the 12 treatments (three strains x four feeds) had four replicates (two in each of two ponds) at each of the two locations (Western and Central Kenya). The experiment tested starter feeds (phase 1, lasting 85 days) and grower feeds (phase 2, lasting 127 days). There were statistically significant differences in growth and feed conversion ratio (FCR) for fish grown on different starter and grower feeds within both areas, but not between fish strains at harvest in Central Kenya where growth of all strains was poor on all feeds. The mean weight over all strains at the end of the starter phase in Central Kenya was 5.9 g (FCR 2.4) and at final harvest 53.6 g (FCR 3.6). In Western Kenya, where temperatures are 5.4 °C greater on average than Central Kenya, mean weight over all strains at the end of the starter phase was 19.5 g (FCR 2.2) and 189.8 g (FCR 1.9) at final harvest. The most cost-effective combination was formulated feed with approximately 35 % protein and a strain with a better FCR than the others tested resulting in 38 % less average feed cost than the next best combination. Mash, the cheapest feed tested, provided such poor weight gain that feed costs per unit gain were higher than for other feed/strain combinations. Production costs in Central Kenya were twice that in Western Kenya and suggest niche business models will be required for that region with careful choice of farm sites. Performances of key inputs (feeds and strains) available in Kenya for tilapia aquaculture vary significantly, and some combinations with sound management provide better outcomes that could determine whether farming is profitable or not.

1. Introduction

There has been limited development of commercial aquaculture and continued under-performance of subsistence farming in Africa despite investments over a number of decades. In the case of Kenya the production of farmed fish grew from 1000 MT in 2000 to 14,952 MT (2016) (Munguti et al., 2014a; KMFRI, 2017). One stimulus for this was the Fish Farming Enterprise Productivity Program (FFEPP), part of the Economic Stimulus Programme (ESP) launched in 2008/09. Through this the government intended to strengthen extension services and improve quality and distribution of key inputs such as seed and feed. More than 7000 new fish ponds were built, growing the total area of fish farming from 220 ha to 468 ha. Farmed fish production peaked at 24,096 tonnes in 2014 (Opiyo et al., 2018). A sharp drop (36 %) in farmed fish production followed the end of the Stimulus Program and its associated subsidies, when many farmers stopped production (Obwanga et al., 2017). Sudden abandonment is common for interventionist approaches (Belton and Little, 2011) and underline the importance of sustainable and market-led business models in aquaculture.

There was also evidence that some of the ponds funded under the ESP did not perform as expected. In Makueni County more than 92.5 % of ponds were reported to underperform and more than 70 % of ponds were abandoned (Musyoka and Mutia, 2016). Today, performance issues are still a concern (Opiyo et al., 2020), with confusion as to which

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combination of suboptimal inputs or management are responsible for underperformance in Kenya (Munguti et al., 2014a) and the lack of robustness of aquaculture value chains (Obwanga et al., 2017). Understanding the reasons for poor performance is required to be able to identify and implement appropriate solutions. However, this is hampered by lack of data on the performance in well characterized circumstances so that appropriate interventions can be identified.

The aquaculture production capacity in Kenya has been estimated at 14 million tonnes per year (Nyandat and Owiti, 2013), well above the peak production of 24,096 tons in 2014. The commonest aquaculture systems in Kenya are earthen and lined ponds, followed by cages, dams, and tanks with tilapia species (mainly *O. niloticus*) accounting for 75–90 percent of farmed fish in Kenya (Munguti et al., 2014a; KMFRI, 2017). Kenya has diverse habitats from sea level to 5,200 m and altitude is one of the key factors influencing average temperature differences of 11 °C (day or night) between low and high altitude areas (Rothuis et al., 2011). Water temperature is a critical factor affecting the growth of *O. niloticus* (El-Sayed et al., 1996).

With respect to key inputs, feed studies for *O. niloticus* in Kenya date back more than a decade when the growth and economic performances of Nile tilapia fed with brans (Liti et al., 2006) and locally formulated feeds, including pig pellets (Liti et al., 2005) were investigated. Recent work tested the effects of probiotics (Opiyo et al., 2019). Research and development efforts have increased productivity of *O. niloticus* mono-sex fingerlings in Kenyan aquaculture to (Githukia et al., 2015). Some hatcheries have imported improved stains (e.g. GIFT) or YY-males to optimize tilapia production (Opiyo et al., 2018). Growth of *O. niloticus* has been reported varying from 150 to 200 g over 180 days in comparison of genetically male, sex-reversed and non sex-reversed tilapia (Opiyo et al., 2020), but information on the specific strain and feed combinations and the details of the management are not provided with any consistency making comparisons difficult. Current studies of productivity and cost associated with different inputs available today are required to establish benchmarks for aquaculture production in different climatic areas in Kenya. This is needed to provide a basis for evidence-based recommendations for the future development of the Kenyan aquaculture sector.

The aim of the present study was to provide a first step towards that goal by evaluating the performance of three strains of Nile tilapia (*O. niloticus*) used in Kenyan farms today with currently available feeds using well documented rearing conditions. The experiment was not designed to assess the effects of environmental variables some of which, such as temperature, are well known (see Mengistu et al., 2020). The goal was to assess the relative weight gain, food conversion ratio and cost of different strain and feed combinations as different systems of production. The experiment was carried out in two of the main climatic zones in Kenya to assess whether the relative performance of these combinations was consistent or varied with environment.

2. Material and methods

2.1. Strains used

Three *O. niloticus* strains used were: strain 1, GMT® from the Fishgen Ltd. (UK, YY-technology) obtained from Jasa Fish Farm (Thika, Central Kenya); strain 2, Til Aqua Silver NMTTM of Til Aqua International BV (YY-technology), obtained from Jambo Fish (Mumias, Western Kenya); and strain 3, *O. niloticus,* a synthetic domesticated stock with fish derived from Lake Victoria, Lake Kyoga, and Lake Turkana obtained from Jewlet Enterprises, Kamwala Fish Hatchery (Kendu-Bay, Western Kenya).

2.2. Feeds used

Feeds from two local and two international feed manufacturers were used and obtained from commercial suppliers. The range of products included starter pellets, starter crumble, grower feeds, and mash. Mash sourced from Jewlet (40 % crude protein 85 KES kg^{-1} = 0.85 US$ at the five-year average exchange rate of 99 KES to 1.0 US$ kg^{-1}) was denoted feed S1. Starter pellets were sourced from Raanan (1 mm, 48 % crude protein 300 KES kg^{-1} or 3.0 US$ kg^{-1}) denoted feed S2, starter crumble from Sigma Feeds Ltd (40 % crude protein 150 KES kg^{-1} or 1.5 US$ kg^{-1}) denoted feed S3, and from Skretting (1 mm, 57 % crude protein 390 KES kg^{-1} or 3.9 US$ kg^{-1}) denoted feed S4. For grow-out, Jewlet mash (40 % crude protein 85 KES kg^{-1} or 0.85 US$ kg^{-1})– feed G1, Raanan grower (2 mm, 40 % crude protein 150 KES kg^{-1} or 1.50 US$ kg^{-1}),- feed G2, Sigma grower (2 mm, 30 % crude protein 100 KES kg^{-1} or 1.0 US$ kg^{-1}) – feed G3 and Skretting grower (2 mm, 35 % crude protein 145 KES kg^{-1} or 1.45 US$ kg^{-1}) – feed G4, were used. The selection of feeds and feed types represented a mix of widely used products in extensive and intensive farming with high availability in Kenya (pers. communication with Farm Africa), and includes products at the higher and lower price spectrum. For validation of ingredient information as provided by supplier, feeds were analyzed for dry matter, crude ash, crude protein, crude fat, and crude fiber at SoilCares Limited (Agrocares, Karen Rd, P.O.Box 1332, Nairobi, Kenya); the results are summarized in Table 1.

2.3. Experiment locations

The trials were conducted at two sites with different environmental conditions. One site was the Kibos Fish Farm, under management of the Lake Basin Development Authority (LBDA), near Kisumu in Western Kenya 1178 m above sea level. The site has an annual average rainfall of 1321 mm, average yearly temperature of 22.9 °C, with average maximum monthly temperature ranging between 28 and 31 °C and average minimum monthly temperatures between 16 and 18 °C (Climate-Data, 2018a, 2018b; NOAA, 2018). The second site was located at the University of Karatina, near Karatina Town in Central Kenya 1763 m above sea level. This site has an average annual rainfall of 1449 mm, average yearly temperature of 17.5 °C with average maximum monthly temperature between 20 and 27 °C and average minimum monthly temperature between 11 and 14 °C.

While precipitation patterns are relatively similar in terms of absolute rainfall, the differences between average annual temperatures is 5.4 °C. Kisumu has year-round high temperatures, with only 3 °C difference in average maximum monthly temperatures. In contrast Karatina is more seasonal with generally lower temperatures between June and August leading to 8 °C difference in average maximum monthly temperatures over the year (Climate-Data, 2018a, 2018b; NOAA, 2018). Crucially, the temperature in Karatina falls beneath the optimal rearing temperature for *O. niloticus* for a greater part of the year than Kisumu. Monthly averages of the pond water temperatures taken daily (08:00 h and 17:00 h) throughout the experiment are given in Table 2.

2.4. Experimental design

There were a total of 12 treatments (four feeds by three strains) and each treatment had four replicates resulting in each experimental site having 48 hapas. At each experimental site, three ponds (each approximately 250 m^2 water surface area and 1-meter depth) were set with 16 hapas (3m × 2m x 1 m). Two replicates for each treatment was placed in each of two ponds. The experiment was carried out in two phases in order to assess productivity and production costs between starter and grower feeds. The entire trial was run over 212 days.

During the first phase of the experiment randomly selected fingerlings were stocked at 100 fish per hapa and nursed for 83.6 ± 1.0 (standard deviation) and 85.1 ± 1.3 days in Western and Central Kenya, respectively. Although fingerlings were ordered at an average weight between two and three grams for each strain, hatcheries supplied fish varying significantly in weight and/or size. In Central Kenya, the overall average stocking weight of fingerlings at stocking was 1.12 ± 1.50 g

Table 1
Results on ingredient content analysis for sampled fish feeds. Values are expressed as % kg^{-1} feed; L = as on label and M = measured in laboratory.

SAMPLE	Dry matter		Crude ash		Crude protein		Crude fat		Crude fibre	
	L	M	L	M	L	M	L	M	L	M
Starter										
Feed S1 mash	90	91.6	12	31.3	40.0	20.9	10.0	4.0	8.0	12.1
Feed S2 (3 mm)	NA	92.1	8.0	7.9	30.0	33.6	5.0	7.3	6.0	4.9
Feed S3 (starter)	NA	93.3	NA	13.3	27.0	30.5	NA	5.3	NA	4.9
Feed S4 (starter)	NA	92.6	10.5	11.2	57.0	58.3	15.0	14.7	0.4	1.1
Grower										
Feed G1 mash	90	91.6	12	31.3	40.0	20.9	10.0	4.0	8.0	12.1
Feed G2 (4.5 mm)	NA	91.0	8.0	8.3	30.0	35.5	5.0	6.9	6.0	5.4
Feed G3 (Grower)	NA	92.0	NA	12.2	27.0	33.8	NA	16.7	NA	4.7
Feed G4 (Grower)	NA	91.6	7.5	8.2	35.0	47.0	9.0	12.6	3.3	3.4

Table 2
Average monthly water temperatures (°C) for the experimental ponds in Central and Western Kenya calculated from the observations collected for the duration of the experiment.

Reading time	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Central Kenya								
0800h	18.4	19.2	19.1	20.2	19.4	20.6	20.5	20.8
1700h	19.9	21.6	22.0	24.3	22.5	23.9	24.3	25.5
Western Kenya								
0800h	26.8	26.8	27.5	27.9	28.4	28.1	27.1	27.2
1700h	27.1	27.5	27.9	28.3	29.1	28.5	27.4	27.5

with strain 1 average 3.0 ± 0.98 g, strain 2 0.29 ± 0.27 g, and strain 3 0.08 ± 0.01 g. In Western Kenya, the average stocking weight of fingerlings was 1.17 ± 0.70 g, with strain 1 average 1.05 ± 0.12 g, strain 2 2.03 ± 0.33 and strain 3 0.43 ± 0.12 g. Fingerlings were fed starter feeds three times per day (09:00 h, 01:00 h, 16:00 h). The daily amount of feed was calculated based on the body weight of fish in grams: fish < 10 g = 7 % of BW; fish > 10 < 20 g = 6 % BW. Sampling to determine the weight of the fish and to adjust feeding was done every seven days. To reduce stress, fish were not fed on the day of sampling. Growth was monitored by individually weighing 30 randomly selected fingerling from each hapa using electronic weighing balances (readability 0.01 g).

The second phase of the experiment was initiated once fish at one site had gained an average weight of 20 g. At that time, after the standard length and weight for each fish was measured, stocking densities were reduced to 3 fish m^{-2} (18 fish per hapa) by random selection for the second phase of the experiment when grower feeds were fed to all fish at all sites. During phase two of the experiment, fish were fed twice a day (09:00 h and 16:00 h). The daily amount of feed was based on the body weight of fish in grams: fish < 10 g = 7 % of BW; fish > 10 < 20 g = 6 % BW; fish > 20 < 30 g 5 % of = BW; fish > 30 < 50 g = 4 % of BW; fish > 50 < 150 g = 3 % of BW; and fish > 150 g = 2 % of BW. Sampling was done 14 days and fish were not fed on the day of sampling. Growth was monitored by individually weighing nine randomly selected fish per hapa.

Water quality monitoring throughout both phases of the experiment included 1) water temperature and DO recorded daily (08:00 h and 17:00 h) and 2) ammonia (NH_4) recorded weekly. Measurements of DO and NH_4 were primarily taken to inform management responses, if necessary, other than the weekly water exchange at 30 % of water for each pond. The performances of the different strain and feed combinations were evaluated based on the average weight gain (WG) in grams, the average feed conversion ratio (FCR) [feed given (g)/ average weight gain (g)]. Feed costs were calculated as total feed given for the hapa * feed costs kg^{-1}.

2.5. Data analysis

The data for each phase were analyzed by a fixed effect model equivalent to a two –way analysis of variance at each site, to examine the effects of feed and strain interactions. For the first phase, the statistical model included nursery pond, fish strain, type of starter feed and the interaction between fish strain and type of feed as fixed effects. Average stocking weight per hapa nested within the nursery pond and the nursery period in days were included as covariates, to account for the effect of differences in stocking weight and growth period. For the second phase, the fixed model effect included grow-out pond, fish strain, type of feed, sex of fish and the two-way interactions of fish strain with type of feed and sex of fish. The average stocking weight at the beginning of phase two, nested within grow-out pond, was treated as a covariate to account for the effect of differences in stocking weight. The Bonferroni adjustment method was used to correct for the multiple pairwise comparisons. All analyses were done using SPSS (Statistical Package for the Social Sciences Inc., IBM Corp., released 2011).

3. Results

Overall survival rates across individual replicates at each phase of the experiment were similar at the two locations. The mean survival across all replicates was 85.0 ± 10.4 % (standard deviation) in Central and 84.0 ± 13.7 % in Western Kenya during the starter phase, and 94.2 ± 6.3 % in Central and 94.8 ± 9.8 % in Western Kenya during the grower phase. In neither phase were mortalities concentrated in any treatment or pond but were spread throughout treatments and replicates. The experiments were contiguous, with a cull of fish to reduce fish densities prior to assessing the grower phase so that the only mortalities between phases were those resulting from the planned culls.

In Central Kenya, over all strains and feeds, the average harvest weight of individual fish at the end of the starter phase was 5.9 ± 8.4 g compared with 19.5 ± 13.7 g in Western Kenya. Thus the average stocking weight for the grower period was 7.1 g ± 8.3 g in Central Kenya and 21.7 g ± 11.7 g in Western Kenya, achieving average weights of 53.6 ± 43.0 g and 189.8 ± 99.1 g and standard lengths of 10.6 ± 2.9 cm and 16.4 ± 2.7 cm, respectively at harvest.

There were significant effects of strain, feed (both starter and grower feeds) and pond on weight gain and FCR, and significant interactions between strain and feed in Western Kenya (Tables 3a, 3b). In contrast, there was no significant effect of strain on weight gain or FCR during the period fish were on grower feed in Central Kenya. Interactions between strain and feed were significant only for weight gain when fish were on starter feeds. There were no significant effects of pond on FCR in Central Kenya.

Sex could not be determined in the younger fish, and FCR was calculated for the total population in a hapa. Therefore, sex and sex x strain effects could only be determined for weight gain on grower feeds and these effects were significant in both Central and Western Kenya.

Table 3a
Least squares means (± SE) of the location effect on weight gain in grams, feed conversion ratio (FCR) and feed costs (KES kg^{-1} over the production cycle for each hapa) for starter and grower feeds in each of Central and Western Kenya averaged over all strains and feeds. All values are significantly different between locations.

Location	Central	Western
Starter		
Weight gain (g)	6.5 ± 0.2	19.4 ± 0.2
FCR [feed (g) / WG (g)]	2.4 ± 0.1	2.1 ± 0.1
Cost (KES kg^{-1})	528.2 ± 15.5	474.9 ± 15.5
Grower		
Weight gain (g)	65.3 ± 4.8	149.5 ± 5.1
FCR [feed (g) / WG (g)]	3.8 ± 0.3	1.7 ± 0.3
Cost (KES kg^{-1})	422.8 ± 27.1	212.5 ± 27.1

With respect to the co-variates, there was some variation for grow-out period in Central Kenya during the starter feed phase, and the effects of this on weight gain were significant (the fish growing for longer being larger). The variation in stocking weight of the fish had significant effects on weight gain (those stocked at larger size having a larger weight at harvest), but no significant effect on FCR, in both starter and grower periods in both Central and Western Kenya.

The magnitude of the differences of the effects of the main factors can be seen in the least squares means of weight gain and FCR for given strains, feeds or sexes (Table 4). The lack of significant differences among strains for weight gain and FCR on grower feeds in Central Kenya is clear as is their much lower weight gain, and higher FCR values, compared with those values for Western Kenya. The relative ranking of individual starter and grower feeds differed in Central and Western Kenya, but the differences in weight gain in Western Kenya were greater. Growth of males was significantly greater than females in both sites and for all feed and strain combinations, although the significant strain x sex (Tables 3a, 3b) showed there was variation in the amount of the difference between the sexes. However, given the significance of the interactions between fish strains and feeds, the main results are seen most clearly in a graphical representation of all strain and feed combinations (Figs. 1–3) discussed in more detail below.

In the starter phase in Western Kenya, all strains had higher weight gain on feed S4 while their performances on the other feeds were similar (Fig. 1 top right graph). There was markedly lower weight gain for all strain and feed combinations in Central Kenya relative to Western Kenya. The three strains ranked consistently differently for FCR values, with strain 1 > strain 2 > strain 3, on all feeds in Central Kenya, and for feeds S2 and S3 in Western Kenya (Fig. 1 bottom graphs). FCR values were marginally greater in Central Kenya relative to Western Kenya.

In the grower phase (Fig. 2), the lack of significant effects of strain on weight gain in Central Kenya was obvious, as was the much lower

Table 3b
Significance levels for the effects of the factors, listed on the left of the table, given separately for the analyses of weight gain (WG) and feed conversion ratio (FCR) and costs (KES kg^{-1}) for starter and grower feeds in each of Central and Western Kenya. Statistically significant effects are given in bold. NA indicates tests were not possible or appropriate: sex could not be determined in the younger fish, and FCR was calculated for the total population in a hapa. Therefore, sex and sex x strain effects could not be determined for starter feeds or for FCR. Significance of the effects of covariates are given at the bottom of the Table. The grow out period was identical for the tested groups in all cases except for starter feeds in Central Kenya, and therefore the test was only appropriate for that one circumstance.

	Central						Western					
	Starter			Grower			Starter			Grower		
Factors	WG	FCR	Cost	WG	FCR	Cost	WG	FCR	Cost	WG	FCR	Cost
Strain	**<0.01**	**<0.01**	**<0.01**	0.20	0.89	0.92	**<0.01**	**0.05**	**<0.05**	**<0.01**	**<0.01**	**<0.01**
Feed	**<0.01**	**0.01**	**<0.01**	**<0.01**	**0.05**	0.08	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Pond	**<0.01**	0.24	0.34	**<0.01**	0.14	0.18	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**0.01**	**<0.01**
Sex	NA	NA	NA	**<0.01**	NA	NA	NA	NA	NA	**<0.01**	NA	NA
Strain x Feed	**<0.01**	0.28	0.79	0.13	0.24	0.32	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**	**<0.01**
Strain x Sex	NA	NA	NA	**<0.01**	NA	NA	NA	NA	NA	**0.02**	NA	NA
Covariates												
Grow-out period	**0.01**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Average stocking weight	**<0.01**	0.30	0.13	**<0.01**	0.35	0.49	**<0.01**	0.68	0.18	**<0.01**	0.09	**0.04**

Table 4
Least squares means (± SE) of the strain, feed and sex effects on weight gain (WG) in grams and feed conversion ratio (FCR) for starter and grower feeds in each of Central and Western Kenya. Values within a column for a given group (strain, feed, or sex) with the same alphabetic superscripts are not significantly different but differ significantly from those with different alphabetic superscripts within that group in that column. Feeds 1−4 refer to feeds S1−S4 for the starter columns data and feeds G1−G4 for the grower columns data.

	Central				Western			
	Starter		Grower		Starter		Grower	
Factors	WG	FCR	WG	FCR	WG	FCR	WG	FCR
Strain								
Strain 1	$7.1^{a} \pm 0.4$	$3.2^{b} \pm 0.3$	$45.6^{a} \pm 4.8$	$3.0^{a} \pm 1.3$	$21.0^{a} \pm 0.3$	$2.3^{a} \pm 0.1$	$162.9^{b} \pm 10.5$	$1.9^{a} \pm 0.0$
Strain 2	$6.0^{ab} \pm 0.3$	$2.4^{b} \pm 0.2$	$51.8^{a} \pm 2.7$	$3.8^{a} \pm 0.8$	$17.7^{b} \pm 0.9$	$2.2^{a} \pm 0.3$	$157.4^{b} \pm 9.5$	$2.8^{b} \pm 0.1$
Strain 3	$5.4^{b} \pm 0.2$	$1.7^{a} \pm 0.2$	$47.6^{a} \pm 3.0$	$4.0^{a} \pm 0.9$	$20.4^{a} \pm 0.8$	$2.0^{a} \pm 0.2$	$236.6^{a} \pm 11.4$	$1.8^{a} \pm 0.1$
Feed								
Feed 1	$4.9^{c} \pm 0.2$	$2.8^{b} \pm 0.3$	$33.4^{c} \pm 4.0$	$5.2^{b} \pm 0.6$	$18.6^{b} \pm 0.3$	$2.1^{ab} \pm 0.1$	$103.9^{d} \pm 8.5$	$2.7^{c} \pm 0.1$
Feed 2	$7.0^{b} \pm 0.2$	$2.3^{ab} \pm 0.2$	$45.5^{b} \pm 4.1$	$3.3^{ab} \pm 0.7$	$17.9^{b} \pm 0.3$	$2.1^{ab} \pm 0.1$	$172.5^{c} \pm 7.8$	$1.9^{b} \pm 0.1$
Feed 3	$4.6^{c} \pm 0.2$	$2.5^{ab} \pm 0.2$	$54.7^{a} \pm 4.1$	$2.8^{a} \pm 0.6$	$16.5^{c} \pm 0.3$	$2.5^{c} \pm 0.1$	$214.1^{b} \pm 10.1$	$1.6^{a} \pm 0.1$
Feed 4	$8.1^{a} \pm 0.2$	$2.1^{a} \pm 0.3$	$52.0^{ab} \pm 4.0$	$3.0^{ab} \pm 0.6$	$25.9^{a} \pm 0.3$	$2.0^{a} \pm 0.1$	$252.0^{a} \pm 7.9$	$1.5^{a} \pm 0.1$
Sex								
Female	NA	NA	$36.0^{b} \pm 2.4$	NA	NA	NA	$151.2^{b} \pm 11.3$	NA
Male	NA	NA	$60.7^{a} \pm 1.2$	NA	NA	NA	$220.1^{a} \pm 5.6$	NA

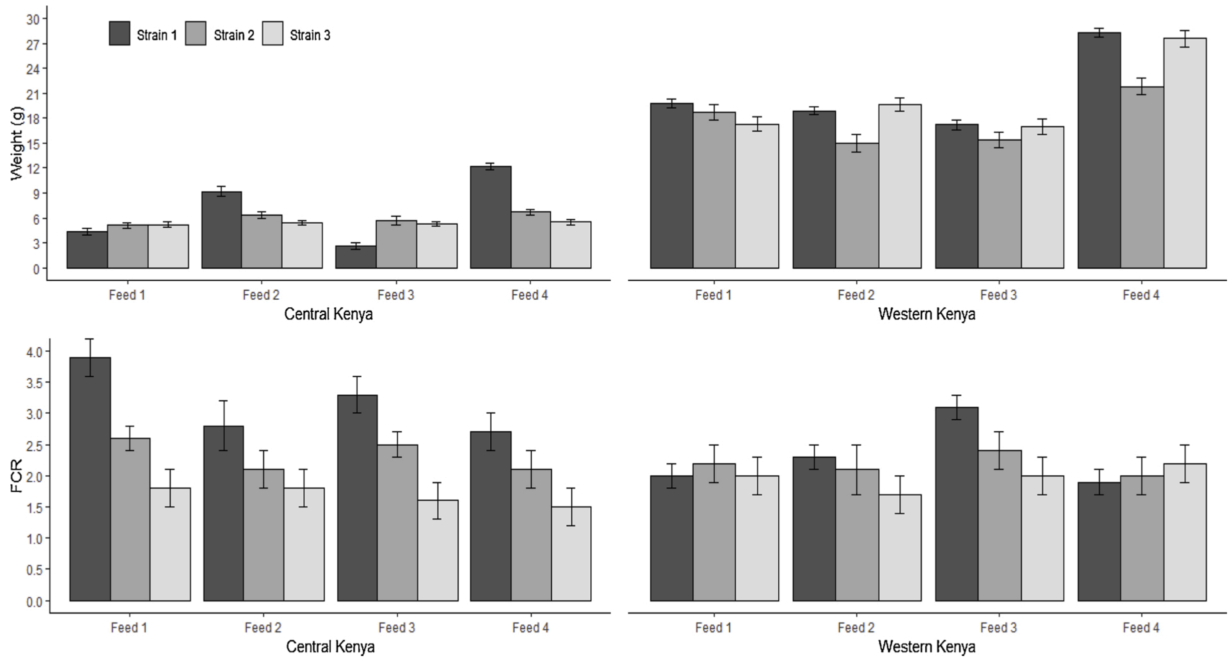

Fig. 1. Weight gain (g) and FCR for starter feeds in Central and Western Kenya for each of the strain and feed combinations. The error bars are standard errors. Feeds 1-4 refer to feeds S1-S4 given the figure reports the starter feed data.

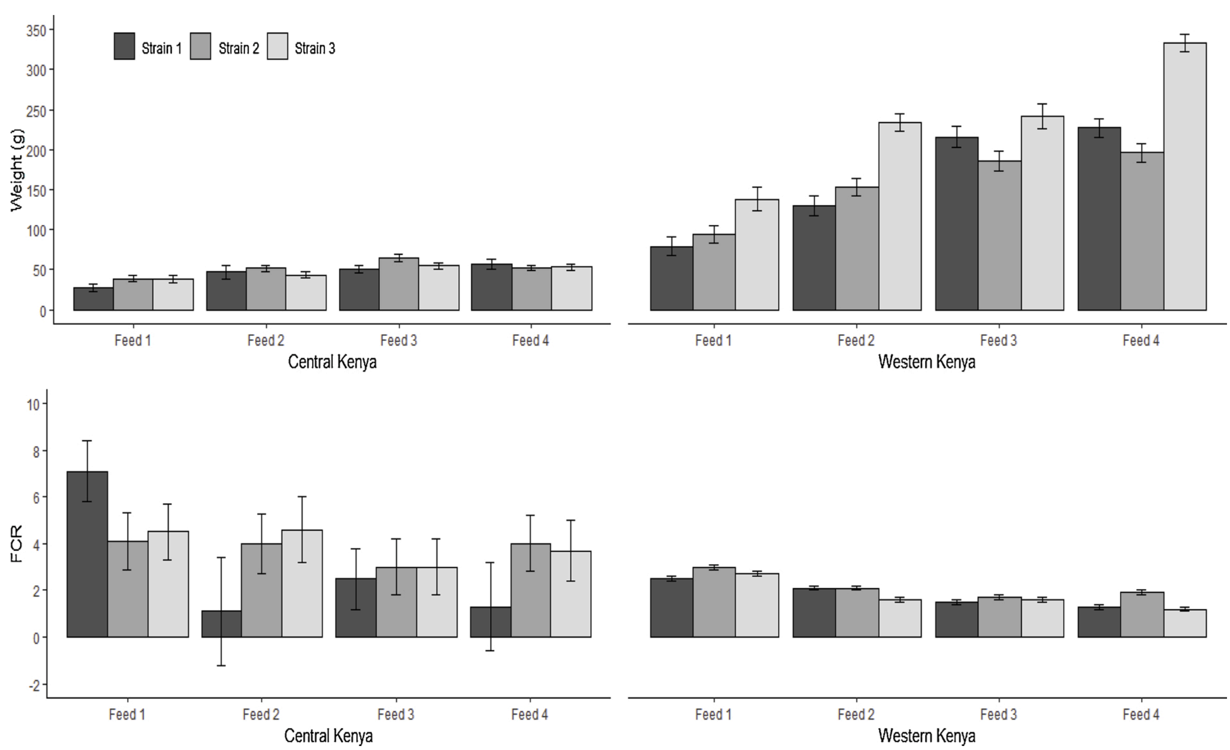

Fig. 2. Weight gain (g) and FCR for grower feeds in Central and Western Kenya for each of the strain and feed combinations. The error bars are standard errors. Feeds 1-4 refer to feeds G1-G4 as the figure reports the grower feed data.

weight gain in Central Kenya compared with Western Kenya (Fig. 2 top graphs). There was a trend of greater weight gain from feed G1 to feed G4 in Western Kenya, and of weight gain for strain 3 being greater than that of strains 1 and 2. There was a similar, but less obvious, trend of reducing FCR from feed G1 to feed G4 in Western Kenya. FCR values were high (around 4) and variable in Central Kenya, lower (around 2) and less variable in Western Kenya (Fig. 2 bottom graphs).

The effects of strains and feeds on costs are summarized in Table 5. Feed costs in the various feed and strain combinations in both the starter and grower phases tended to reflect the same patterns as the respective FCR values in Figs. 1 and 2 (Fig. 3). The starter phase costs for strain 1 $\geq$ strain 2 $>$ strain 3 for all feeds in Central Kenya and all feeds except feed S4 in Western Kenya (Fig. 3 top graphs). Costs for feed S1 $<$ feed S3 $<$ feed S2, $<$ feed S4 in both Central and Western Kenya. In the grower phase, there was greater variability of costs for a given feed strain combination in Central Kenya relative to Western Kenya (Fig. 3 bottom

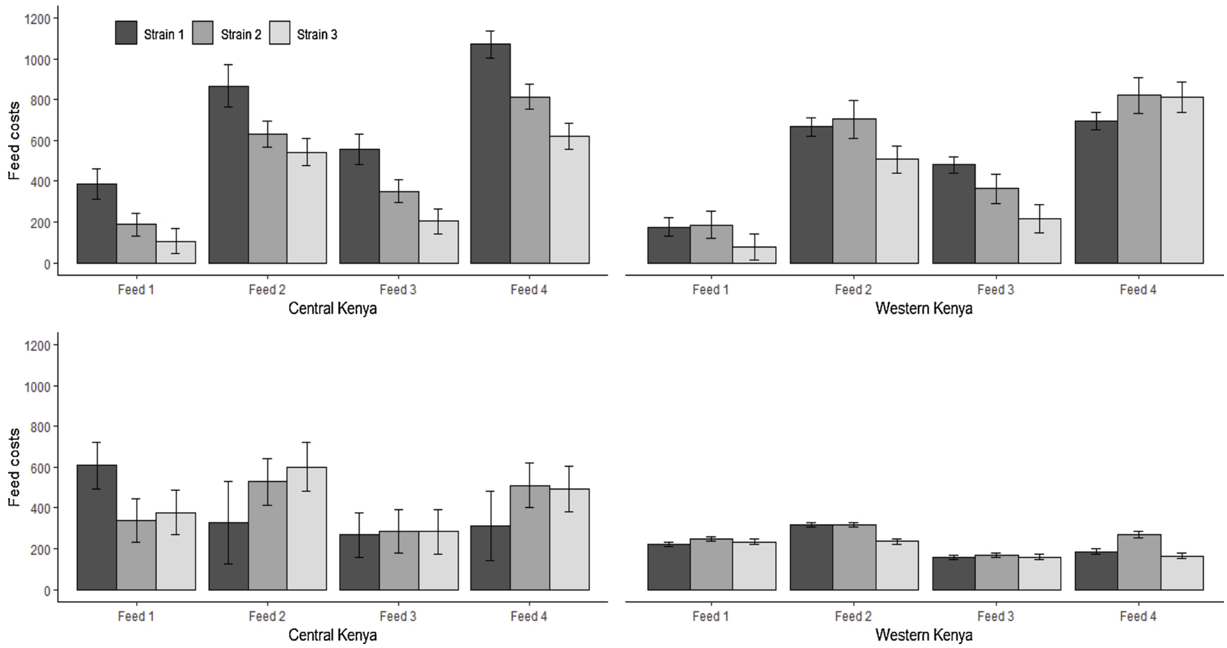

Fig. 3. Feed costs (KES kg^{-1} fish produced) for starter feeds (top graphs) and grower feeds (lower graphs) in Central and Western Kenya for each of the strain and feed combinations. The error bars are standard errors. Feeds 1-4 refer to feeds S1-S4 for the starter graphs (top two graphs) data and feeds G1-G4 for the grower columns data (lower two graphs).

Table 5
Least squares means (± SE) of the strain and feed effects on costs (KES kg^{-1} fish produced per hapa) for starter and grower feeds in each of Central and Western Kenya. Values within a column for a given group (strain, feed, or sex) with the same alphabetic superscripts are not significantly different but differ significantly from those with different alphabetic superscripts in that column. Feeds 1-4 refer to feeds S1-S4 for the starter columns data and feeds G1-G4 for the grower columns data.

	Central		Western	
	Starter	Grower	Starter	Grower
Factors				
Strain				
Strain 1	720.5^{b} ± 64.8	380.1^{a} ± 118.5	503.6^{a} ± 24.1	221.0^{a} ± 5.8
Strain 2	496.1^{b} ± 37.6	416.2^{a} ± 69.6	519.0^{a} ± 70.8	251.1^{b} ± 6.5
Strain 3	368.4^{a} ± 41.6	438.6^{a} ± 75.2	403.8^{a} ± 58.5	199.1^{a} ± 6.1
Feed				
Feed 1	226.9^{a} ± 31.0	442.0^{a} ± 57.1	146.9^{a} ± 24.2	234.4^{b} ± 6.8
Feed 2	680.3^{c} ± 31.3	486.6^{a} ± 57.8	625.8^{c} ± 24.3	290.3^{c} ± 6.8
Feed 3	371.0^{b} ± 31.0	279.2^{a} ± 57.3	353.5^{b} ± 23.6	162.8^{a} ± 7.3
Feed 4	835.1^{d} ± 32.7	438.7^{a} ± 56.7	775.7^{d} ± 23.6	207.3^{b} ± 9.3

graphs). Feed G3 had the lowest cost over all strains in both Central and Western Kenya. Costs among strains varied with feed and location.

4. Discussion

The optimal conditions for good growth of tilapia are well known (Thomas and Michael, 1999; El-Sayed, 2006; Mjoun et al., 2010; Santos et al., 2013) and the loss in production when these are not used (yield gaps) have been analyzed (Mengistu et al., 2020). Low water temperature constrains fish growth as fish can metabolically convert only a fraction of the nutrition provided in those conditions, and tilapia do not feed when temperatures drop below 18–20 °C. The lower growth, higher FCRs (average 3.6) and limited differentiation in performance of feeds and strains in Central Kenya are clear indicators of culture in a sub-optimal environment. The lower temperatures there reduced growth and appear to have done so irrespective of the quality of feed or strain.

The more optimal environment in Western Kenya permitted a clearer differentiation of the growth potential of different feeds and strains. One of the formulated starter feeds (feed S4) had better performance over all strains than the other feeds and was differentiated in the ingredient analysis by higher crude protein and fat levels than the other feeds. During the grower phase greater weight gain was observed in the formulated feeds (feeds G2-G4) compared with bran mash (feed G1). The higher performing formulated feeds (feeds G3 and G4) were differentiated in the ingredient analysis by having higher crude fat levels than the other formulated feed (feed G2). The pattern of increasing weight gain from bran to formulated feed was mirrored in decreasing values of FCR indicating increasing efficiency of feed utilization using formulated diets. Higher weight gain and reduced FCRs during the grower phase were observed clearly for strain 3 relative to the two other strains tested in Western Kenya and had better FCRs in both Central and Western Kenya during the starter phase. The better performance of Nile tilapia on formulated feeds relative to brans and differences between formulated feeds have been reported before, including in Kenya (Munguti et al., 2014b; Opiyo et al., 2018) but a key observation from the present comparisons was that the degree of improved performance differs between strains, with the faster growing fish having greater levels of improvement than slower growing ones.

Realizing efficiencies is a key factor influencing the economic success and failure of farm businesses. The additional gain in growth, but more importantly, the improved FCRs which indicate greater efficiencies resulting from the use of formulated feeds and superior strains, clearly demonstrated the value of using quality inputs (see also the review of feeds in Kenya by Munguti et al., 2014b). However, the additional growth obtained by the use of more expensive feeds/strains is only profitable if they provide efficiencies, or additional income from the extra production, that exceed the added costs. Given the constraints of experimental rearing in hapas the growth rates differed from that in open ponds and were slower than that reported for tilapia in other experiments in Kenya (e.g. Opiyo et al., 2020). Similarly, the experimental costs were not representative of pond rearing, so the actual cost of the experimental treatments will not be pertinent, but the relative values are informative.

For example, formulated starter feed S4 produced approximately 50 % greater weight gain than the other feeds in Western Kenya but the cost of production was still about twice that of other formulated feeds and four times that of bran. This suggests that the additional production was not achieved with an improved efficiency sufficient to offset the additional cost of the feed, and indeed similar FCRs were observed among all the starter feeds. The starter feed data also show the benefits of superior performing breeds like strain 3. This strain had similar weight gain to other strains but better FCRs than those for a given feed, and so had reduced cost of production (kg^{-1} of fish) relative to the other strains for feeds S1-S3 in Western Kenya and for all feeds in Central Kenya.

The results for the grower phase also illustrated the cost effectiveness of superior performing feeds and strains where the formulated feeds G3 and G4, in combination with strain 3, had the lowest costs of production in the data set. They also showed that a cheap feed that produces limited growth may have a large cost per unit weight of fish produced. The costs of production (kg^{-1} of fish) in Western Kenya for the formulated feeds G3 and G4 was less than that for bran, (feed G1), the cheapest feed to buy, irrespective of fish strain used. However, where environmental conditions are not optimal such as in the Central Kenyan site, these efficiencies were not obtained providing no significant difference in cost observed between feeds or strains. The top performing grower combination in Western Kenya of strain 3 with feed G4 provided a 38 % higher weight gain compared to the second best performing combination, strain 3 with feed G3. Both had similar costs of production, however, suggesting careful comparison of additional cost and actual performance in relation to achieved FCRs for a given farm environment is necessary to optimize profitability.

The experiment showed the importance of culturing tilapia in environmental conditions within the optimum range in order to benefit from investment in more expensive but higher performing strains and feeds, although some differentiation was observed in Central Kenya in the starter phase among strains/feeds. In the grower phase, costs in the Central Kenyan were roughly twice that in Western Kenyan site. Profitable aquaculture in the Central region may only be achieved in particularly favorable sites, stocking larger fingerlings to take account of shorter growing seasons, perhaps using heating or indoor phases when fingerlings are more sensitive to thermal conditions (Azaza et al., 2008, 2010). The proximity to large population centers in Nairobi and relatively high value markets is the attraction for farmers to the Central region and are sufficiently high to support greater production costs.

5. Conclusions

The work has demonstrated that the quality of inputs available in the country vary and that different feed and strain combinations lead to significant differences in the relative weight gain, food conversion ratio and cost. The large differences in performance achieved by different feed and strain combinations grown in the same circumstances and the fact that the relative outcomes can vary markedly between environments, underscores the need for more benchmarking studies in Kenyan production systems to identify the better performing feeds and strains for given environments. Higher upfront investment in quality feeds and quality strains, especially during the grow-out period of fish, can provide significant benefit as the overall production costs can be lower and farm profitability higher. The use of mash, the cheapest feed tested, produced lower weight gain in the grow-out phase and relatively higher cost per unit weight of fish produced than high protein well-formulated feeds which gave significantly higher weight gain at comparatively lower feed costs, particularly when used in combination with feed efficient strains.

Successful farming is dependent on well thought out business plans and sound operational management to obtain the efficiencies required to be profitable. Promotion of tilapia aquaculture will need to address such business skills, take account of regional differences in environments, markets and differential access to quality inputs and the variable performance of inputs demonstrated in the present study. Given that the choice of the right feed and strain combinations will have an important influence on the profitability of operations there is a need for more benchmarking of key inputs. This study did not test all feeds and strains available in Kenya, but contributes to a practical basis for recommendations to stakeholders in the Kenyan aquaculture sector. If combined with costs known from pond production and prices of fish in given markets the potential profitability for given circumstances could be calculated.

Author statement

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Ethics approval and consent to participate

Protocols used were in accordance with the Guiding Principles of the Animal Care, Welfare and Ethics Policy of WorldFish Center.

Declaration of Competing Interest

The authors report no declarations of interest.

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