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Performance Evaluation of Available Strains of Nile Tilapia (*Oreochromis niloticus*) Fed Commercial and Locally-Made Feeds in the Democratic Republic of the Congo

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Abstract: The performance of two strains of Nile tilapia (the Nyakabera and Lake Kivu) fed a commercial feed or either a fishmeal-based or a fishmeal-free feed formulated using local ingredients was evaluated for 99 days in Bukavu, eastern highlands of the DR Congo (Experiment 1). Strain × feed interaction was significant ($p < 0.05$) for final body weight (FBW) and condition factor (CF). Growth of both strains was best with the commercial feed. Fish-meal free formulated feed resulted in similar or better fish growth than a local fishmeal-based formulated feed depending on the strains. Lake Kivu strain had significantly ($p < 0.05$) higher FBW when fed the commercial and fishmeal-free feeds than the Nyakabera strain, but when fed the fishmeal-based feed the difference was not significant. The performance of the other three Nile tilapia strains (the GIFT-Congo Futur, GIFT-RATALBI and Tihange strains) fed a single commercial feed was evaluated for 84 days in Kinshasa, western lowlands of the DRC (Experiment 2). Male GIFT-Congo Futur and GIFT-RATALBI did not differ significantly ($p > 0.05$) in FBW and CF, but both performed better than the Tihange. FBW of the female GIFT-Congo Futur was significantly higher than that of the other two strains, while CF was not significantly ($p > 0.05$) different among strains in females.

Keywords: aquaculture; Bukavu; feeds; fish strains; Kinshasa

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1. Introduction

Aquaculture is the fastest growing sector of food production globally, with an average of 4.5% annual growth between 2011 and 2018 and the highest growth rate (>10%) recorded in Africa [1–3]. Despite the recent developments in aquaculture in Africa [3], the sector is yet to realize its full potential [4], as aquaculture only contributed 18% of the total fish production on the continent in 2018 [1,2]. The current trends suggest a continued growth in African aquaculture in the future [2,3], although this growth will likely not be sufficient to satisfy the needs of the growing human population (and income) in Africa, especially in the context of stagnant global capture fisheries.

In the Democratic Republic of the Congo (DR Congo), the main constraints to aquaculture development are the lack of availability and access to quality seed, feed and extension

services, in addition to trade barriers on associated inputs and products [5]. Good, commercial feeds are often imported at a price that is prohibitive for smallholder farmers, and the government extension service is not effective in providing support due to inadequate funding and training [6].

Of the fish species produced in DR Congo, Nile tilapia (*Oreochromis niloticus*) is the most popular [7]. As a result of the limited number of hatcheries in the country, farmers have had to use any seed of apparently good quality available locally or imported from the neighboring countries. Many strains of Nile tilapia have been introduced in the DR Congo, both formally and informally. These fish strains include the Genetically Improved Farmed Tilapia (GIFT) strain reported to have originated from Zambia, the Tihange strain imported from Belgium, and the Nyakabera strain imported from Rwanda found in Bukavu (Eastern DR Congo). These strains are farmed and bred either among themselves or with local Nile tilapia such as the Lake Kivu strain. Little information is available on the growth performances of the Lake Kivu and Nyakabera strains found in Eastern DR Congo as well as the Tihange and two GIFT-derived strains found in Western DR Congo. A benchmark study to obtain basic information of the performance of the available strains, in different farming contexts, is necessary.

The increasing use of aquafeeds is anticipated to play a pivotal role in aquaculture development in Africa [8]. The high cost of commercial feeds prevents most of the smallholder farmers in rural areas from feeding their fish with pellets [9]. The farmers, therefore, often rely on the primary production of natural food in the ponds or the use of low quality mashes made of local ingredient(s) such as unused bread crumbs, distiller's dried grains with soluble (DDGS), and rice and maize brans [10]. A recent survey revealed that many of the conventional ingredients necessary to produce balanced aquafeeds are available in most of the markets in DR Congo [11]. Formulating, testing and validating feeds made of local ingredients, which could be cheaper and readily available to farmers, could directly provide viable feeding options to farmers and indirectly support the sustainable growth of tilapia farming in DR Congo.

The objectives of this study were therefore (1) to benchmark the relative performance of Nile tilapia strains currently available in DR Congo and (2) to assess the potential of fishmeal-based and fishmeal-free feeds formulated with local ingredients as compared with imported commercial pelleted feed. The goal of the study was thus to assess the potential of fish strains available for farms today with currently available local ingredients and feeds in two different climatic zones, as a first step to provide directions for meeting performance gaps in fish farming in DR Congo.

2. Materials and Methods

Two experiments were run concurrently in two different regions of DR Congo: experiment 1 from 19 August to 26 November 2019 (99 days), and experiment 2 from 12 September to 5 December 2019 (84 days). Each experiment focused on the feeds and strains locally available as the regions differ in the Nile tilapia strains to which they have ready access given the geographical extent of DR Congo. The nature of the experimental facilities available determined the complexity and scale of the experiment at each location. Experiment 1 was conducted at the Nyakabera fish station in Bukavu, eastern highlands of DR Congo, to evaluate the performance of two strains of Nile tilapia, the Nyakabera and Lake Kivu strains, fed a commercial feed or either a fishmeal-based or a fishmeal-free feeds formulated using the local ingredients. Experiment 2 was conducted at the RATALBI fish station in Kinshasa, western lowlands of DR Congo, to assess the performance of three strains of Nile tilapia, two GIFT-derived strains (GIFT-Congo Futur and GIFT-RATALBI) and the Tihange-derived strain, fed a single commercial feed. Fish handling throughout the two experiments was in accordance with the animal care and ethics policy of WorldFish.

2.1. Experiment 1 in Bukavu, Eastern Highlands DR Congo

2.1.1. Experiment Design and Facility

The experiment was conducted using a 2 × 3 factorial randomized complete block design. The experiment was carried out in net enclosures referred to as "hapas" (experimental units) of 1.1 × 0.9 × 0.8 m (0.8 m^2 surface) each, with 1 mm mesh size. The hapas were installed in ponds (33 m × 16 m each). The first factor was 'strain', with two levels, the Nyakabera and Lake Kivu strains. The second factor was 'feed', with three levels, commercial feed manufactured in Zambia, a locally-made feed containing 30% local fishmeal (trash freshwater fish) in the diet and fishmeal-free locally-made feed. Ingredients available in the local markets of Bukavu, South Kivu, were used to formulate the last two feeds [11]. There were thus six treatments (two strains × three feeds), with each treatment applied in triplicate. There were therefore 18 (2 × 3 × 3) experimental hapas, with nine hapas per strain ("Nyakabera" or "Lake Kivu" strains) and six hapas receiving each of the three experimental feeds. The experiment was conducted in three experimental ponds (blocks), with one replicate for each of the six treatments applied in one pond (block).

2.1.2. Pond Preparation

Prior to the start of the experiment, all three experimental ponds were emptied and the dikes repaired. Thereafter, the ponds were immediately limed (150 g/m^2), dried for one week and filled with water (80 cm depth on average). The water inlet and outlet were covered with a fine-meshed wire screen to prevent the entry of predators or wild fish into the pond. Di-ammonium phosphate (DAP) and urea fertilizers were applied at 1.5 g/m^2/day and 2 g/m^2/day, for a total of seven days. The fertilizers were first diluted with pond water in a bucket and then the fertilizer solution was sprayed evenly on the surface of the pond. The application of the inorganic fertilizers stopped when Secchi disc transparency was below 40 cm. The experimental fish were stocked in the ponds nine days after the ponds were filled with water.

2.1.3. Fish

The Nyakabera strain was introduced to the Nyakabera station in Bukavu in 2005 from the Université Nationale du Rwanda, Rwasave fish farming station in Butare, Rwanda [12]. This Nyakabera strain is described as a mix of Ivorian and Egyptian strains of Nile tilapia that was introduced to the l'Université Nationale du Rwanda de Rwasave in Butare from Auburn University in the US, between 1984 and 1985 [12]. The broodstock used to produce the fry of the Lake Kivu strain used in the experiment was collected from the Bukavu basin of Lake Kivu and bred at the Nyakabera government station. The two strains are referred to as the Nyakabera strain and the Lake Kivu strain in the various sections of the present paper only for simplicity and consistency with the appellations used by other authors who worked with these strains in the past [12–14].

The eggs and larvae from the two strains were incubated and reared at The President Olusegun Obasanjo Research Campus, in Kalambo, South Kivu, before being transferred to the Nyakabera fish station, where the experiment was conducted. Each of the experimental hapas was stocked at a density of 30 fish/0.84 m^2 of hapa (300 fish per hapa) for a total of 5400 fry for the 18 hapas. The average initial weights ± standard deviation of the fish were 0.84 ± 0.06 g and 0.84 ± 0.02 g for the Nyakabera and Kivu strains, respectively.

2.1.4. Feed Formulation and Feeding

The commercial diet was purchased from Zambia (Table 1). This feed was the only commercial feed available on the market in Bukavu at the time of the experiment and cost USD 2 per kg. Two experimental feeds were locally formulated to satisfy the known nutrient requirements of Nile tilapia [15] (Table 1). Each ingredient used in the locally-made feeds was first milled to the size of <750 µm. The finely ground ingredients were weighed and mixed with a locally made mixer for 30 min for homogeneity. Oil was slowly added to the mixture. Thereafter, hot water was added to the mixture to achieve a dough. This

dough was then pelleted using a locally made pelletizer, and then dried overnight at 60 °C on a locally made belt dryer. The feeds were sealed into labelled zipper bags and stored at −20 °C until use. A total of 5 kg of 0.5 mm pellet size and 5 kg of 1 mm pellet size was prepared for each of the formulated experimental feeds. The estimated cost of the ingredients used to produce 1 kg of feed was USD 1.18 and USD 1.13 for the fishmeal-based and fishmeal-free formulated feeds, respectively (Table 1). The cost of the formulated diets did not take into account the costs related to ingredients sourcing, feed processing and transport. Given that the overall cost of the ingredient sourcing and processing cannot be accurately calculated for the formulated diets, we assumed that it represents about 30% of the feed cost, which is USD 0.51 for the fishmeal-based feed for a total cost of USD 1.64 per kg feed, and USD 0.49 for the fishmeal-free feed for a total cost of USD 1.62 per kg feed.

Table 1. Experiment 1 in Bukavu, eastern highlands DR Congo—composition of the commercial feed and the fishmeal-based and fishmeal-free feeds formulated using local ingredients fed Nile tilapia (*Oreochromis niloticus*) fry of the "Nyakabera" and "Lake Kivu" strains in Bukavu, DR Congo.

Ingredients (%)	Fishmeal-Based Feed	Fishmeal-Free Feed	Commercial Feed
Blood meal (cow)	20.00	29.50	
Fishmeal (37.5% CP)	30.00	0.00	
Soybean (local, full-fat)	20.00	24.00	
Cassava flour	5.00	5.00	
Corn (7.5% CP)	7.50	6.50	
Distillers/brewers grain	5.00	20.00	
Rice bran	5.00	3.00	
Palm oil	1.00	1.00	
Bone meal	1.00	4.00	
Trace mineral premix [a]	1.00	2.00	
Vitamin C	1.00	1.00	
Vitamin premix [a]	1.00	1.00	
DL-Methionine	0.75	1.00	
L-Lysine	0.75	1.00	
Palm kernel cake	1.00	1.00	
TOTAL	100.00	100.00	
Analyzed composition			
Dry matter, dm (%)	89.84	92.37	91.28
Crude protein (% dm)	28.52	22.66	26.95
Ash (% dm)	8.22	12.08	13.45
Total carbohydrate (% dm) [b]	52.46	54.60	48.65
Crude lipid (% dm)	10.81	10.67	10.94
Gross energy (kcal/100 g dm)	447.33	379.98	444.23
COST/kg (USD) [c]	1.184	1.134	2.000

[a] Mineral and vitamin premixes were purchased from a feed store in the market in Bukavu, and there were no indication on their composition. [b] Total carbohydrate calculated as 100-crude protein (%)-ash (%)-crude lipid (%). [c] The cost of the commercial feed was based on the purchase price, while the estimated cost of the formulated feeds did not take into account the costs related to ingredients sourcing, feed processing and transport.

During the experiment, the fish were hand-fed four times daily (8 h, 10 h, 12 h and 16 h), seven days a week, at the feeding rate of 10% feed/unit wet body weight/day initially. The feeding rate was gradually reduced to about 8% after 21 days, 5% after 42 days and 4% after 70 days. Each feeding episode in all the hapas lasted a maximum of one hour and the fish were observed during the feeding to assess whether the feeding rate was adequate and changes were made accordingly to avoid feed wastage.

2.1.5. Sample Collection and Analyses

Prior to the start of the experiment, a sample (1 kg) of each feed was collected for proximate analyses. In addition, two samples of 10 fish were randomly selected from initial fish group, killed with an overdose of clove oil and weighed to the nearest 0.01 g

and measured to the nearest 0.1 cm. These samples were then deep-frozen until further proximate analyses of the body composition.

Every two weeks, fish from each hapa were weighed and measured individually to estimate growth and adjust feeding rates. The hapas were changed during sampling; the dirty hapas were replaced by clean ones to allow good water circulation in and out of the hapas, and the dirty ones were washed and used for the next sampling.

At the end of the experiment, all fish from each hapa were harvested, counted and weighed individually to the nearest 0.01 g and measured to the nearest 0.1 cm. A pool of 10 fish was randomly collected from each hapa, killed with an overdose of clove oil, pooled and deep-frozen until later proximate analysis of the body composition. Five other fish were collected from each hapa, individually weighed, and their livers and gonads were collected and weighed for the calculation of the hepato- and gonado-somatic indexes.

Data on the water quality parameters such as temperature, dissolved oxygen, pH, and Secchi disk transparency were collected on a daily basis throughout the experiment. The temperature was on average 22.9 $\pm$ 1.2 at 9:00 AM, 24.9 $\pm$ 1.4 at 12:00 PM, and 23.3 $\pm$ 1.4 at 4:00 PM; the dissolved oxygen level at 12:00 PM was 7.7 $\pm$ 0.8 mg L^{-1}; the pH at 12:00 PM was 7.8 $\pm$ 0.7; and the water transparency was between 25 and 35 cm.

2.1.6. Analytical Methods

The fish and feed samples were collected and shipped to the International Institute of Tropical Agriculture (IITA) for subsequent laboratory analyses at the Kenya Agricultural and Livestock Research Organization (KALRO) in Nairobi, Kenya. The laboratory analyses included dry matter, ash, crude protein, crude lipid, and gross energy.

2.2. Experiment 2 in Kinshasa, Western Lowlands of DR Congo

2.2.1. Experiment Design, Facility and Fish

The experiment was conducted using a completely randomized design. The experimental treatments included three strains of Nile tilapia, namely the GIFT-derived RATALBI strain found at the fish station of the non-governmental organization RATALBI, the GIFT-derived Congo Futur strain obtained from the commercial farm Cap Congo Pisciculture, and the Tihange-derived strain originally imported from Belgium and available at the RATALBI fish station. Information from the farms indicated that the GIFT-derived Congo Futur and the GIFT-RATALBI strains of Nile tilapia used in this experiment were obtained in 2017 from the same commercial fish farm in Lubumbashi which sourced its broodfish from Chirundu, Southern Province, in Zambia. The GIFT-RATALBI strain was directly introduced to the station of the RATALBI Pisciculture where the experiment was conducted, while the GIFT-derived Congo Futur strain transited to the Cap Congo Pisciculture where they spent two years before being moved to the RATALBI Pisciculture for this experiment. During the two years that preceded the experiment, the GIFT-derived Congo Futur strain was isolated from any other strain available at the Cap Congo Pisciculture in Kinshasa and was fed balanced commercial farm-made floating feeds following a good feeding program, but did not undergo any planned breeding or genetic improvement program. During the same period, the GIFT-RATALBI strain was administered a less strict management protocol, and was fed low-quality farm-made powder or bullet feeds. In addition, it is possible that the GIFT-RATALBI strain was mixed and bred with another unknown Nile tilapia strain available at the RATALBI Pisciculture. As such, the GIFT-derived stain available at the Cap Congo Pisciculture (GIFT-Congo Futur) and the GIFT-derived strain available at the RATALBI Pisciculture (GIFT-RATALBI) are considered two distinct strains in the present experiment.

Little information is available on the precise origin of the Tihange-derived strain of Nile tilapia that was introduced to the RATALBI Pisciculture following importation from Belgium between 1985 and 1995 (precise dates not available). Over the years, no systematic measures were put in place to effectively control inbreeding within the imported Tihange-derived strain, and between this strain and any other known or unknown stock of fish

available at the RATALBI Pisciculture. Throughout the following text, these strains will be referred to as GIFT-Congo Futur, GIFT-RATALBI and Tihange, respectively.

Each treatment was applied in triplicate. Nine experimental hapas (experimental units) of 1.9 × 2.6 × 0.8 m (5.0 m^2 surface) each, with 1 mm mesh size were installed in a single large pond. The pond preparation and fertilization as well as the fish stocking methods were the same as in experiment 1, conducted in the eastern part of DR Congo. Each hapa was stocked at a density of 3 fish/m^2 of hapa. The initial average body weights ± standard deviation of the fish were 19.12 ± 0.06 g, 18.96 ± 0.11 g and 19.00 ± 0.08 g for the Tihange, GIFT-RATALBI and GIFT-Congo Futur, respectively. The experiment lasted 84 days (12 weeks).

2.2.2. Feed Formulation and Feeding

All the fish were fed a single commercial extruded feed of 2 mm pellet size (diameter = 2 mm, length = 2 mm), purchased from Cap Congo Pisciculture in Kinshasa, that contained analyzed values of 87.1% for dry matter, and 38.9% for crude protein, 7.8% for ash, 4.5% for crude lipid, 2.3% for crude fiber, 48.8% for total carbohydrate and 391.5 kcal/100 g for gross energy, all on a dry matter basis.

During the experiment, the fish were hand-fed twice daily (10:00 AM and 15:00 PM), seven days a week, at the initial feeding rate of 5% feed/unit wet body weight/day during the first 14 days of the experiment, and then reduced to 3.5% feed/unit wet body weight/day in each hapa until the end of the experiment. Each feeding episode in all the hapas lasted a maximum of one hour.

2.2.3. Sample Collection and Analytical Methods

The methods used to collect the samples and data during the experiment, and to analyze the samples at the end of the experiment were the same as the ones described for experiment 1. However, in Kinshasa, the water quality parameters collected at 10:00 AM fluctuated around 24.3–27.8 °C for temperature, 6.5–7.2 for pH and 28–35 cm for Secchi disc transparency throughout the experiment.

2.3. Calculations

2.3.1. Data on Individual Fish

Individual final body weight (FBW, in g) was measured for each fish at the end of the experiment using an electronic scale measuring to the nearest 0.1 g.

Individual condition factor (CF, g/cm^3) was calculated as $\frac{\text{weight of fish}}{\text{length of fish}^3} \times 100$, where weight of fish is final individual body weight (FBW) and length of fish is final individual body standard length.

Hepato-somatic Index (HSI) was calculated as $\frac{\text{liver wet weight (g)}}{\text{live body weight (g)}}$.

Gonado-somatic index (GSI) was calculated as $\frac{\text{gonad wet weight (g)}}{\text{live body weight (g)}}$.

2.3.2. Data on Mean (Average) Value Per Hapa

Growth was calculated as weight gain (WG, in g) = $\left(\frac{\text{hapa FBW}}{\text{number of fish}} - \frac{\text{hapa IBW}}{\text{number of fish}}\right)$, where FBW is final average body weight per hapa (g/fish) and IBW is average initial body weight per hapa (g/fish).

Feed conversion ratio (FCR) was calculated as $\frac{\frac{\text{dry feed intake}}{\text{number of fish}}}{\frac{\text{hapa FBW}}{\text{number of fish}} - \frac{\text{hapa IBW}}{\text{number of fish}}}$.

Protein Efficiency Ratio (PER) was calculated as $\frac{\text{weight gain (g)}}{\text{total protein intake (g)}}$.

Lipid Efficiency Ratio (LFR) was calculated as $\frac{\text{weight gain (g)}}{\text{total lipid intake (g)}}$.

Survival in each hapa (%) was calculated as $\frac{\text{final number of fish}}{\text{initial number of fish}} \times 100$.

2.4. Statistical Analysis

Data are presented as mean ± standard deviation. Data were analyzed using R software package version 3.6.3. Individual data were available for some parameters, while for other parameters only mean (average) value for each hapa was available (See Sections 2.4.1 and 2.4.2 for details of the parameters in each experiment). Where individual data were available the analyses included all that information. For all parameters, *p*-values in type III Sum of Square ANOVA were calculated using package 'car' [16], and was deemed significant at 0.05. If an effect was found significant, pairwise comparisons of means for its levels were calculated using package 'agricolae' [17].

2.4.1. Experiment 1 in Bukavu, Eastern Highlands DR Congo

All parameters for which there were individual values, FBW and CF, were analyzed using the following linear model Equation (1):

$$y_{ijkl} = \mu + pond_i + strain_j + diet_k + (strain \times diet)_{jk} + e_{ijkl} \quad (1)$$

where, y_{ijkl} is individual value for final body weight and CF of the lth fish, μ is the population mean, $pond_i$ is the fixed effect of three experimental ponds or blocks (1, 2, and 3), $strain_j$ is the fixed effect of the two Nile tilapia strains (the Nyakabera and Lake Kivu strains), $diet_k$ is the fixed effect of the three feeds (the fishmeal-based and fishmeal-free formulated feeds, and the commercial feed), $(strain \times diet)_{jk}$ is the fixed effect of the jk interaction of strain (the Nyakabera and Lake Kivu strains) and feed (1, 2, and 3), and e_{ijkl} is the random residual term.

2.4.2. Experiment 2 in Kinshasa, Western Lowlands of DR Congo

Four of the parameters for which there were individual values, FBW, HSI, CF and GSI were analyzed using the following linear model Equation (2)

$$fw_{ijk} = \mu + strain_i + sex_j + (strain \times sex)_{ij} + e_{ijk} \quad (2)$$

where, fw_{ijk} is individual value for FBW, CF, HSI and GSI of the kth fish, μ is the population mean, $strain_i$ is the fixed effect of three strains (the GIFT-RATALBI, GIFT-Congo Futur, and Tihange strains), sex_j is the fixed effect of sex (female and male), $(strain \times sex)_{ij}$ is the fixed effect of the ij combination of strain (the GIFT-RATALBI, GIFT-Congo Futur, and Tihange strains) and sex (female and male), and e_{ijk} is the random residual term.

There was no separate sex information for WG, FCR, PER, and LER, because individual fish identity was unknown and it was impossible to obtain both the IBW and FBW of individual fish. Mean values per hapa for WG, FCR, PER, and LER were therefore analyzed using the following linear model Equation (3) which only 'strain' as a fixed effect as

$$y_{ij} = \mu + strain_i + e_{ij} \quad (3)$$

where, y_{ij} is mean value of WG, FCR, PER, and LER for the jth hapa, μ is the population mean, $strain_i$ is the fixed effect of the three Nile tilapia strains used (the GIFT-RATALBI, GIFT-Congo Futur, and Tihange strains), and e_{ij} is the random residual term.

3. Results

3.1. Experiment 1 in Bukavu, Eastern Highlands DR Congo

For the two parameters FBW and CF for which individual values were available, there were significant effects of pond and feed on both, but the strain effect was significant only on CF (Table 2). The strain × feed interaction was significant for FBW and CF, suggesting varied responses by different strains to different feeds. For the four parameters for which only mean values per hapa were available, the effects of pond and feed were significant only for WG and FCR, and the effect of strain was only significant for WG.

Table 2. Experiment 1 in Bukavu, eastern highlands DR Congo—*F*-values of fixed effects for final body weight (FBW), condition factor (CF), initial body weight (IBW), weight gain (WG), feed conversion ratio (FCR), hepato-somatic index (HSI), gonado-somatic index (GSI), protein efficiency ratio (PER), and lipid efficiency ratio (LER). FBW and CF calculated using data from individual fish, while the other parameters based on hapa data. All parameters were analyzed using Equation (1).

Effect †	FBW	CF	WG	FCR	HSI	GSI	PER	LER
Pond	83.5 ***	76.9 ***	21.6 ***	4.5 *	2.5 ^{NS}	1.6 ^{NS}	-	-
Strain	3.2 ^{NS}	26.3 ***	0.7 **	0.6 ^{NS}	0.0 ^{NS}	0.02 ^{NS}	0.14 ^{NS}	0.01 ^{NS}
Feed	113.8 ***	36.5 ***	28.3 ***	4.5 *	0.8 ^{NS}	1.34 ^{NS}	8.98 **	64.4 ***
Strain × feed	12.2 ***	17.4 ***	3.0 ^{NS}	1.2 ^{NS}	0.1 ^{NS}	0.33 ^{NS}	NS	NS

†: Significant levels are indicated as *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ^{NS} = Not significant.

The significant interaction between strain and feed for FBW and CF means that it is necessary to interpret the differences among the six strain × feed combinations rather than the effect of strain or feed alone. Therefore, only the significant differences among strain × feed combinations are indicated in Table 3. They showed that the Lake Kivu fish had significantly higher FBW when fed the commercial and fishmeal-free feeds compared with the Nyakabera strain, but when fed the fishmeal-based feed the difference was not significant. When fed the two non-commercial feeds the Lake Kivu fish had significantly higher CF than Nyakabera fish but not when fed on the commercial feed.

For parameters for which mean values for hapas were available (WG, FCR, HSI, GSI, PER and LER), the lack of significant interaction permits meaningful identification of significant main effects of strain and feed (Table 3). Of these parameters, only WG was significantly different between strains, with the Lake Kivu strain growing faster than the Nyakabera.

Fish fed the commercial feed had significantly greater WG and better FCR than fish fed the other two feeds, which did not differ significantly from each other (Table 3). FI was significantly greater and LER significantly lower for fish fed the local fishmeal-based feed than fish fed the other two feeds, which did not differ significantly from each other. In contrast, fish fed fishmeal-free feed had significantly higher PER than fish fed the other two feeds, which did not differ significantly from each other. The fish fed the fishmeal-free feed had significantly lower survival than those fed the fishmeal-based feeds. However, the survival of fish fed the commercial feed was not significantly different from that of fish fed the other two feeds. There were no significant differences among the three feeds for HSI and GSI.

The strain × feed interaction and the strain and the feed main effects were not significant on the fish whole body dry matter, crude protein, ash, total carbohydrate and gross energy (Table 4). The strain effect was significant only for the whole body crude lipid, with the Nyakabera strain showing higher fish whole body crude lipid than the Lake Kivu strain.

Table 3. Experiment 1 in Bukavu, eastern highlands DR Congo—mean ± standard deviation for initial body weight (IBW), final body weight (FBW), weight gain (WG), feed intake (FI), feed conversion ratio (FCR), protein efficiency ratio (PER), lipid efficiency ratio (LER), survival (SUR), condition factor (CF), hepato-somatic index (HSI), and gonado-somatic index (GSI) of two Nile tilapia strains (LK = the Lake Kivu strain, NY = the Nyakabera strain) fed three feeds (D1 = the fishmeal-based formulated feed, D2 = the fishmeal-freed formulated feed, and D3 = the commercial feed) †.

Strain	Feed	# of Fish	IBW (g/Fish)	FBW (g/Fish)	CF (g/cm^3)	# of Hapas	WG (g/Fish)	FI (g dm/Fish)	FCR (g dm/g)	PER (g/g dm)	LER (g/g dm)	SUR (%)	HSI (%)	GSI (%)
LK		225	0.88 ± 0.11	16.7 ± 1.5	2.1 ± 0.4	9	15.8 ± 1.3 ^{a}	32.7 ± 2.6	2.0 ± 0.3 ^{a}	1.9 ± 0.4	5.9 ± 2.3	79.4 ± 10.8 ^{a}	1.41 ± 0.04 ^{a}	2.14 ± 0.04 ^{a}
NY		225	0.84 ± 0.12	15.8 ± 1.3	2.0 ± 0.4	9	15.0 ± 0.9 ^{b}	31.6 ± 3.0	2.1 ± 0.3 ^{a}	1.9 ± 0.3	5.8 ± 2.5	77.4 ± 10.3 ^{a}	1.42 ± 0.04 ^{a}	2.15 ± 0.06 ^{a}
D1		150	0.85 ± 0.13	15.4 ± 1.0	2.2 ± 0.3	6	14.6 ± 0.7 ^{a}	33.4 ± 1.3	2.2 ± 0.3 ^{a}	1.6 ± 0.1 ^{a}	4.0 ± 0.3 ^{a}	84.7 ± 10.1 ^{a}	1.39 ± 0.04 ^{a}	2.12 ± 0.02 ^{a}
D2		150	0.87 ± 0.11	16.1 ± 1.2	2.0 ± 0.3	6	15.3 ± 0.7 ^{a}	31.1 ± 3.5	2.2 ± 0.2 ^{a}	2.2 ± 0.3 ^{b}	4.7 ± 0.6 ^{b}	70.3 ± 7.0 ^{b}	1.43 ± 0.05 ^{a}	2.16 ± 0.07 ^{a}
D3		150	0.86 ± 0.10	17.3 ± 1.5	2.0 ± 0.4	6	16.4 ± 1.2 ^{b}	32.0 ± 3.1	1.9 ± 0.2 ^{b}	1.8 ± 0.2 ^{a}	4.8 ± 0.6 ^{b}	80.3 ± 8.9 ^{ab}	1.44 ± 0.03 ^{a}	2.15 ± 0.03 ^{a}
LK	D1	75	0.86 ± 0.13	15.6 ± 1.0 ^{c}	2.3 ± 0.3 ^{a}	3	14.7 ± 0.8	33.6 ± 2.1	2.3 ± 0.2	1.6 ± 0.2	4.0 ± 0.4	82.8 ± 15.5	1.39 ± 0.05	2.12 ± 0.04
LK	D2	75	0.91 ± 0.11	16.6 ± 0.9 ^{b}	2.1 ± 0.4 ^{b}	3	15.7 ± 0.6	30.8 ± 2.4	2.0 ± 0.2	2.3 ± 0.3	4.8 ± 0.6	70.6 ± 1.0	1.42 ± 0.03	2.14 ± 0.03
LK	D3	75	0.87 ± 0.09	17.9 ± 1.4 ^{a}	1.9 ± 0.3 ^{cd}	3	17.1 ± 1.1	33.8 ± 2.8	2.0 ± 0.3	1.8 ± 0.2	8.8 ± 1.2	85.0 ± 6.7	1.43 ± 0.04	2.15 ± 0.05
NY	D1	75	0.83 ± 0.13	15.3 ± 0.9 ^{c}	2.1 ± 0.3 ^{b}	3	14.5 ± 0.8	33.3 ± 0.2	2.3 ± 0.1	1.6 ± 0.1	4.0 ± 0.2	86.7 ± 1.7	1.39 ± 0.03	2.12 ± 0.01
NY	D2	75	0.83 ± 0.11	15.6 ± 1.2 ^{c}	1.8 ± 0.2 ^{d}	3	14.8 ± 0.3	31.4 ± 4.9	2.1 ± 0.3	2.1 ± 0.3	4.5 ± 0.7	70.0 ± 10.9	1.43 ± 0.06	2.18 ± 0.11
NY	D3	75	0.85 ± 0.11	16.6 ± 1.3 ^{b}	2.0 ± 0.4 ^{bc}	3	15.7 ± 1.0	30.2 ± 2.4	1.9 ± 0.3	1.8 ± 0.3	9.0 ± 1.2	75.6 ± 9.2	1.45 ± 0.01	2.15 ± 0.01

†: Data within the same column with different superscript letters are significantly different (see Table 2).

Table 4. Experiment 1 in Bukavu, eastern highlands DR Congo—mean ± standard deviation for whole body composition of Nile tilapia (*Oreochromis niloticus*) fry of the Lake Kivu and the Nyakabera strains fed on the commercial feed and the fishmeal-based and fishmeal-free feeds formulated using local ingredients †.

Factors			Dry Matter (%)	Crude Protein (% dm)	Ash (% dm)	Gross Energy (kcal/g dm)	Crude Lipid (% dm)	Total Carbohydrate (% dm)
Strain								
	Lake Kivu		28.3 ± 5.7	36.2 ± 3.6	6.04 ± 1.06	4.1 ± 0.1	14.6 ± 1.8 ^{a}	43.2 ± 4.3
	Nyakabera		31.1 ± 3.6	36.7 ± 5.4	7.48 ± 1.38	4.2 ± 0.2	12.6 ± 1.1 ^{b}	43.3 ± 5.1
Diet								
	Fishmeal-based feed		30.7 ± 5.6	37.2 ± 3.4	7.00 ± 1.62	4.1 ± 0.2	13.3 ± 2.2	42.5 ± 3.4
	Fishmeal-free feed		28.7 ± 5.1	36.7 ± 5.7	6.44 ± 1.48	4.1 ± 0.1	14.3 ± 1.8	42.5 ± 5.6
	Commercial feed		29.5 ± 4.4	35.3 ± 4.7	6.83 ± 1.32	4.2 ± 0.1	13.2 ± 1.2	44.7 ± 5.0
Interaction								
	Lake Kivu	Fishmeal-based feed	31.0 ± 8.4	35.8 ± 4.1	6.48 ± 1.69	4.10 ± 0.04	14.9 ± 2.0	42.8 ± 4.3
	Lake Kivu	Fishmeal-free feed	26.2 ± 3.7	36.9 ± 5.3	5.48 ± 0.24	4.1 ± 0.1	15.7 ± 1.5	42.0 ± 6.6
	Lake Kivu	Commercial feed	27.6 ± 5.2	35.8 ± 2.5	6.14 ± 0.90	4.2 ± 0.1	13.2 ± 1.2	44.9 ± 2.1
	Nyakabera	Fishmeal-based feed	30.6 ± 3.1	38.7 ± 2.4	7.51 ± 1.70	4.2 ± 0.2	11.6 ± 0.2	42.2 ± 3.1
	Nyakabera	Fishmeal-free feed	31.3 ± 5.6	36.6 ± 7.3	7.41 ± 1.62	4.3 ± 0.2	13.0 ± 0.6	43.0 ± 5.8
	Nyakabera	Commercial feed	31.4 ± 3.4	34.8 ± 6.9	1.45	4.2 ± 0.2	13.2 ± 1.5	44.6 ± 7.6
p-Values								
Strain			0.271	0.833	0.300	0.284	0.006 **	0.987
Diet			0.796	0.795	0.160	0.605	0.278	0.711
Strain × Feed			0.649	0.787	0.344	0.881	0.102	0.962
Pooled SEM			3.02	2.96	0.13	0.08	0.75	3.05

†: Data within the same column with different letters are significantly different (see Table 2). ** = $p < 0.01$

3.2. Experiment 2 in Kinshasa, Western Lowlands of DR Congo

For parameters for which individual values were available (FBW, CF, HSI, and GSI), there were significant effects of strain × sex interaction for FBW and HSI (Table 5). The strain effect was significant only for CF and the sex effect was significant only for GSI (Table 5). For parameters for which only mean values for hapas were available (WG, FI, FCR, PER, LER, and SUR) only the strain effect was significant.

Table 5. Experiment 2 in Kinshasa, western lowlands DR Congo—*F*-value (*p*-value) of fixed effects for final body weight (FBW), condition factor (CF), hepato-somatic index (HSI), gonado-somatic index (GSI), initial body weight (IBW), weight gain (WG), feed intake (FI), feed conversion ratio (FCR), survival (%) (SUR), protein efficiency ratio (PER), and lipid efficiency ratio (LER). FBW, HSI, CF and GSI were calculated using data from individual fish and were analyzed using Equation (2). The other parameters, based on hapa data, were analyzed using Equation (3) [†].

	FBW	HSI	CF	GSI	WG	FI	FCR	SUR	PER	LER
Strain	26.4 ***	3.4 *	4.05 *	1.76 ^{NS}	14.6 **	36.2 ***	7.8 *	0.8 ^{NS}	7.8 *	7.8 *
Sex	17.9 ***	11.5 ***	0.04 ^{NS}	17.34 ***	-	-	-	-	-	-
Strain × sex	0.03 *	4.3 *	0.51 ^{NS}	1.86 ^{NS}	-	-	-	-	-	-

[†]: Significant levels are indicated as *** = $p < 0.001$, ** = $p < 0.01$, * = $p < 0.05$ and ^{NS} = Not significant.

The significant interaction between strain and sex for FBW and HSI means that it is necessary to interpret the differences among the six strain × sex combinations rather than the effect of strain or sex alone. Therefore, only the significant differences among strain × sex combinations are indicated in Table 6. Male GIFT-Congo Futur and GIFT-RATALBI did not differ significantly in FBW and CF, but both were significantly higher than Tihange (Table 6). Female GIFT-Congo Futur had significantly greater FBW than both other strains, which did not differ from each other. In contrast, CF was not significantly different among strains in females. The difference in FBW between males and females was largest for GIFT-RATALBI and smaller for Tihange and GIFT-Congo Futur. The difference in CF between males and females was significant for GIFT-RATALBI and GIFT-Congo Futur. For CF and GSI, the lack of significant interaction permits meaningful identification of the significant main effects of strain and sex (Table 6). GIFT-Congo Futur had a significantly greater CF than GIFT-RATALBI, but Tihange did not differ significantly from either GIFT-Congo Futur or GIFT-RATALBI. Females of every strain had significantly higher GSI than males.

For parameters for which mean values for hapas were available (WG, FI, FCR, SUR, PER, and LER), the absence of sex information allows only identification of significant main effects of strain (Table 6). The data showed GIFT-Congo Futur had significantly greater WG than GIFT-RATALBI and Tihange, which were not significant from each other. The FI of GIFT-Congo Futur was significantly greater than that of GIFT-RATALBI, which in turn was greater than that of Tihange. For FCR, PER, and LER the GIFT-Congo Futur performed significantly better than Tihange. The GIFT-RATALBI performances for all of these three parameters were intermediate but not significantly different from GIFT-CF and Tihange. Survival was not significantly different among the three strains.

The fish strain effect was not significant on the whole-body dry matter of the fish, crude protein, crude lipid, total carbohydrate, and gross energy (Table 7). The fish strain effect was significant on the whole-body ash content of fish. The whole-body ash content of fish was higher for the Tihange strain than the GIFT-Congo Futur strain, but there was no significant difference between the GIFT-RATALBI and Tihange strains, and between the GIFT-RATALBI and the GIFT-Congo Futur strains.

Table 6. Experiment 2 in Kinshasa, western lowlands DR Congo—mean ± standard deviation for fish and parameters for which there were individual values such as initial body weight (IBW), final body weight (FBW), condition factor (CF), hepato-somatic index (%) (HSI), gonado-somatic index (%) (GSI) organized by strain (GIFT-CF = GIFT Congo Futur, GIFT-RA = GIFT RATALBI, and Tihange) and sex (female and male); and parameters for which there were only mean values for hapas such as initial body weight (IBW), weight gain (WG), feed intake (FI), feed conversion ratio (FCR), survival rate (%) (SUR), protein efficiency ratio (PER), and lipid efficiency ratio (LER) organized by strain †.

Strain	Sex	# of Fish	FBW	CF	HSI	GSI	# of Hapa	WG	FI	FCR	SUR	PER	LER
GIFT CF	-	39	77.9 ± 25.7	2.0 ± 0.5 ^{a}	10.6 ± 3.8	8.7 ± 6.7	3	59.0 ± 6.4 ^{a}	89.4 ± 2.2 ^{a}	1.5 ± 0.1 ^{a}	86.7 ± 6.7 ^{a}	1.69 ± 0.15 ^{a}	28.7 ± 2.6 ^{a}
GIFT RA	-	42	60.0 ± 23.0	1.8 ± 0.2 ^{b}	8.5 ± 3.5	7.9 ± 4.3	3	41.2 ± 10.3 ^{b}	79.0 ± 6.1 b	2.0 ± 0.4 ^{ab}	93.3 ± 6.7 ^{a}	1.33 ± 0.26 ^{ab}	22.6 ± 4.3 ^{ab}
Tihange	-	42	47.2 ± 14.5	1.9 ± 0.3 ^{ab}	7.1 ± 2.3	7.9 ± 7.1	3	28.1 ± 0.8 ^{b}	63.0 ± 1.3 ^{c}	2.2 ± 0.1 ^{b}	93.3 ± 6.7 ^{a}	1.14 ± 0.03 ^{b}	19.4 ± 0.6 ^{b}
-	Female	66	48.3 ± 21.7	1.9 ± 0.4	7.6 ± 3.1	12.2 ± 6.4 ^{a}		-	-	-	-	-	-
-	Male	57	76.3 ± 18.9	1.9 ± 0.2	9.8 ± 3.5	4.3 ± 1.8 ^{b}		-	-	-	-	-	-
GIFT CF	Female	21	68.1 ± 26.5 ^{bc}	2.0 ± 0.6	9.0 ± 3.7 ^{bc}	11.9 ± 7.5		-	-	-	-	-	-
	Male	18	89.3 ± 19.9 ^{a}	2.0 ± 0.2	12.6 ± 2.8 ^{a}	4.7 ± 2.2		-	-	-	-	-	-
GIFT_RA	Female	24	43.3 ± 11.1 ^{d}	1.7 ± 0.2	6.3 ± 2.2 ^{c}	10.9 ± 3.9		-	-	-	-	-	-
	Male	18	82.2 ± 14.1 ^{ab}	1.8 ± 0.2	10.4 ± 3.3 ^{ab}	4.8 ± 1.7		-	-	-	-	-	-
Tihange	Female	21	34.3 ± 7.0 ^{d}	1.9 ± 0.4	7.1 ± 2.6 ^{c}	14.2 ± 7.5		-	-	-	-	-	-
	Male	21	60.1 ± 5.6 ^{c}	1.9 ± 0.2	7.2 ± 2.1 ^{c}	3.6 ± 1.2		-	-	-	-	-	-

†: Data within the same column with different superscript letters are significantly different (see Table 5).

Table 7. Experiment 2 in Kinshasa, western lowlands DR Congo—whole body composition of Nile tilapia (*Oreochromis niloticus*) fingerlings of the "Tihange", GIFT-RATALBI and GIFT- Congo Futur strains fed a commercial feed in Kinshasa, western lowlands highlands of DR Congo †.

Treatments	Dry Matter (%)	Crude Protein (% dm)	Ash (% dm)	Gross Energy (kcal/g dm)	Crude Lipid (% dm)	Total Carbohydrate (% dm)
Tihange	21.32 ± 0.91	38.54 ± 2.98	8.81 ± 1.52 ^{b}	4.38 ± 0.22	14.39 ± 0.38	38.27 ± 4.66
GIFT-RATALBI	20.70 ± 1.38	42.06 ± 6.31	8.33 ± 0.75 ^{ab}	4.49 ± 0.26	20.28 ± 0.93	29.34 ± 7.22
GIFT-Congo Futur	21.59 ± 1.32	41.41 ± 5.17	6.33 ± 0.20 ^{a}	4.53 ± 0.06	20.55 ± 1.50	31.71 ± 3.81
p-Values	0.676	0.68	0.0462	0.65	0.44	0.0991
Pooled SEM	0.70	2.895	0.57	0.11	3.58	2.48

†: Data within the same column with different superscript letters are significantly different (see Table 5).

4. Discussion

4.1. Feed Comparisons

The commercial feed resulted in better growth of fish than the fishmeal-based and fishmeal-free feed in experiment 1. The specific reason for the difference in growth between the fishmeal-based local feeds and the commercial feed cannot be identified because the ingredient composition of the commercial feed was not made available by the feed manufacturer. One likely contributing factor was that the fishmeal purchased from the local market in Bukavu and used to formulate the local fishmeal-based feed was of low quality. Visual analysis of this local fishmeal, which was made from sun-dried small pelagic fish from the Lake Victoria such as the Mukene (also called Daaga) (*Rastrineobola argentea*) and imported from Uganda [11], showed that it was mostly made of bony, not fleshy, parts of the fish. Laboratory analysis confirmed it had 37.5% crude protein, which is lower than the conventional fishmeal (50–72% crude protein) used for most of the commercial feeds. Nalwanga, et al. [18] reported that Mukene quality and corresponding crude protein content reduce (CP) from as high as 65% CP to below 30% CP due to adulteration, as the product leaves the landing sites on Lake Victoria to other points of sale including local and regional shops and stores.

The growth of fish fed the local fish-meal free feed was the same as (for the Nyakabera strain) or better than (for the Lake Kivu strain) that fed the local fishmeal-based feed. Fish growth, FCR and CF of the fish fed the fishmeal-free formulated feed were not different from those of the other feeds. However, the fishmeal-free feed had higher PER compared with the fishmeal-based diet, suggesting that the fish used the protein contained in the local full-fat soybean (and the blood meal) available locally more efficiently compared with the local fishmeal for growth and maintenance. These results indicated that diet of the local strains of Nile tilapia can be formulated and applied locally without the need to include the fishmeal [19,20]. This finding further demonstrated that the combination of available local ingredients can replace imported feeds or fishmeal for tilapia diets, and thus increase the sustainability of smallholder tilapia farming in rural DR Congo.

There was no obvious reason to explain the lower survival (70.0%) of fish fed the fishmeal-free formulated feed compared with those fed the other feeds (82.5–87.0%). In fact, all survival rates observed in the experiment can be considered high, considering the small size of the fish stocked (0.8 g), as high mortality is frequently observed at this early life stage [21,22].

A financial assessment of the feed cost would be needed to decide which of the available feeds to use. Considering the assumptions that the costs of the ingredient sourcing and processing represent about 30% of the feed cost, the fishmeal-based and fishmeal-free diets formulated diet would cost 18% and 19% less than the commercial diet in Bukavu, which confirms the fact that the use of locally available ingredients could be a viable alternative to imported, expensive feeds and feed ingredients in DR Congo [9]. However in the consideration of quality local feed as a suitable alternative, caution should be taken to source quality ingredients, including fishmeal.

4.2. Strain Comparisons

The differences in performance between strains in both experiments may reflect fundamental differences among the strains related to their origins and selection strategies. The differences may also be influenced by their recent history of acquisition and subsequent management of farms in the DR Congo.

In the eastern highlands of DR Congo, although the Nyakabera strain was selected for fast growth in the 1980s at Auburn University [23] and introduced to Bukavu in 2005, its growth, depending on the feed, was similar to or less than that of the Lake Kivu population, whose parents were collected from the wild. The possibility of accumulated inbreeding may explain some of the differences between the Lake Kivu and Nyakabera strains, or indicate fundamental differences in performance between these two original stocks.

In the western lowlands of DR Congo, the two GIFT-derived strains (the GIFT-RATALBI and GIFT-Congo Futur strains) grew better than the Tihange strain, with the GIFT-Congo Futur growing faster than the GIFT-RALBI. The availability of sex information for individual fish also allowed analysis showing males grew better than females, as observed in Nile tilapia [24]. The difference in the growth of the three strains was associated with progressively greater FI and better feed utilization (lower FCR and higher PER and LER) in the faster growing strains. Given that the two GIFT-derived strains originated from the same farm in Zambia, the difference in growth was likely caused by different stock management methods that were applied in the two farms, the Cap Congo Pisciculture and the RATALBI Pisciculture. Over the two years that preceded the start of the experiment, the Cap Congo Pisciculture farm kept the Congo-Futur strain isolated from any other strains on the farm. This means it was less likely that unintended inter-breeding occurs with other fish. The RATALBI Pisciculture, on the other hand, applied less strict stock management. Since the introduction of the Tihange strain of Nile tilapia at the RATALBI Pisciculture farm more than two decades ago, there was no strict broodstock management program in place at the station, possibly leading to a loss of performance relative to the initial stock imported from Belgium. The poor growth of the Tihange strain led RATALBI Pisciculture farm to import the GIFT-derived strain from Zambia two years before the start of this experiment. This emphasizes the importance of broodstock management at the farm level, which is important to maintain the genetic diversity of the stock [25], and proper broodstock feed and feeding regime to achieve good reproductive performance and quality offspring [26,27].

5. Conclusions

The commercial feed resulted in better growth of fish than the fishmeal-based and fishmeal-free feed, particularly in Bukavu. Evidence of a fish-meal free formulated feed showing better Nile tilapia growth than a fishmeal-based (30% local fishmeal in the composition) formulated feed indicates that the use of locally made feed with available ingredients could be a viable alternative to imported, expensive feeds and poor quality feed ingredients in DR Congo. The differences in growth performance among Nile tilapia strains in both the eastern highlands and western lowlands of DR Congo reflect fundamental differences among the strains related to their origins, selection strategies, the recent history of acquisition, and subsequent management in the country. Two applied research activities that need further investigation include (1) experiments on the digestibility of selected local ingredients for better feed formulations, and (2) research focusing on developing farm models based on the strains and feed types to help different farming systems select the models that are more suitable for their available resources.

6. Disclaimer

The opinions expressed here belong to the authors, and do not necessarily reflect those of the CGIAR Research Program on Fish Agri-Food Systems, WorldFish, the International Institute for Tropical Agriculture or CGIAR.

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References

1. FAO. *The State of World Fisheries and Aquaculture 2018—Meeting the Sustainable Development Goals*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2018.
2. FAO. *The State of World Fisheries and Aquaculture 2020—Sustainability in Action*; FAO: Rome, Italy, 2020.
3. Adeleke, B.; Robertson-Andersson, D.; Moodley, G.; Taylor, S. Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa. *Rev. Fish. Sci. Aquac.* **2020**, *29*, 167–197. [CrossRef]
4. Brummett, R.E.; Lazard, J.; Moehl, J. African aquaculture: Realizing the potential. *Food Policy* **2008**, *33*, 371–385. [CrossRef]
5. Parker, A.; Nampuru, A.; Nyembo, A.; Jenal, M. Short-Term Research Support: Rapid Assessment of the Aquaculture Sector in the DRC. 2019. Available online: http://bit.ly/DRCaquaculture (accessed on 9 July 2020).
6. Micha, J.-C. Fish Farming in the Congo Basin: Past, Present and Future. In Proceedings of the International Conference: Nutrition and Food Production in the Congo Basin, Brussels, Belgium, 30 September–1 October 2013.
7. Kinkela, M.; Kambashi Mutiaka, B.; Dogot, T.; Dochain, D.; Rollin, X.; Kinkela, C.; Mawfila, J.; Bindelle, J. Diversity of farming systems integrating fish pond aquaculture in the province of Kinshasa in the Democratic Republic of the Congo. *J. Agric. Rural. Dev. Trop. Subtrop.* **2017**, *118*, 149–160.
8. Tacon, A.G. Global Trends in Aquaculture and Compound Aquafeed Production. *World Aquac.* **2018**, *49*, 33–46.
9. Tshinyama, A.; Proulx, E.; Deschamps, M.H.; Okitayela, F.; Khasa, D.; Vandenberg, G. Contribution to the identification of a local and available food source for sustainable production of Nile Tilapia (Oreochromis niloticus, Linnaeus, 1758) in the Democratic Republic of Congo. *Tropicultura* **2018**, *36*, 109–122.
10. Agboola, J.; Yossa, R.; Verreth, J. *Assessment of Existing and Potential Feed Resources for Improving Aquaculture Production in Selected Asian and African Countries*; CGIAR Research Program on Fish Agri-Food Systems, Program Report: FISH-2019-03; The WorldFish Center: Penang, Malaysia, 2019.
11. WorldFish. Aquaculture Assessments and Value Chain Pilots for Improving Fish Supply, Employment and Nutrition in Democratic Republic of Congo and Angola Project. 2018. Available online: https://hdl.handle.net/20.500.12348/3335 (accessed on 9 July 2020).
12. Nihoreye, F.J.; Masilya, P.M.; Isumbisho, M.P.; Okitayela, O.F. Morphological differentiation between two wild and one cultured strains of Nile tilapia Oreochromis niloticus (Linnaeus, 1758) in South-Kivu, DR Congo. *Int. J. Innov. Appl. Stud.* **2019**, *27*, 323–336.
13. Nihoreye, F.; Muzumani, R.; Nshombo, M. Résultats préliminaires sur la différenciation morphologique des deux souches du tilapia du Nil Oreochromis niloticus (Teleostei, Cichlidae) utilisées en pisciculture à l'Est de la R.D. Congo. *Cah. CERUKI Nouv. Série* **2009**, *39*, 192–200.
14. Nihoreye, F.J.; Nyongombe, U.N.; Alunga, L.G.; Akonkwa, B.D.; Isumbisho, M.P.; Okitayela, O.F. Reproductive performance of female Nile tilapia Oreochromis niloticus L. in South Kivu (DR Congo): Comparison of two strains differing in origin and history of domestication. *Int. J. Sci. Res. Manag.* **2019**, *7*, 224–236. [CrossRef]
15. NRC. *Nutrient Requirements of Fish and Shrimp*; National Academy Press: Washington, DC, USA, 2011.
16. Fox, J.; Weisberg, S. *An R Companion to Applied Regression*, 3rd ed.; Sage: Thousand Oaks, CA, USA, 2019. Available online: https://socialsciences.mcmaster.ca/jfox/Books/Companion (accessed on 9 July 2020).
17. De Mendiburu, F.; Yaseen, M. Agricolae: Statistical Procedures for Agricultural Research. R Package Version 1.4.0. 2020. Available online: https://myaseen208.github.io/agricolae (accessed on 9 July 2020).

18. Nalwanga, R.; Liti, D.; Waidbacher, H.; Munguti, J.; Zollitsch, W. Monitoring the nutritional value of feed components for aquaculture along the supply chain—An East African case study. *Livest. Res. Rural. Dev.* **2009**, *21*, 148.
19. Ogello, E.; Munguti, J.; Sakakura, Y.; Hagiwara, A. Complete Replacement of Fish Meal in the Diet of Nile Tilapia (Oreochromis niloticus L.) Grow-out with Alternative Protein Sources: A review. *Int. J. Adv. Res.* **2014**, *2*, 962–978.
20. Koch, J.; Rawles, S.; Webster, C.; Cummins, V.; Kobayashi, Y.; Thompson, K.; Gannam, A.L.; Twibell, N.G.; Hyde, N. Optimizing fish meal-free commercial diets for Nile Tilapia, Oreochromisniloticus. *Aquaculture* **2015**, *452*, 357–366. [CrossRef]
21. Drummond, C.D.; Murgas, L.D.S.; Vicentini, B. Growth and survival of tilapia Oreochromis niloticus (Linnaeus, 1758) submitted to different temperatures during the process of sex reversal. *Ciênc. Agrotecnologia* **2009**, *33*, 895–902. [CrossRef]
22. Kunda, M.; Harun-Al-Rashid, A.; Morshed, F.; Islam, M.A.; Mazumder, S. Production of Tilapia (Oreochromis niloticus) Fingerling in Hapa Using Swim-up Fry Involving Women in the Haor Region of Bangladesh. *IOSR J. Agric. Vet. Sci.* **2014**, *7*, 2319–2372. [CrossRef]
23. Khater, A.A.; Smitherman, R.O. Cold tolerance and growth of three strains of Oreochromis niloticus. In Proceedings of the Second International Symposium on Tilapia in Aquaculture, Bangkok, Thailand, 16–20 March 1987; ICLARM: Manilla, Philippines, 1988.
24. Beveridge MC, M.; McAndrew, B.J. *Tilapias: Biology and Exploitation*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2000; Volume 25.
25. Said, M.; Mekkawy, W. Genetic Evaluation of Growth and Survival at 6 Weeks old Fry of Egyptian Nile Tilapia (Oreochromis niloticus) Between Improved Abbassa and Commercial Manzala Strains in a Diallel Crossing. *J. Egypt. Soc. Anim. Prod.* **2016**, *53*, 141–146.
26. Izquierdo, M.S.; Fernández-Palacios, H.; Tacon AG, J. Effect of broodstock nutrition on reproductive performance of fish. *Aquaculture* **2001**, *197*, 25–42. [CrossRef]
27. Lazzarotto, V.; Corraze, G.; Larroquet, L.; Mazurais, D.; Médale, F. Does broodstock nutritional history affect the response of progeny to different first-feeding diets? A whole-body transcriptomic study of rainbow trout alevins. *Br. J. Nutr.* **2016**, *115*, 2079–2092. [CrossRef] [PubMed]