

Research Article

Use of Local Agro-food By-products in Feeding of *Oreochromis niloticus* (Linnaeus, 1758) Fry

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Abstract

New sources of carbohydrates obtained from local agro-food by-products were tested in the diet of *Oreochromis niloticus* fry. Five (5) iso-protein (40%) and iso-energy 17 kJ/g feeds were composed with stale bread flour (SB), cassava peelings (CP), cassava chips (CC), cassava couscous made with fermented and steamed cassava (Atti & ò dried (AD), and corn flour dust (CFD). A commercial Rahanan fish feed with 40% protein was used as a control. The feeding tests were carried out in an aquarium containing 50 liters of water with *Oreochromis niloticus* fry weighing 4.37 ± 0.87 g at a density of one fish per liter for 21 days. The effects of the feeds on growth, survival, and costs were calculated. At the end of the experiment, the survival rate ranged from 98% to 100%. The control commercial feed resulted in the highest growth in *Oreochromis niloticus* fry compared to the compound feeds. The daily weight gain values were 0.53 ± 0.01 g/d (control), 0.42 ± 0.01 g/d (SB), 0.42 ± 0.012 g/d (CP), 0.39 ± 0.005 g/d (AD), 0.36 ± 0.005 g/d (CFD), and 0.35 ± 0.004 g/d (CC). The SB, CP, and AD compound feeds provided better growth in *Oreochromis niloticus* fry compared to CFD and CC feeds. Using compound feeds made from flours of local agro-food by-products reduces the feeding cost for *Oreochromis niloticus* fry by half compared to the imported extruded, granulated, floating control feed. These results confirm that flours from stale bread, cassava peelings, and cassava couscous (dry Atti & ò) can serve as sources of carbohydrates in the diet of *Oreochromis niloticus* fry.

Keywords

By-products, Agro-food, Carbohydrates, *Oreochromis niloticus* Fry, Growth, Costs

1. Introduction

The tilapia *Oreochromis niloticus* is the most farmed fish species in Côte d'Ivoire [1, 2]. Additionally, the nutritional requirements of this fish are well understood and documented [3-5]. Indeed, tilapia needs a balanced diet with specific nutrients at different growth stages to quickly reach a competitive market weight [3-5]. For optimal growth, fry require

higher levels of essential nutrients such as proteins, lipids, amino acids, vitamins, minerals, essential fatty acids, and digestible carbohydrates [6, 7]. The feeds used during the fry stage are the most expensive due to their high protein content, ranging from 40% to 50% [4, 5], which is unfavorable for fish farmers seeking quality feeds at lower costs. However,

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producing quality feeds affordably requires detailed knowledge of raw materials, quality, and pricing [8, 9]. Consequently, ingredients in manufactured fish feeds vary from region to region and include raw materials rich in proteins, lipids, minerals, energy, oils, vitamins, and purified amino acids such as lysine, methionine, and cysteine. These ingredients provide essential nutrients for farmed fish diets [8]. Fish meal (66-71% protein), cottonseed meal (42% protein), and soybean meal (42-48% protein) serve as primary protein sources [4, 10, 11]. Fish, soybean, and palm oils are common lipid sources. Globally, brewers' grains, broken corn and rice, wheat, rice and corn flours, fine rice flour, copra cakes, palm kernel cakes, peanut cakes, and wheat bran are used as carbohydrate and energy sources [8]. In Côte d'Ivoire, the most widely used carbohydrate sources in fish feed are whole corn flour (71% carbohydrates), corn bran (55% carbohydrates), wheat bran (42% carbohydrates), rice bran (36% carbohydrates), and fine rice flour (44% carbohydrates). Many of these carbohydrate sources are high in fiber, and their availability, quality, and cost vary regionally [11, 12]. The inclusion of carbohydrates in fish feed remains closely linked to their digestibility and incorporation rates, generally not exceeding 20% of the digestible energy of the feed, as recommended [13]. Exceeding this carbohydrate threshold can result in intolerance phenomena in fish [14].

In Côte d'Ivoire, various products and by-products could be used in fish feed formulation alongside conventional carbohydrate sources. The country is home to different ethnic groups with diverse cultures and foods, providing a variety of by-products and food waste suitable for fish farming. Agro-food by-products such as stale bread, cassava peelings, cassava chips, steamed fermented cassava couscous (dried Attiéké), and corn flour dust are available in the Abidjan area and are inexpensive. Over 2,000 bakeries operate across Côte d'Ivoire, with more than half located in Abidjan [15]. The national bread production exceeds one million tons annually. While exact figures for unsold bread per bakery are unavailable, studies estimate bread losses at around 9.6% [15]. Cassava production in Côte d'Ivoire was about 6,300,000 tons in 2022, growing annually by 8.2%, and is projected to reach 8 million tons by 2025 [16, 17]. About 80% of cassava production is processed into Attiéké [17]. Processing and consumption generate waste and rejects, such as peels, chips, and dried Attiéké which are difficult to quantify. Cassava peels are the most abundant and environmentally problematic solid by-products, making up 20 to 35% of the processed roots' weight [18]. A study in Yamoussoukro found that 46 cassava processors produce 1,154.95 tons of peelings annually [19]. In Côte d'Ivoire, the country's annual maize production is estimated at 1,610,000 tons, mainly processed into maize flour by various processing units [20, 16]. This processing produces corn flour dust.

Recovering agro-food rejects and waste is a significant issue in Côte d'Ivoire, particularly for animal feed and environmental protection. This implies the need to process this

agro-food waste to protect the environment and human health. Using crop residues, agricultural by-products, and food rejects in animal feed is promoted as an alternative to usual feeding practices and would reduce feed cost [21, 22]. In this study, we propose to determine the nutritional quality of the identified agro-food by-products and use them as a source of carbohydrates in the formulation of feed for breeding tilapia *Oreochromis niloticus*. The study aims to reduce the price of formulated feeds for fry by offering new accessible sources of carbohydrates.

2. Materials and Methods

2.1. Fry of *Oreochromis niloticus*

Nine hundred fry of *Oreochromis niloticus* all-comers with an initial weight of 4.37 ± 0.87 g and an initial length of 6.66 ± 0.38 cm, were transported from Bingerville to the hatchery of the Oceanological Research Center under oxygen and conditioned in an aquarium for testing.

2.2. Experimental Device

The feeding trials in this study took place at the hatchery of the Aquaculture Department of the Oceanological Research Center. A set of 18 aquariums measuring 47 cm x 40 cm x 28 cm was supplied with drinking water in a closed circuit comprising an electric motor pump, a water distribution tower, and a collection tank. The bottom of each aquarium has an opening through which a pipe is attached to maintain a constant water level throughout the circuit for the duration of the experiment. The water volume of each aquarium was 50 liters.

2.3. Compound Feeds Made from Local By-products

Agro-food by-products were collected from various locations. Stale bread was collected from a bakery in Abobo's commune (Abidjan district). Whole stale bread is sold to vendors early in the morning; however, stale bread is generally thrown away in pieces that women reject. These two types of stale bread were purchased at 20 FCFA/kg. Women preparers reject cassava peelings. Traditional cassava couscous made with steamed fermented cassava (Attiéké) was harvested in the Anyama commune. The peelings were removed from their brown outer shell and washed in water. Dried cassava chips are commonly sold (100 FCFA/kg) in the markets and used to prepare a dish from Côte d'Ivoire. The chips used were obtained from a trader at the Koumassi market (district of Abidjan). Leftover cassava couscous made from fermented, steamed cassava (Attiéké) that was unsold from the day before and no longer of interest to consumers was purchased at 110 FCFA/kg from Attiéké-tuna fish sellers

(Garba) in the Koumassi commune. Corn flour dust was purchased at 50 FCFA/kg in the commune of Anyama. It is a by-product of grinding corn grains into flour in mills. Corn flour dust consists of excellent corn powder that escapes into the dust. The mills collect this corn dust in a bag and sell it to pig farmers. These by-products were chosen because of their high carbohydrate value (Table 1), market availability, and relatively low cost. The various by-products collected in the

form of pieces were dried in an oven at 80 °C and 105 °C for 4 hours and then transformed into flour. One kilogram of each flour was sampled, packaged, labeled, and sent to the laboratory for biochemical and nutritional composition analyses. The different samples of dry fine flours (% moisture < 10%) and other ingredients (Table 1) were analyzed in the laboratory according to the methods [23].

Table 1. Biochemical composition of agro-food by-product flours (% in DM).

Agro-food by-product flours	Humidity	Carbohydrates	Proteins	Fibers	Ashes	Lipids
Stale bread flour	8.97 ±0.18	79.50 ±2.27	6.42 ±1.13	3.56 ±0.83	1.17 ±0.27	0.69 ±0.01
Cassava peelings flour	11.60 ±0.32	71.39 ±1.37	6.79 ±0.10	7.29 ±1.15	1.86 ±0.15	1.13 ±0.63
Dry Cassava chips flour	10.27 ±0.34	84.26 ±0.30	0.74 ±0.52	2.08 ±0.93	1.72 ±0.02	0.74 ±0.07
Cassava couscous flour (dry Atti & é)	9.94 ±0.17	85.41 ±0.24	0.59 ±0.28	3.08 ±0.34	0.68 ±0.13	0.30 ±0.01
Corn flour dust	11.71 ±1.19	73.06 ±1.78	4.71 ±0.27	5.48 ±1.17	2.85 ±0.38	1.68 ±0.14

2.4. Formulation and Nutritional Quality of Feeds

The ingredients used to formulate the different feeds included fish meal (55% protein) and soybean meal (42% protein) purchased from feed mills, serving as protein sources in the formulated feeds. By-product meals provided carbohydrates. Red palm oil was used as a supplementary lipid source and incorporated at 3% in each formulation [24]. The linear programming method helped formulate the other feeds based on the biochemical compositions of various ingredients. The calculated proportions of the remaining ingredients were weighed, ground into fine flours, mixed, and homoge-

nized by hand. One kilogram of each feed was produced, with subsamples taken to determine the biochemical composition using the same methods to assess the quality of the inventoried agro-food by-products. The 40% protein feed was formulated for the *Oreochromis niloticus* fry stage. These feeds meet the recommended nutrient requirements for *O. niloticus* fry [5, 25, 26]. Essential amino acids, lysine and methionine, were added at 0.5% and 1% of the vitamin-mineral premix to various compound feeds [27]. The composition table of the five formulated feeds is presented in Table 2. The compound feeds were in flour form, while the commercial control feed, Rahanan Fish feed tilapia fry 40% protein, was a floating extruded pellet.

Table 2. Percentage, biochemical nutrient composition (% DM), and feed prices.

Raw materials	Control	Feeds formulas (g/100 g)				
		SB	CP	CC	AD	CFD
Fish meal 55	-	45	45	49	49	45
Soybean meal	-	30	30	26	26	30
Stale Bread Flour	-	20	-	-	-	-
Cassava Peelings Flour	-	-	20	-	-	-
Cassava Chip Flour	-	-	-	20	-	-
Dry Atti & é Flour	-	-	-	-	20	-
Corn Flour Dust	-	-	-	-	-	20

Raw materials	Control	Feeds formulas (g/100 g)				
		SB	CP	CC	AD	CFD
Red palm oil	-	3	3	3	3	3
Lysine	-	0,5	0,5	0,5	0,5	0,5
Methionine	-	0,5	0,5	0,5	0,5	0,5
Vitamin-mineral premix	-	1	1	1	1	1
Total	-	100	100	100	100	100
Biochemical composition	Control	SB	CP	CC	AD	CFD
Humidity (%)	9.0	10.33	10.94	10.65	10.58	10.96
Protein (%)	40	40.54	40.61	39.83	39.80	40.20
Lipids (%)	7	7.74	7.82	8.04	7.95	7.93
Ash (%)	11	11.58	11.72	12.29	12.08	11.91
Fiber (%)	2.5	3.19	3.93	2.80	3.00	3.57
Carbohydrates (%)	30.5	25.76	24.12	25.48	25.71	24.45
Energy (kJ/g)	17.93	17.64	17.54	17.48	17.51	17.48
P/E (mg/kJ)	22.29	22.98	23.15	22.79	22.73	22.99
Calcium/Phosphate	-	2.11	2.11	2.15	2.16	2.11
Feed price	815	525	525	560	560	535

Stale bread (SB), Cassava peelings (CP), Cassava chips (CC), Cassava couscous made with fermented and steamed cassava (Atti & ð dried (AD), and Corn flour dust (CFD).

2.5. Experiments

The *Oreochromis niloticus* fry were distributed in eighteen (18) aquariums of 47 cm x 40 cm x 28 cm each, at a rate of 50 fish per aquarium, and then acclimatized for one week. During this period, the fish were fasted for two days, then fed with a commercial feed for five days. The five formulated and composed test feeds (SB, CP, CC, AD, and CFD) with 40% protein, along with the control feed, Rahanan fish feed, were distributed to different groups of fish. Three trials were conducted for each feed. The fish in each aquarium

were fed at 10% of their biomass, divided into six daily meals (8 a.m., 10 a.m., 12 p.m., 2 p.m., 4 p.m., and 6 p.m.) [28]. Dead fish were removed and counted daily from each aquarium. Each morning, the bottoms of the aquariums were siphoned to remove feces and feed debris before feeding. The feeding trials lasted 21 days. At the end of the trials, the fish were fasted for 16 hours, then netted from each aquarium and transferred into buckets filled with water. The fish were then individually removed from the water, weighed, and measured. Using this data, various zootechnical performance, production, and feeding-related cost parameters were calculated (Table 3).

Table 3. Formulas used for calculating zootechnical performance parameters, production, and feed-related costs.

Parameters	Formula	
Survival Rate (SR)	(Final number of fish / Initial number of fish) x 100	(1)
Coefficient of Variation (CV)	(Standard Deviation / Mean) x 100	(2)
Weight Gain (WG) (g)	Final mass - Initial mass	(3)
Length Gain (LG) (cm)	Final length - Initial length	(4)
Daily Weight Gain (DWG) (g/d)	(Final mass - Initial mass) / feeding duration	(5)

Parameters	Formula	
Biomass Gain (BG) (kg)	Final biomass - Initial biomass	(6)
Specific Growth Rate (SGR) (%/day)	$[(\ln(\text{Final mass}) - \ln(\text{Initial mass})) / \text{feeding duration}] \times 100$	(7)
Total amount of feed used (g)	$\sum$ Quantities of feed used by batch	(8)
Nutrient Quotient (Qn)	Quantity of dry feed distributed / Fresh fish weight gain	(9)
Protein Efficiency Ratio (PER)	Mass gain / Amount of protein ingested	(10)
Cost of feed used (FCFA)	Cost price of feed x amount of feed used	(11)
Cost price of fed fish (FCFA/ind)	Final mass of fish fed x Cost of feed used	(12)



Figure 1. Agro-food by-products and their flours are used in the formulation of feeds for the fry of *Oreochromis niloticus*.

2.6. Statistical Analysis

Descriptive analysis of the calculated parameters was per-

formed using STATISTICA 7.1 software. Results were expressed as mean $\pm$ standard deviation. The effect of feed on the estimated parameters was assessed with a one-way ANOVA test. The test was considered significant at the

$\alpha=0.05$ threshold. Subsequently, Duncan's test was used for multiple comparisons when there was a substantial difference between the data.

3. Results

3.1. Effects of Formulated Feeds on the Survival and Growth of Fry of *Oreochromis niloticus*

Survival and growth data of fry from *O. niloticus* fed in the aquarium with the feeds for 21 days are presented in Table 4. Survival rates ranged between 98 and 100%. Growth parameters showed variation with the feed used. Fry fed with the control feed recorded the best ($P<0.05$) values of final

weight (15.44 ± 0.22 g), weight gain (11.07 ± 0.22 g), and specific growth rate ($6.01 \pm 0.07\%/d$). At the level of compound formulated feeds, the values of final weight, weight gain, daily weight gain, specific growth rates, final length and length gain are significantly higher ($P<0.05$) in fish fed with feeds composed of stale bread flour and cassava peelings flour, followed by the values recorded with fish fed with dry Atti é flour, corn flour dust and the lowest values ($P<0.05$) are recorded with fish fed with feeds composed of cassava chips flour (Table 4). The coefficient of variation values lower than 50% show that the fish weights recorded for the same feed treatment are homogeneous, regardless of the feed used. However, the weights and lengths of fish fed with dry Atti é flour feed are the most heterogeneous. The weights of fish were more homogeneous ($P<0.05$) with the control feed and the feed composed of stale bread flour.

Table 4. Growth and survival parameters of tilapia fry *Oreochromis niloticus* fed with feeds for 21 days in an aquarium.

Parameters*	Control	Formulated compound feeds				
		SB	CP	CC	AD	CFD
Survival rate (%)	99.33 $\pm$ 1.15	98.00 $\pm$ 3.46	99.33 $\pm$ 1.15	99.33 $\pm$ 1.15	99.33 $\pm$ 1.15	100.00 $\pm$ 0.00
Initial weight (g)	4.37 $\pm$ 0.87	4.37 $\pm$ 0.87	4.37 $\pm$ 0.87	4.37 $\pm$ 0.87	4.37 $\pm$ 0.87	4.37 $\pm$ 0.87
Final weight (g)	15.44 $\pm$ 0.22 ^e	13.30 $\pm$ 0.13 ^d	13.30 $\pm$ 0.25 ^d	11.64 $\pm$ 0.09 ^a	12.65 $\pm$ 0.10 ^c	12.05 $\pm$ 0.12 ^b
Coefficient of variation of weight (%)	14.42 $\pm$ 0.12 ^a	15.08 $\pm$ 0.58 ^{ab}	18.61 $\pm$ 0.74 ^c	18.09 $\pm$ 0.14 ^c	20.89 $\pm$ 0.03 ^d	15.72 $\pm$ 0.80 ^b
Initial length (cm)	6.66 $\pm$ 0.38	6.66 $\pm$ 0.38	6.66 $\pm$ 0.38	6.66 $\pm$ 0.38	6.66 $\pm$ 0.38	6.66 $\pm$ 0.38
Final length (cm)	9.46 $\pm$ 0.51 ^e	9.10 $\pm$ 0.42 ^d	8.97 $\pm$ 0.56 ^c	8.63 $\pm$ 0.10 ^a	8.81 $\pm$ 0.13 ^b	8.75 $\pm$ 0.36 ^b
Coefficient of variation of length (%)	6.35 $\pm$ 0.15 ^c	5.64 $\pm$ 0.25 ^b	7.42 $\pm$ 0.25 ^d	5.32 $\pm$ 0.08 ^a	7.65 $\pm$ 0.03 ^d	5.29 $\pm$ 0.10 ^a
Final biomass (kg)	0.77 $\pm$ 2.26 ^e	0.65 $\pm$ 24.21 ^d	0.66 $\pm$ 16.80 ^d	0.58 $\pm$ 8.62 ^a	0.63 $\pm$ 5.23 ^c	0.60 $\pm$ 5.78 ^b
Weight gain (g)	11.07 $\pm$ 0.22 ^e	8.91 $\pm$ 0.13 ^d	8.92 $\pm$ 0.25 ^d	7.27 $\pm$ 0.09 ^a	8.28 $\pm$ 0.10 ^c	7.68 $\pm$ 0.11 ^b
Length gain (cm)	2.80 $\pm$ 0.51 ^e	2.41 $\pm$ 0.42 ^d	2.31 $\pm$ 0.56 ^c	1.97 $\pm$ 0.10 ^a	2.15 $\pm$ 0.13 ^b	2.09 $\pm$ 0.36 ^b
Daily weight gain (g/d)	0.53 $\pm$ 0.01 ^e	0.42 $\pm$ 0.01 ^d	0.42 $\pm$ 0.012 ^d	0.35 $\pm$ 0.004 ^a	0.39 $\pm$ 0.005 ^c	0.36 $\pm$ 0.005 ^b
Biomass gain (kg)	0.55 $\pm$ 0.02 ^e	0.43 $\pm$ 0.02 ^d	0.44 $\pm$ 0.02 ^d	0.36 $\pm$ 0.08 ^a	0.41 $\pm$ 0.05 ^c	0.38 $\pm$ 0.05 ^b
Specific growth rate (%/day)	6.01 $\pm$ 0.07 ^e	5.30 $\pm$ 0.05 ^d	5.30 $\pm$ 0.09 ^d	4.67 $\pm$ 0.04 ^a	5.06 $\pm$ 0.04 ^c	4.83 $\pm$ 0.05 ^b

Stale bread (SB), Cassava peelings (CP), Cassava chips (CC), Cassava couscous made with fermented and steamed cassava (Atti é) dried (AD), and corn flour dust (CFD)

* values are expressed as mean $\pm$ standard deviation n = 150

Values with the same alphabetic letters (a, b, c, d, or e) on the same line are not significantly different ($\alpha \geq 0.05$).

3.2. Effects of Feeds Formulated on Feeding Parameters

The calculated values of nutrient quotient and protein efficiency coefficient are presented in Table 5. The fish with the

control feed presented significantly better data ($P<0.05$) than those fed the formulated compound feeds. Among the formulated compound feeds, the fish that received the feeds composed of stale bread flour, cassava peelings flour, and dry Atti é flour recorded the best values ($P<0.05$) compared to those fed cassava chips flour and corn flour dust.

Table 5. Feeding utilization parameters for fry of *Oreochromis niloticus* fed with feeds for 21 days of aquarium rearing.

Parameters	Control	Formulated compound feeds				
		SB	CP	CC	AD	CFD
Quantity of feed used (g)	458.85	458.85	458.85	458.85	458.85	458.85
Nutrient quotient (Qn)	0.84±0.003 ^a	1.06±0.06 ^b	1.04±0.04 ^b	1.28±0.03 ^d	1.12±0.01 ^b	1.20±0.02 ^c
Protein efficiency ratio	2.99±0.01 ^c	2.33±0.13 ^b	2.37±0.09 ^b	1.97±0.05 ^a	2.24±0.03 ^b	2.08±0.03 ^a

Stale bread (SB), Cassava peelings (CP), Cassava chips (CC), Cassava couscous made with fermented and steamed cassava (Atti & é) dried (AD), and corn flour dust (CFD)

* values are expressed as mean ± standard deviation n = 150

Values with the same alphabetic letters (a, b, c, d, or e) on the same line are not significantly different ($\alpha \geq 0.05$).

3.3. Effects of Feeds Formulated on Feed-related Costs

Table 6 presents the results of the calculated feed costs. The costs of feeds used to feed the fish are significantly high ($P < 0.05$) with the control batches, followed by feeds composed of cassava chips flours, dry Atti & é, followed by fish

fed with feeds composed of corn flour dust, the lowest costs ($P < 0.05$) are recorded with fish fed with feeds consisting of stale bread flour and cassava peelings flour. The control feed records the best ($P < 0.05$) nutrient quotient values, followed by stale bread flour and cassava peelings feeds. Fish feed costs related to the feed recorded with the control feed (10±0.09 FCFA/ind) are double the prices recorded with the formulated compound feeds (5 FCFA/ind).

Table 6. Cost parameters recorded with fry of *Oreochromis niloticus* fed with the feeds during the 21 days of aquarium rearing.

Parameters	Control	Formulated compound feeds				
		SB	CP	CC	AD	CFD
Feed prices (FCFA/kg)	815	525	525	560	560	535
Quantity of feed used (g)	458.85	458.85	458.85	458.85	458.85	458.85
Cost of feed used (FCFA)	375 ^d	240 ^a	240 ^a	255 ^c	255 ^c	245 ^b
Consumption index	0.84±0.003 ^a	1.06±0.06 ^b	1.04±0.04 ^b	1.28±0.031 ^d	1.12±0.014 ^b	1.20±0.02 ^c
Cost price of fed fish (FCFA/ind)	10±0.09 ^b	5±0.18 ^a	5±0.06 ^a	5±0.06 ^a	5±0.06 ^a	5±0.00 ^a

Stale bread (SB), Cassava peelings (CP), Cassava chips (CC), Cassava couscous made with fermented and steamed cassava (Atti & é) dried (AD), and corn flour dust (CFD)

* values are expressed as mean ± standard deviation n = 150

Values with the same alphabetic letters (a, b, c, d, or e) on the same line are not significantly different ($\alpha \geq 0.05$).

4. Discussion

Stale bread, dried cassava peelings and chips, dried Atti & é and corn flour dust are locally available and accessible at affordable costs (unsold, 20 FCFA/kg, 50 FCFA/kg, 100 FCFA/kg, and 110 FCFA/kg). Among them, cassava peelings are food waste, and stale bread, dried Atti & é and cassava chips are marketing losses, while corn flour dust is a by-product of corn flour production. Their high availability

is thought to be due to the high local production of corn and the eating habits of bread and cassava by the Côte d'Ivoire population [16, 15]. Indeed, Ivorian's are big consumers of bread and products made from cassava (Atti & é cassava chips, dish made from cassava paste) and corn [21, 20, 16]. Their processing by-products and waste from unsold products are mostly released into the environment [18]. Their transformation into low-cost food carbohydrates that can be used in animal feed is an opportunity. These by-products transformed into flours are rich in carbohydrates (71 to 85%

carbohydrates) and low in fiber (2 to 7%). Their access to fish feed is a local opportunity to formulate fish feed. Because very few sources of carbohydrates low in fiber are accessible for fish feed. In Côte d'Ivoire, the sources of carbohydrates identified among feed producers and used in fish feed are corn flour (seasonal, with competition with human food), wheat bran (imported and rich in fiber), rice bran (rich in fiber and not recommended for fish feed) [11, 12]. Fiber is not digestible for tilapia *Oreochromis niloticus*; their presence in the feed at levels above 10% is not recommended, and for feeding fry, fiber levels of less than 8% are recommended [5].

The feeds are formulated at 40% protein, such as stale bread flour, cassava peelings, dried cassava chips, dried Attiéké corn flour dust, and Rahanan fish feeds (40% protein), which meet the recommended nutrient requirements for good growth of tilapia fry, as prescribed [29, 6, 7]. In addition, they were used according to feeding practices [5, 28]. However, the industrial and imported control feed recorded the best growth and utilization results. This could be explained by the control feed being an industrial, granulated, and extruded feed, produced with appropriate technology. In contrast, the feeds are formulated with compounds, and local by-products are made by hand and presented in flour. Indeed, the feed's cooking, preparation, and presentation influence the quantity of feed ingested, digestion, and absorption by the fish [30]. Also, extrusion improves the quality and texture of the feed's macronutrients and facilitates the feed's buoyancy, absorption, and digestion [30], unlike artisanal feed. However, daily mass gains of between 0.35 ± 0.004 and 0.42 ± 0.012 g/d recorded with compound feeds made with local by-products are greater than or equal to that of 0.35 ± 0.05 g/d reported with industrial crumbled feed for the rearing of tilapia fry of 2 to 15 g [28]. Also, the specific growth rate values recorded with the feeds formulated included 4.67 ± 0.04 and 5.30 ± 0.09 /day, greater than 3%/day for good tilapia growth [26]. In addition, the values of survival rates (98 ± 1.15 - 100%) are similar to those (97.14 and 100%) recorded in an aquarium with feeds formulated at 40 to 45% protein [31]. The homogeneity of fish growth confirms the quality of the tested feeds and their good use by the *Oreochromis niloticus* fry in aquariums. Furthermore, the better fish growth recorded with SB, CP, and AD compound feeds compared to CFD and CC feeds would be due, on the one hand, to the quality of the carbohydrates provided, influenced by the different production technologies of the by-products, and on the other hand, to the concentration of non-precooked starch in these by-products. Indeed, the stale bread underwent several treatments (kneading, fermentation, cooking, addition of yeasts and improvers) which improved the texture and quality of the carbohydrates in the bread [32]. Similarly, the carbohydrates of Attiéké underwent fermentation, spinning, drying, and steaming during its cooking, which improved the quality of the carbohydrates of Attiéké [16]. Conversely, cassava peelings, chips, and corn flour dust

underwent drying and grinding only. The treatments undergone by bread and Attiéké improved the quality of carbohydrates and facilitated their absorption by tilapia fry. Cassava peelings flour reported better growth than corn flour dust, cassava chip, and dry Attiéké flours. In fact, drying cassava peelings helps reduce cyanide, a compound toxic to animals, from 112 to 23 ppm, which is harmless to fish [33]. Also, cassava peelings are rich in rapidly fermentable carbohydrates [22], resulting in the good performances recorded with cassava peelings flour by fish. The best consumption index and protein efficiency coefficient values were recorded with feeds formulated with stale bread flour, cassava peelings flour, and dried Attiéké. These results show that in the fry of *O. niloticus*, using precooked and digestible carbohydrates improves feed utilization and absorption of dietary protein. Indeed, in fish, the effective use of digestible energy from carbohydrates allows the coverage of energy needs and the sparing of proteins, which could promote the use of proteins for growth [34, 35].

The high selling price of the control feed (815 FCFA/kg) compared to manufactured feeds 525 - 560 FCFA/kg was influenced by the higher feed costs used with the control feed (375 FCFA) compared to the test feeds (between 240 - 255 FCFA) for the same quantity of feed used. Using feeds composed of local by-products allows for a half reduction in the feed fry's production cost. The results of growth, feed use, and costs recorded with the use of feeds manufactured with local by-products allow us to conclude that stale bread flour, cassava peelings, and dried Attiéké can be used in the feeding of tilapia *O. niloticus* fry, thus improving the accessibility of quality carbohydrate sources while reducing environmental pollution from agro-food waste.

5. Conclusions

Feeds formulated from agro-food by-products, including flours from stale bread, cassava peelings, dried Attiéké dried cassava chips, and corn flour dust, which are rich in carbohydrates, can be used as accessible and inexpensive alternative carbohydrate sources to formulate local fish feeds. The daily weight gain, specific growth rate, homogeneity, and survival rates recorded during the feeding trials carried out with iso-protein (40%) and iso-energy formulated feeds with stale bread flour, cassava peelings, dried Attiéké cassava chips, and corn flour dust demonstrate good utilization of compound feeds by the fry. However, feeds formulated with stale bread flour, cassava peelings, and dried Attiéké flours show the best growth and feed utilization rates. The use of these compound feeds can reduce feed costs by half. Flours from stale bread, cassava peelings, and dried Attiéké can feed tilapia *O. niloticus* fry. From this perspective, it would be appropriate to set up a process for collecting, processing, and making available fish meal and feed made from by-products and continuously improving these processes.

Abbreviations

SB	Stale Bread
CP	Cassava Peelings
CC	Cassava Chips
AD	Atti & éDried
CFD	Corn Flour Dust
FCFA	Franc Des Colonies Françaises d'Afrique
DM	Dry Matter

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Conflicts of Interest

The authors declare no conflicts of interest.

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