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EVALUATION OF THE IMPACT OF AGRICULTURAL BY-PRODUCTS ON THE INTEGRATED PRODUCTION OF MERCHANTABLE TILAPIA OREOCHROMIS NILOTICUS (LINNÉ, 1758) AND RICE (ORYZA GLABERRIMA, STEUD, 1853) IN BONOUFLA, CÔTE D'IVOIRE

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ABSTRACT

The trials involved 60,132 GBEBI rice (*Oryza glaberrima*) seedlings and 4,703 tilapia juveniles with an average weight of 38 ±9.16 g fed with two complementary diets: (AC), (ASF) and a natural food (AN). Stocking density was 1.5 fish/m2. Nine ponds were used, 3 of which were randomly allocated to each feeding treatment to assess fish growth and rice production. Daily rations of 3% of the reared fish biomass were distributed in two meals (9 am and 3 pm). Rice seedlings were transplanted at a spacing of 25 cm x 20 cm. After 180 days of testing, for the complementary ASF and AC diets, the best nutrient quotients (Qn) (2.74 ±0.75) and daily growth (3.47 ±0.88 g/day) were obtained with AC. On the other hand, the highest Qn (4.56 ±1.15) and the lowest daily growth (2.36 ±0.56 g/day) were recorded with ASF.Comparison of all batches showed that fish fed only natural feed (AN) had the lowest daily growth (1.27 ±0.64 g/day). Rice yields where the supplementary feeds ASF (3.04 ± 0.04 t/ha) and AC (3.91 ± 0.40 t/ha) were fed were better than those of AN (control) (2.59 ±0.54 t/ha). This study shows that it is possible to improve the production of *O. niloticus* merchantable tilapia and the yield of GBEBI rice (*Oryza glaberrima*) with the use of supplementary feeds in the rice-fish system.

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INTRODUCTION

Strong demographic growth, combined with changing tastes and eating habits, has led to a significant increase in the demand for animal proteins and foodstuffs that people can afford. This situation has encouraged the Ivorian population to take an interest in fish on the one hand because of its high protein content and high biological value, and in rice on the other because of its nutritional value. At present, satisfying the demand for fish and rice is a major concern for the government. Despite the long history of the aquaculture and rice-growing sectors, fish farming and rice-growing are still unable to make a significant contribution to fish and rice production and to meet the needs of the population. Annual consumption of fish (more than 330,000 tonnes) and rice (more than 2.697.938 tonnes) is supported by substantial imports, around 90% for fish (Amian *et al*., 2017; PREPICO, 2019) and 50% for rice (ONDR, 2017; Bouet *et al*., 2022). To reduce this growing deficit, or even achieve self-sufficiency, the Ivorian government has promoted and encouraged the development of rice and fish farming, given the country's assets.These advantages include the availability of large quantities of agricultural by-products, the existence of major freshwater rivers with a total surface area of about 64,000 ha, more than 1,000 small dam lakes, a vast lagoon water body of about 1,200 km2 and thousands of low-lying areas, mangrove vegetation, rivers and water reservoirs (Yao *et al*., 2021). Despite these advantages, the efforts made by the government and the fact that fish farming and rice growing are practised almost everywhere in the country, the contributions of fish farming (4,500 tonnes) and rice farming (1,363,215 tonnes of milled rice) to national production are still low, representing only 2.4% (MIRAH, 2014) and 50% (ONDR, 2017; USDA, 2017) respectively. The constraints identified that hamper the development of these two sectors of activity are numerous and can be grouped according to the production sectors. For fish farming, the main constraints relate to (i) the lack of mastery of feed manufacturing technologies, (ii) certain unsuitable fish farming production systems, and above all (iii) the high cost of feed (MIRAH, 2014; ECOWAS & FAO, 2020).These same sources indicate that fish feed accounts for 40-60% of production costs. Other sources have added that pond-based production systems in developing countries remain vulnerable to extreme weather events (Ringler *et al*., 2010; Nelson *et al*., 2014; FAO, 2020). In the case of rice growing, despite the efforts made and the size of the rice-growing area, the difficulties that reduce productivity are mainly weeds, poor cultivation practices, the very high cost of mineral fertilisers, low soil fertility and, above all, drought (Ofori *et al*., 2005; Bouet *et al.,* 2013). Several studies have been initiated in Côte d'Ivoire to find a simple, inexpensive form of aquaculture practice that is adapted to the local socio-economic context and likely to be rapidly adopted by rural populations. Avit *et al* (2012, 2014) and Kamagaté *et al* (2020) have shown that the rice-fish association generates good symbiotic relationships in which each entity draws on the resources necessary for its remarkable growth, and presents favourable conditions for high fry production.According to the same sources, the results show that 40% of rice-fish farmers produce between 0.5 and 1.5 tonnes of fish. As for rice production, 43% of rice-fish farmers produce between 500 and 1,200 kg and 31% produce between 500 and 900 kg. Fish growth parameters and rice yields are slightly higher in the rice-fish farming environment. However, in Côte d'Ivoire, rice-fish farmers do not create refuge areas or trenches for the fish in order to protect them in the event of a decline and also to facilitate harvesting, whether for pre-growth or grow-out. Furthermore, they do not always maintain the water level at 1/5 of the height of the rice stem in order to limit losses of synthesised natural food and optimise photosynthetic activity. The work of Avit *et al* (2014) has made it possible to use rice bran as a feed supplement that is cheaper but not too rich in protein to effectively improve marketable fish growth and rice yield. This study was devoted to the grow-out of Oreochromis niloticus in rice-fish culture ponds fed with agricultural by-products. More specifically, the aim was to: i) analyse the zootechnical performance of *O. niloticus* during the grow-out phase, ii) determine the growth parameters for rice yields in a rice-fish farming environment, and iii) assess the economic profitability of the treatments applied.

MATERIALS AND METHODS

Presentation of production infrastructures: The experiment was carried out at the "Kouadiokro-Bonoufla" rice-fish farm (N 7°11'40.03"; W 6°31'39.03") located 12 kilometres from the village of Bonoufla in the Vavoua sub-prefecture (Figure 1). The trials were conducted in nine ponds ranging in size from 200 to 675 m2, with 3 ponds per feeding treatment. The ponds were supplied with water by gravity from a one-hectare dam with a flow rate of 15 L/min.

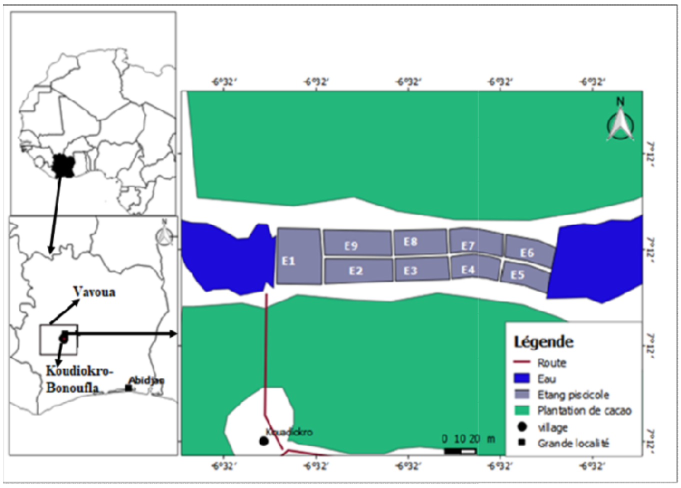


Figure 1. Location of the Kouadiokro-Bonoufla rice-fish farm and sampling points (Zie *et al.*, 2022)

Experimental fish and rice used: The tests were carried out on male juveniles of *O. niloticus* with an initial average weight of 38.16 ±9.34 g obtained by manual sexing of pre-pregnant fry in rice-fish ponds for 90 days. The plant material used consisted of seedlings of *Oryza glaberrima* Steud, locally known as 'Gbêbi' (flood rice). The choice of this variety was based on its 180-day cropping cycle (Becker & Diallo, 1992), which covers the length of *O. niloticus* growth in semi-intensive fish farming. This rice variety is also very popular with local people.

Formulation of experimental diets: The raw materials used in the experimental feed consisted of maize bran, low-grade rice flour, soya and cotton cakes, shellfish meal and cooking salt. These ingredients were purchased from local suppliers. The maize bran was air-dried in the sun for 6 to 8 hours. Two local diets (Table I) were formulated for the trials. The basic compositions of these feeds were as follows: AC (soya and cotton cakes, maize bran and low-grade rice flour) and ASF (low-grade rice flour only). To manufacture the AC feed, the raw ingredients were ground (1 mm diameter) using a locally manufactured hammer mill and passed through a 1 mm mesh sieve.These ingredients were weighed and homogenised using a blender until a homogeneous powder was obtained. Vegetable oils, cooking salt and shellfish meal were added to this mixture, which was then homogenised again to obtain a homogeneous product. The ASF feed (simple feed), consisting solely of low-grade rice flour, was not homogenised or otherwise modified. This feed was simply packaged in 25kg and 50kg bags stored on wooden pallets. These two complementary feeds are in powder form. Their bromatological analysis was carried out at the Laboratoire Central d'Analyses de l'Université Nangui Abrogoua. The bromatological compositions are shown in Table I.

Table 1. Formulation and incorporation proportions of ingredients in feed for growing juveniles of *Oreochromis niloticus* (g/100 g).

Ingredients	Simple food (ASF)	Compound feed (AC)
Soya meal	0	23
Cotton cake	0	22
Rice flour	100	29
Corn bran	0	22,5
Sodium chloride	0	1,5
Shell flour	0	1
Palm oil	0	1,5

ASF : Simple feed based on low-grade rice flour; AC: Compound feed based on soya and cotton cakes, maize bran and low-grade rice flour.

Table 2. Bromatological composition of the supplementary feeds used

	Food treatments	
Composition	ASF	AC
Dry matter	90,33	87,63
(% of dry matter)		
Crude protein	13,21	23,08
Lipids	5,42	10,31
Ash	5,22	7,55
Total carbohydrates	62,64	47,69
Non-nitrogenous extractive	38,26	35,53
Fibres	13,51	11,37
Metabolizable energy: EM (MJ/kg de MS)	2,41	3,07

ASF : Simple feed based on low-grade rice flour; AC: Compound feed based on soya and cotton cakes, maize bran and low-grade rice flour.

Rice seed nursery: *Oryza glaberrima* rice seeds were pre-germinated by soaking them for 24 hours in water (Figure 2 A). After soaking for 24 hours, they were placed in bags, filled to ¾ full and then placed in the shade for 48 hours and watered to stimulate germination before being sown in the nursery. The soil used for the nursery was carefully selected and consisted of a mixture of clay, loam and sand soils to make it easier to pull out the seedlings when transplanting. The seed was evenly broadcast. After sowing, the nursery was watered regularly, twice a day in the morning and evening. The nursery lasted

21 days (Figure 2 B) before transplanting rice seedlings in accordance with Kouakou *et al*. (2016).

A: Soaking of Oryza glaberrima seeds for 24 hours, B: Nursery

Figure 2. Setting up the nursery

Experimental set-up: Two cycles of expérimentations were carried out, the first between August 2019 and January 2020 and the second between April and September 2020. They consisted of producing rice and fish in the same ponds for 180 days. The trials were conducted in 9 ponds to create a completely randomised Fisher block design with three feed treatments and three replicates (Figure 3). In each test pond, a refuge pond 60 cm deep was created over 5% of the total surface area, and trenches 20 cm wide and 30 cm deep were dug along the entire perimeter of each rice plot. For each pond, a water inlet and outlet opposite each other in the rice-growing area and a water outlet in the refuge pond were created to allow good control of the water level in the rice field for the fish.This piping system has been fitted with mosquito netting (mesh size: 1 mm) to prevent the entry of unwanted animals and the escape of farmed fish. The refuge pond and trenches created in each of the production ponds provide shelter for the fish during weeding. They also facilitate access to exogenous food and the harvesting of fish, and serve as a fish-feeding and stocking area for the ponds.

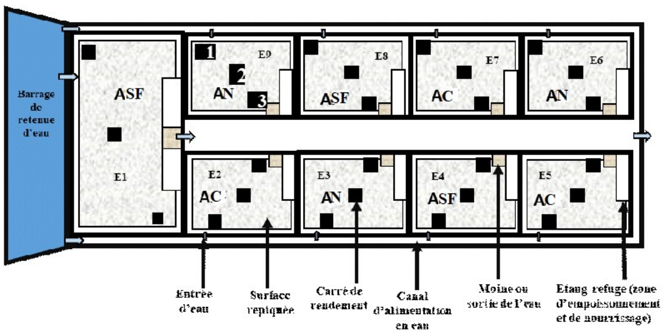
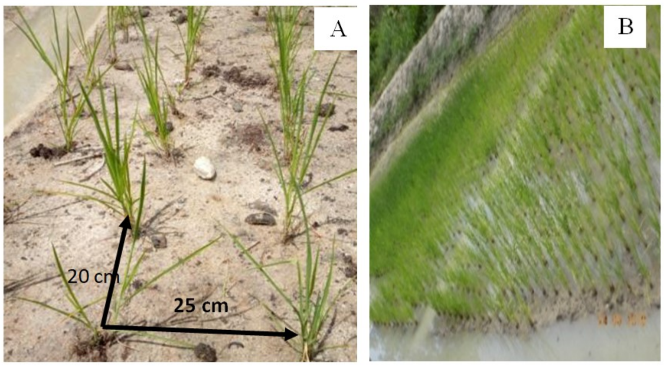


Figure 3. Experimental set-up. (1): water inlet, (2): middle of the pond and (3): towards the monk. AN: natural feed, AC: compound feed and ASF: low-grade rice flour feed

Transplanting rice seedlings and stocking ponds: The rice was transplanted to the ponds over a period of four days. Areas ranging from 189 m2 to 657.4 m2 were transplanted per pond at a rate of 1 rice seedling per 500 cm² (Figure 4), i.e. 3780 to 13 148 seedlings per pond (Table III). The ponds were supplied with water progressively according to the size of the rice seedling. The water level was gradually raised to 1/5th the height of the rice stem. The water level in the rice-growing areas was maintained at 1/5th the height of the rice plant (Avit *et al*., 2014). This water level is suitable for fish and also for rice. The water level in the refuge ponds was maintained at 60 cm. The production structures were stocked 45 days after rice transplanting with 4703 male *O. niloticus* juveniles with an average initial weight equal to 38.16 ±9.34 g. The stocking density of these juveniles was 1.5 fish/m2 and 60,132 rice seedlings. In addition, 50 individuals were taken from each pond and weighed individually. This individual weighing was carried out to determine weight variability at the beginning and end of the experiment if possible.The fish to be reared were transferred in batches of 50 to their respective ponds. The predator Hemichromis fasciatus (25 g) was added to each structure at a rate of 5% of the total biomass of the *O. niloticus* population (Bamba *et al*., 2014). This predator eliminates fry from the sexing error and does not use the food distributed.



A) spacing between rice stacks and transplants and B) gradual flooding of the rice field.

Figure 4. Setting up a rice-fish pond

Feeding fish and monitoring farms: Two local feeds (ASF and AC) were used. Daily feed rations were served manually and on the fly in two meals (9 am and 3 pm). Rations of 4% (first month), 3% (second to fifth month of rearing) and 2.5% (sixth month) of total live weight were applied in accordance with Bamba *et al*. (2014). In addition, batches of fish not fed with exogenous feed (AN) were used as controls to assess the natural input from rice-fish structures. Monthly weight growth checks were carried out on a sample of 25% of the population in each pond. These checks made it possible to readjust the feed rations for the following month in proportion to the total biomass. At the end of the 180th day of rearing, 50 individuals were sampled in each pond, after which their individual weights were measured (Bamba *et al.,* 2014) for comparative statistical processing. From these data, various zootechnical performance, production and cost parameters used were calculated. At the end of each cycle (180 days), the water in the ponds was drained into the refuge channels where all the fish congregated.The fish were caught using landing nets. They were weighed using a "Terraillon" portable electronic scale to assess fish production and survival.

Measurement of water quality parameters: The water quality of the ponds was monitored by measuring the pH, dissolved oxygen, temperature, conductivity and transparency of the water every week. Transparency was measured by immersion of a Secchi disc. pH, temperature and dissolved oxygen were measured respectively with a portable multi-parameter Model "HANNA Instruments HI 83141 pH & Water Analysis" and a portable oximeter Model "HANNA Instruments HI 9146". Conductivity was measured with a conductivity probe Model TetraCon 325-6. All measurements were taken each week between 6 and 7 am and between 1 and 2 pm.

Rice data collection: For rice data collection, three yield squares (water inlet, middle of the pond and next to the monk) were defined in each pond. Each yield square was marked out using wooden stakes and a roll of nylon thread. The yield square in the middle of the pond was placed equidistant from those at the monk and the water inlet to the pond. Ten bunches were randomly selected within each of these three yield squares. The number of tillers in these 10 bunches was counted manually and their height measured using a tape measure. Rice data were recorded every fortnight between 21^e and 105^e days after transplanting.

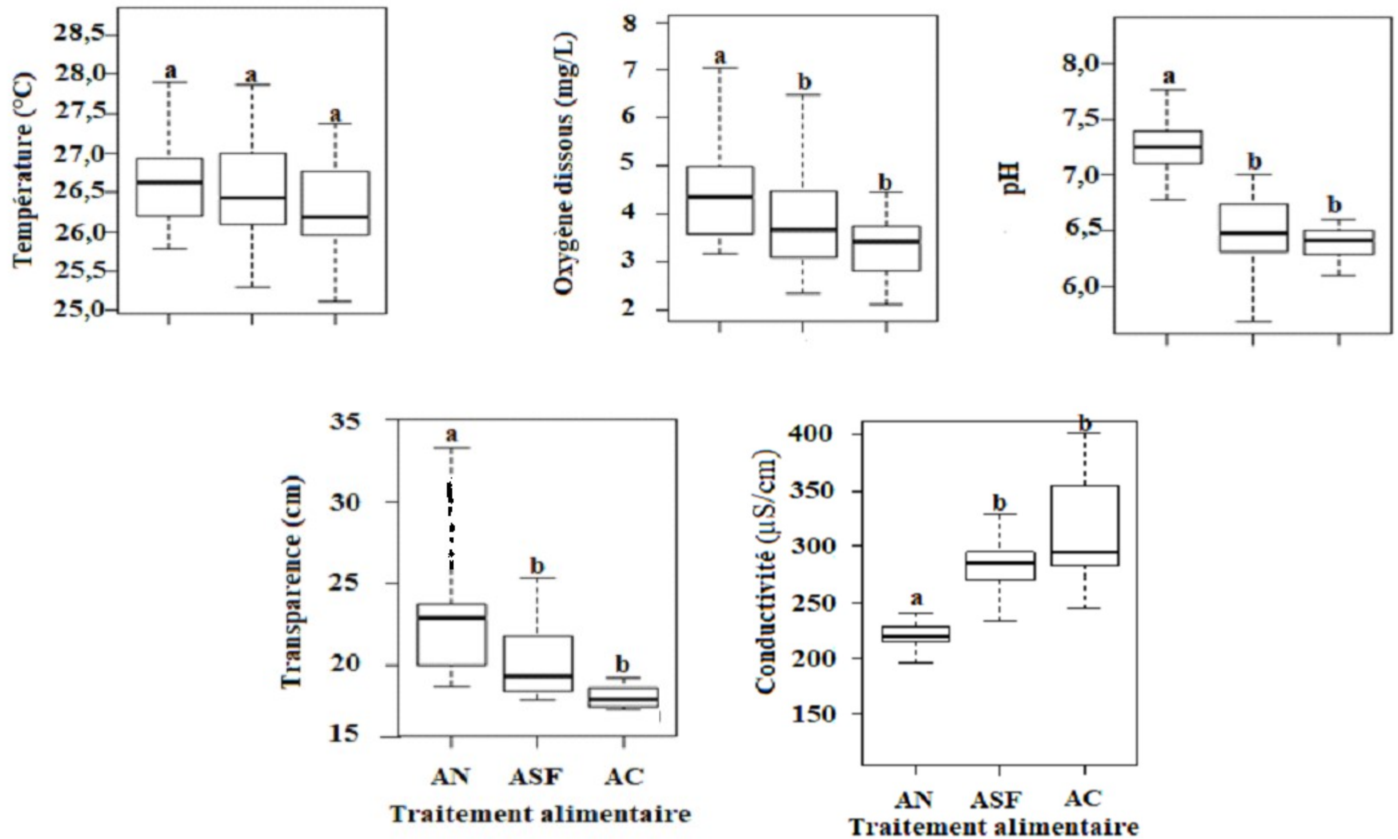
Calculation of rice yield and fish zootechnical parameters: Rice yield (R) per hectare was determined according to the following formula (Avit et al., 2012):

R (kg/ha) = Dry production (kg) / area (ha).

With regard to the zootechnical parameters of the fish, the values of the metabolizable energies of the two exogenous diets were therefore calculated in accordance with the prediction equation of Sibbald (1980).

Table 1. Experimental system for conducting rice stocking and transplanting trials

Treatment	Structure d'élevage	Area (m^2)	Area Rice-fish farming (m^2)	Fish density (ind / m^2)	Number of rice seedlings	Number of fish	Average weight of fish (g)
Rice-fish farming without supplementary feed (AN)	E1	675	657,4	1,5	13 148	1013	38,16 ±0,28
	E2	220	208,4	1,5	4 168	330	38,16 ±0,28
	E3	300	286	1,5	5 780	450	38,16 ±0,28
Rice-fish farming + low-grade rice flour feed (ASF)	E4	360	344,2	1,5	6 884	540	38,15 ±0,24
	E5	360	344,2	1,5	6 884	540	38,15 ±0,24
	E6	360	344,2	1,5	6 884	540	38,15 ±0,24
Rice-fish farming + compound supplementary feed (AC)	E7	360	344,2	1,5	6 884	540	38,14 ±0,86
	E8	300	286	1,5	5 780	450	38,14 ±0,86
	E9	200	189	1,5	3 780	300	38,14 ±0,86



AN = control feed, ASF = pond with simple feed based on low-grade rice flour, AC = pond with compound feed (soya and cotton cakes, low-grade rice flour and maize bran); box plots with a letter (a, b) in common do not differ significantly (Mann-Withney, p > 0.05).

Figure 5. Physico-chemical characteristics of water used for food processing at the production stage of marketable fish

According to Janssen & Carré (1985), metabolizable energy (ME) can be estimated using equations based on chemical analysis in the absence of direct measurement.

Metabolisable Energy was calculated according to the following equation:

ME (MJ / kg DM) = 3.95 + [0.0544 x % fat] - [0.0887 x % fibre] - [0.0408 x % ash]. The equations below, which were also used to compare zootechnical parameters between feed treatments, were calculated as follows:

- *Weight gain (Gp, g) = (final weight (g) - initial weight (g));*
- *Daily weight gain (Gpj, g/d) = (final weight (g) - initial weight (g)) / rearing duration; - Survival rate (%) = 100 x (final number of fish / initial number of fish);*
- *Specific growth rate (SGR, %/day) = 100 × [Ln (final weight) - Ln (initial weight)] / rearing time;*
- *Conversion Index (CI) or Nutrient Quotient (Qn) = Amount of dry feed distributed / Fresh weight gain;*
- *Protein Efficiency Ratio (PER) = (fresh weight gain) / (protein intake) ;*
- *-Yield (Rdt) (kg/a/yr) = (Net biomass x 365) / (Rearing period x area) ;*
- *Carbohydrate (non-nitrogenous extractive) (%) = 100 - (% moisture + % crude protein + % crude fat + % fibre + % ash content) ;*
- *Cost of feeding per unit of weight gain = Cost of one (1) kg of feed x IC, where IC is the feed conversion index and Qn is the nutrient quotient;*
- *Rate of cost reduction compared with the compound diet (%) = 100 x ([cost of compound feed (AC) - cost of simple feed (ASF)] / [cost of compound feed (AC)]) ;*
- *Rate of increase in feed production compared with the natural diet AN (%) =. 100 x [feed yield (AN) - feed yield (x) / (AN yield)].*

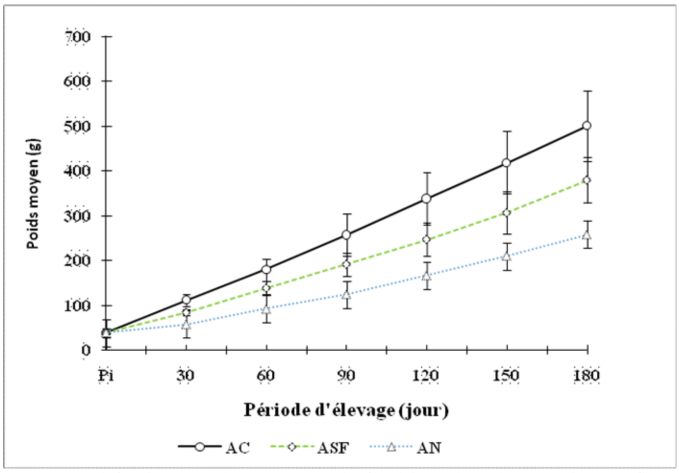
Evaluating the cost of supplementary feedingstuffs: This study takes a forecasting approach to the gross margin that could be generated by the use of each experimental feed. The economic analysis aims to assess the impact of using supplementary feeds (ASF: low-grade rice flour only and AC: compound feed) on feeding costs. The analysis is based mainly on the cost price per kilogram of the supplementary feeds and the feed costs per unit of weight gain. The estimated cost of diets was based on the cost of raw materials on the local market, transport, feed manufacture and packaging. The comparison between feed treatments was based on the rate of increase in yield compared with the (AN) diet, the feeding costs to produce one unit (1 kg) of weight gain and the rates of reduction compared with the AC compound diet.

Statistical analysis of data: Prior to the various statistical analyses, the normality of the distribution of the data collected was verified using the Kolmogorov-Smirnov test. Collected was checked using the Kolmogorov-Smirnov test. Water quality parameters that did not follow the normal distribution ($p > 0.05$) were subjected to the non-parametric Kruskal-Wallis test. When a significant difference was revealed, this test was followed by Mann-Withney tests for pairwise comparisons of variables. Growth and production parameters that followed a normal distribution were all subjected to one-factor analysis of variance (ANOVA 2). Where differences were significant at the 5% level, several comparisons between means were carried out using Tukey's HSD test. All these analyses were performed using STATISTICA 7.1 software.

RESULTS

Water quality: The values of the water quality parameters during production are presented in Figure 5, which shows that the minimum temperature (25.11°C) was obtained with the AC treatment, while the maximum (28.7°C) was recorded with the (AN) treatment. Dissolved oxygen ranged from 2 mg/L (AC) to 7 mg/L (AN). pH values varied between 5.1 (AC) and 7.9 (AN). As for conductivity, the lowest value (195.8 µS/cm) was observed with thetreatment AN,while the highest (400.9 µS/cm) was recorded with the AC treatment. As for transparency, its minimum value (16.4 cm) was observed in the AC treatment and the maximum (34.3 cm) was obtained in the ponds that had not received exogenous feed (AN). Statistically, the water temperature values did not vary significantly from one treatment to another ($p > 0.05$), but the dissolved oxygen, pH, conductivity and transparency values recorded in the ASF and AC treatments were significantly different from those in the control ($p < 0.05$).

Weight growth: Figure 6 shows the evolution of the average weight of *O. niloticus* specimens fed no artificial feed (AN) and those fed two exogenous feeds (ASF and AC) over a period of 180 days in rice-fish culture. Three batches were distinguished at the end of the first growth test, and these maintained this trend until the end of the experiment. The first batch consisted of fish fed with the AC feed, while the other two were made up of fish fed with the ASF feed and those not fed (AN). The fish fed the AC feed showed a better change in average weight than the control batches and those fed ASF. This trend was maintained until the end of the experiment. In general, the AC feed gave the fish a higher growth rate than the other two batches. The fish that did not receive exogenous feed (AN treatment) stood out from the others and were characterised by the lowest change in mean weight.



AN: natural food (control), ASF: simple food based on low-grade rice flour and AC: compound food.

Figure 6. Weight growth curve for Oreochromis niloticus reared at a density of 1.5 ind./m2 fed in rice-fish ponds with AN, ASF and AC feed

Zootechnical parameters: Results of growth parameters (mean final weight, daily weight gain, specific growth rate) and feed utilisation (feed conversion index, protein efficiency ratio) in O. niloticus are presented in Table V. After 180 days of rearing, mean final weights were 250.87 ±50.64 and 350.28 ±78.65 g, respectively for ASF and AC, compared with 152.8 ±57.82 g for AN (unfed batch). The corresponding mean daily weight gain (GPj) values were 2.36 ±0.56 g/d (ASF) and 3.47 ± 0.88 g/j (AC), *versus* 1,27 ± 0,64 g/j for AN. The calculated specific growth rates (TCS) were 1.46 ±0.45, 2.07 ± 0.22 and 2.44 ± 0.26 %/j for the AN, ASF and AC diets. The feed conversion indices calculated for the AC and ASF diets were 4.56 ±1.15 and 2.74 ±0.75 respectively. These two formulated diets were characterised by mean protein efficiency coefficient values of 1.69 ± 0.43 (AC) and 2.46 ± 0.59 (ASF). Statistical analyses showed that the zootechnical performances observed in batches fed complementary diets (ASF and AC) were significantly ($p < 0.05$; ANOVA 2) better than those of fish not fed diets (AN). Similarly, the growth performance recorded for the AC diet was significantly better ($p < 0.05$; ANOVA 2) than that obtained for ASF.Overall, the lowest zootechnical performance ($p < 0.05$; ANOVA 2) was recorded with the control diet (AN).

Table 5. Zootechnical performance of *Oreochromis niloticus* merchant tilapias subjected to three feed treatments over a period of 180 days in rice-fish culture

Parameters	Food treatments		
	Feed AN	Feed ASF	Feed AC
Initial weight : Pi (g)	38,16 ±0,28^{a}	38,15 ±0,24^{a}	38,14 ±0,86^{a}
Final weight: Pf (g)	152,8 ±57,82^{a}	250,87±50,64^{b}	350,28 ±78,65^{c}
Weight saving*: GP (g)*	114,64±57,81^{a}	212,72 ±50,40^{b}	312,13 ±78,79^{c}
Weight gain/day*GPj (g/j)*	1,27 ±0,64^{a}	2,36 ±0,56^{b}	3,47 ±0,88^{c}
Specific growth rate : TCS (%/j)	1,46 ±0,45^{a}	2,07 ±0,22^{b}	2,44 ±0,26^{C}
Nutrient quotient : Qn	None	4,56 ±1,15^{a}	2,74 ±0,75^{b}
Protein Efficiency Coefficient : C.E.P	None t	2,46 ±0,59^{b}	1,69 ±0,43^{a}
Survival rate : (%)	69,79 ±1,15	77,78 ±1,55	93,3 ±1
Performance (Rdt) (kg/a/an)	6,74 ±0,91	15,87 ±1,97	29,39 ±1,18

AC: compound feed; ASF: simple feed based on low-grade rice flour; AN: plain feed). The results were expressed as : Mean (±: standard deviation) of three replicates and two production cycles. On each line, the values (Means ± SD), affected by different letters, are significantly different (p < 0.05). On each line, the values (Means ± ECT), bearing at least one letter in common, were not significantly different (p > 0.05).ASF : Aliment simple à base de farine basse de riz ; AC : Aliment composé à base de tourteaux de soja et coton, son de maïs et farine basse de riz ; AN : Aliment naturel).

Table 6. Evaluation of the costs of AC and ASF supplementary feeds for the production of *O. niloticus* merchantable tilapia

Parameters	Food treatments		
	AN	ASF	AC
Cost of manufacturing one kilogram of feed (F CFA)	None	10	10
Cost of a kilogram of feed/kg (F CFA/kg)	None	60	207,5
Nutrient quotient (Qn)	None	4,56 ±1,15^{a}	2,74 ±0,75^{b}
Financial cost of feeding per unit of weight gain (F CFA/ kg weight gain)	None	273,6	568,55
Proportion (%) of marketable fish reaching 300 g (threshold weight of marketable fish after 180 days)	0	24	70
Yield (Rdt) (kg/y/yr)	6,74 ±0,91	15,87 ±1,97	29,3 9±1,18
Rate of yield reduction (%) compared to AC	77	46	0

*The results were expressed as : Mean ± ECT (standard deviation) of three replicates and two production cycles. On each line, the values (Means ± ECT), affected by different letters, are significantly different (P < 0.05). **ASF**: Simple feed based on low-grade rice flour; AC: Compound feed based on soya and cotton cakes, maize bran and low-grade rice flour; AN: Natural feed.*

Table 7. Evolution of the number of tillers and the height of the plants (Gbêbi rice, *Oryza glaberrima*, as it is known in the local language) in the different treatments

		Production period					
Trial period	Food treatment	Growth parameter	21^{e}	42^{e}	63^{e}	84^{e}	105^{e}
	AN		2,08 ±1,38^{a}	2,92 ±1,78^{a}	3,58 ±0,79^{a}	3,91 ±1,88^{a}	3,91 ±1,88^{a}
	ASF	Number of Talles	2,92 ±1,11^{a}	3,08 ±1,08^{a}	3,67 ±0,8^{a}	4,08 ±0,90^{a}	4,08 ±0,90^{a}
	AC		4,17 ±1,08^{b}	4,67 ±1,92^{b}	5,68 ±1,97^{b}	6,83 ±1,47^{b}	6,83 ±1,47^{b}
	AN		39,83 ±4,79^{a}	61,08 ±8,08^{a}	79,42 ±12,32^{a}	89,91 ±8,41^{a}	104,08 ±6,02^{a}
	ASF	Height of rice plant of rice(cm)	44,83 ±2,91^{a}	65,08 ±8,65^{a}	80,5 ±11,65^{a}	93,17 ±10,29^{a}	105,67 ±9,53^{a}
	AC		55,42 ±1,31^{b}	70 ±4,89^{b}	87,92 ±6,76^{b}	107,67 ±5,76^{b}	113,5 ±7,32^{b}

The results were expressed as : Mean ± ECT (standard deviation) of three replicates and two production cycles. In each column, the values (Means ± ECT), affected by different letters, are significantly different (P < 0.05). In each column, the values (Means ± ECT), bearing at least one letter in common, are not significantly different (P > 0.05). ASF: Simple feed based on low-grade rice flour; AC: Compound feed based on soya and cotton cakes, maize bran and low-grade rice flour; AN: Natural feed).

Table 7. Yield of Gbêbi rice obtained under three feed treatments for 180 days

Parameters	Food treatment		
	AN	ASF	AC
Area (m^2)	1151,8	1032,6	819,2
Dry weight (kg)	298	306	319
Average yield (t/ha)	2,59 ± 0,54	3,04± 0,04	3,91 ± 0,40
Rate of increase in yield compared with AN (%)	None	17,4	50,9

ASF : Simple feed based on low-grade rice flour; AC: Compound feed based on soya and cotton cakes, maize bran and low-grade rice flour; AN: Natural feed.

In the same pond, the number of tillers located in the middle of the pond is lower than in the water inlet and the monk. The average number of tillers per planting increased from 2.08 ±1.38 to 3.91 ±1.88 (AN) and 4.17 ±1.08 to 6.83 ±1.47 (AC) from day 21^{e} to day 105^{e} after transplanting (DAR). These values were statistically different ($p < 0.05$) from one treatment to another. The highest numbers of tillers were observed in ponds fed the AC diet (6.83 ± 1.47), followed by ponds fed the ASF diet (4.08 ± 0.90). Beyond the 84th day after transplanting, these numbers remained constant for all the different treatments. With regard to rice plant growth, sizes varied significantly (ANOVA 2; $p < 0.05$) between treatments. Growth was better with the AC diet than with the other diets (ASF and AN) (Table VI). Indeed, after 105 days after transplanting (DAR), the respective sizes of the rice plants in the AN, ASF and AC treatments were 104.08 ±6.02 cm, 105.67 ±9.53 cm and 113.5 ±7.32 cm, respectively. Statistical analysis (ANOVA 2; $p > 0.05$) revealed that the sizes of the rice plants from the control ponds (AN) (ponds not fed the exogenous feed) and those from the ponds fed the ASF simple feed were similar.Similarly, ponds fed with the ASF treatment produced rice plants of significantly smaller size (ANOVA 2; $p < 0.05$) than those obtained in ponds fed with the AC feed. The yields obtained were 3.04 ±0.04 and 3.91 ±0.40 t/ha for ASF and AC respectively, compared with 2.59 ±0.54 t/ha for AN. These yields varied little between the AC and ASF treatments. On the other hand, the rice yield obtained (2.59 ±0.54 t/ha) in the control ponds (AN) was the lowest (Table VI). Compared with the control, yields increased by 17.4 and 50.9% respectively for ASF and AC.

DISCUSSION

With the exception of the control ponds, all the other ponds had similar physico-chemical characteristics. In the ponds that received artificial feed, the various abiotic parameters assessed did not differ (Mann-Withney, $p > 0.05$) from one structure to another or from one feed treatment to another. On the other hand, the dissolved oxygen concentration and transparency values of the ponds that received artificial feed were significantly lower ($p < 0.05$) than those recorded in the control structures. Similarly, conductivity values were significantly higher in ponds fed artificial feed than in control ponds. Water temperature showed no significant difference ($p > 0.05$) between the control structures and the other two treatments. With regard to dissolved oxygen content, conductivity and transparency, analysis of the values shows variations of varying significance between the control ponds and the other ponds that had received artificial feed.The lowest levels of dissolved oxygen concentration were obtained in the ponds fed the artificial feeds, i.e. 3.53 and 3.55 mg/L for the ASF and AC feeds, respectively, compared with 4.54 mg/L for the controls. The variations in dissolved oxygen levels could be explained by the decomposition and mineralisation of organic matter (consisting of feed distributed but not consumed and fish faeces) by bacteria and protozoa (Arrignon, 2002; Boyd *et al*., 2017). There is a negative correlation between dissolved oxygen and the quantities of food provided (Obirikorang *et al.,* 2015). For these authors, the drop in dissolved oxygen values is linked to the amount of organic matter present in the water body.

According to Billard & Marie (1980); Chen & Borges (2009) and Boyd *et al*. (2017), the dissolved oxygen available in a body of water is the resultant between the quantity of oxygen produced (diffusion of oxygen from the atmosphere to the water or oxygen released into the water as a by-product of photosynthesis by aquatic plants) and that consumed for the respiration of aquatic organisms and for the degradation of organic matter. According to various other authors (Baccarin & Camargo, 2005; Chabalier *et al*., 2006; Guettaf, 2017; Djamai *et al.,* 2020), the low dissolved oxygen levels in ponds can only be explained by the abundance of organic matter and the presence of significant bacterial activity that consumes dissolved oxygen.) They have also reported that organic matter contributes to the reduction in dissolved oxygen content, the latter being consumed by micro-organisms for their degradation and mineralisation. Transparency is one of the water quality indicators used to determine the trophic status of a body of water. According to Richter *et al* (2004), the differences in transparency values observed could be explained by the fact that the ponds that had received the artificial feed were higher in phytoplankton organisms than the controls. This is due to the fertilisation of the water by the feed distributed but not consumed. In addition, Chikafumbwa (1996), Schlumberger & Bouretz (2002) and Bachasson (2012) have reported that in fish ponds, there is a high production of nutrient salts that come from the degradation and mineralisation of uneaten feed, fish droppings and detritus (plant and animal), which stimulate the primary productivity of the water in rearing structures. For these authors, this contributes to reducing water transparency. The high transparency values observed in the control environments are therefore the result of the low quantities of nutrient salts produced, which are necessary for good primary productivity in the ponds (El-Shafai *et al*., 2007; Shokr, 2015).

With regard to conductivity, the maximum value of 400.9 µs/cm was significantly higher in the ponds receiving exogenous feed (AC) than in the other non-fed ponds (AN) at 195.8 µs/cm. This higher conductivity in the artificially fed ponds could be linked to the high mineralisation activity due to the availability of organic matter from the artificial feed not ingested by the fish.In an aerobic environment, the mineralisation activity of the decomposer microorganisms is accelerated, making available a high level of nutrient salts, which also enriches the environment in dissolved solids, hence the high conductivity. With regard to zootechnical parameters, the differences observed in growth and production performance between the experimental units could be attributed to the performance of the feed treatments applied. The average specific growth rate (SGR) values obtained ranged from 1.46 ±0.45 to 2.44 ± 0.26%/d. These figures are close to those (1.4 ±0.1-2.46 ± 0.05%/d) recorded in populations of *O niloticus* with an initial weight of 30 g (Azaza *et al.,* 2006; Koumi *et al.,* 2011). In this study, the initial weight was 38.15 g. With regard to dietary nutrient quotients (Qn) (2.74 ±0.75-4.56 ±1.15) at the end of the experiment, the mean values collected are not as good as those (1.50-2.6) reported previously (Soltan *et al.,* 2008; Bamba *et al*., 2018). The difference in feed utilisation performance observed between this study and previous work is thought to result from the protein levels and the greater degree of convertibility (by the fish) of the diets compared. In previous studies (Soltan *et al*,2008 ; Bamba *et al.,* 2018), ln the feeds used contained 27% and 35% protein, respectively, compared with 13% and 23% in this study. On the other hand, the mean values of food quotients (2.74 ±0.75-4.56 ±1.15) obtained in this study were much better than those reported by Brou *et al*. (2020) (4.16 ±0.46-10.37 ±2).

These authors used feed containing 12%-15% protein, compared with 13.21% and 23.08% protein respectively in this study. In terms of survival rates, the mean values obtained ranged from 69.79 ±1.15 (AN) to 93.3 ±1% (AC). These relatively high mean values for survival rates are thought to be linked to physico-chemical parameters whose values favour better living conditions for *Oreochromis niloticus*. Similar survival values in Nile tilapia have been reported by Bamba et al (2014) (86 to 93% survival) and Brou et al (2020) (80.2 % to 96.26 %), in O. niloticus fed on local feed based on agricultural by-products. Throughout the trials, very few dead or moribund fish were recorded. Dead fish were generally observed one to three days after each growth control. This suggests that the mortality observed was probably the result of stress associated with handling, on the one hand, and the addition of supplementary feed, on the other, which increased the survival rate in ponds fed supplementary feed. Thus, almost all mortalities could be due to the action of predators (snakes, monitor lizards and birds) seen in the ponds during the experiment. These observations are confirmed by the results of Koesoemadinata & Costa-Pierce (1992) and Arrignon (1993), which indicate that the varan could be a frequent and formidable predator of pond fish. It is interesting to note that the zootechnical performance of fish decreases significantly ($p < 0.05$) from the AC, ASF diet to the AN diet. The differences in growth performance observed between the AC and ASF diets are thought to be the result of protein, fibre, metabolizable energy and lipid content.

The AC diet differs from ASF by having a relatively low fibre content (12.16%) and higher protein (23.08%), metabolizable energy (3.07 MJ/kg DM) and lipid (9.31%) values (Table V). According to Francis *et al* (2001) and Krogdahl *et al* (2010), high levels of dietary fibre accelerate gastrointestinal transit, leading to low digestive enzyme efficiency and reduced bioavailability of proteins, lipids and minerals. Similar results have been recorded in O. niloticus fed a diet based on plant by-products (Anderson *et al*., 1984; Hilton *et al*., 1993; Bamba *et al*., 2015).These authors reported a reduction in growth performance and food processing efficiency in this species fed a diet containing more than 10% fibre. In addition, some authors (Du *et al.,* 2005; Krogdahl *et al*., 2005) have reported that an increase in the lipid content of the feed can lead to a reduction in the use of protein in fish and an increase in their growth performance. Similar results were reported by Ghanawi *et al*. (2011) for Siganus rivulatus. The difference in zootechnical performance observed between AC and ASF diets could also be due to the nature of the ingredients used and the feed formula or composition. It has been shown that the quality (digestibility, assimilation, etc.) of a feed is improved by combining several agricultural by-products (Nguyen *et al*., 2009; Burel & Medale, 2014). However, the ASF diet contains only low-grade rice flour (Table IV). The study by Ouattara (2004) showed that maize bran produced better fish growth than low-grade rice flour. This suggests that the observed difference in growth is probably due to the composition of the feed. The poorest growth performance was observed in the unfed batches. These differences in growth performance between the fed batches and those that did not receive exogenous feed could be related to undernourishment and nutritional imbalance affecting growth performance (Dabrowski *et al*., 2007). Indeed, De Silva (1995) indicates that planktonic organisms are less energetic but more protein-rich (55 and 60%). Consequently, the control batches would have received less feed and energy to cover their needs and ensure good growth. With regard to rice production, the differences in growth performance and yield recorded between the treatments could be related to the feed provided. This could be due to fertilisation by artificial feed that is not ingested by the fish. Fish farming is a production method that generates waste (Hargreaves *et al*., 2005). Ponds fed with feed are said to be particularly fertile due to the decomposition and mineralisation of feed not consumed by bacteria and protozoa (Arrignon, 2002). Overall, the number of tillers recorded was satisfactory, ranging from 3.91 (AN) to 6.75 (AC). These figures are higher than those reported by Paradis (2017) (3.46-3.75) in Madagascar. This could be explained by the fact that fish activity induces a better tillering capacity of rice plants. Our results are lower than those obtained by Bouet *et al*. (2015) (7.5-12.5) in *O. sativa*, WITA 9.

This could be explained by the fact that there was an absence of soil ploughing carried out after clearing, by a power tiller. On the other hand, no NPK (12 24 18) fertiliser was applied at a rate of 300 kg ha-1 before the second ploughing operation, as was the case with Bouet.Urea (46% N) was not applied at a rate of 100 kg ha-1 on the day of transplanting. With regard to the height of the rice seedlings in each plot, the values obtained ranged from 104.08 ±6.02 cm to 113.5 ±7.53 cm. These figures are higher than those (73.50 ±0.1 cm - 91.8 ± 0.05 cm) obtained at the CNRA research stations of Man and Tiassalé in 2013 during the evaluation of promising rice varieties for resistance to some major biotic constraints and for their agronomic performance in Côte d'Ivoire (Bouet *et al*., 2015). In this study, rice production ranged from 2.59 ±0.54 (AN) to 3.91 ±0.40 t/ha (AC). According to the FAO (1992), rice yields of 3.5 to 4.5 t/ha were obtained in fertilised monocultures in Madagascar, while slightly higher yields of 4 to 5 t/ha were obtained in managed, stocked and fertilised situations. This could be due to fertilisation by artificial feed not ingested by the fish. As far as exogenous feed is concerned, in general, the ponds fed the AC feed produced significantly better growth and yield performances ($p < 0.05$; ANOVA 2) than those fed the ASF feed. The differences in rice growth and yield performance observed between the different feed treatments could be related to the composition of the feed and its nitrogen (protein) content. The results highlight both the positive effects of the combination of several agricultural by-products and the protein content of the feed. In fact, AC feed containing 23% (Nitrogen (N) x 6.25) protein compared with 13% (Nitrogen (N) x 6.25) for ASF does not have the same nitrogen values.

AC feed contains around 3.7% nitrogen compared with 2.1% for ASF. It should be noted that rice growth performance and yields increased with the increase in nitrogen content and the number of by-products contained in the feed. In other words, the degradation of the uneaten AC feed (3.7% nitrogen) by the fish would have made more mineral elements, in this case nitrogen, available to the rice plants than the ASF feed (2.1% nitrogen) composed solely of rice-based flour. In view of the above, the nitrogen content of the feed and its basic composition could be the cause of the differences in yield and growth performance observed between the feed treatments. The poorest growth performance was observed in farms that did not receive any exogenous feed. These differences in growth performance between the ponds fed and those not fed could be related to the nutrients in the fish faeces. Similar results were obtained by Paradis (2017) in Madagascar during studies of the effect of development and stocking of rice-fish areas. Our results are similar to those of Bouet et al. (2015). These authors obtained 2.36 to 3.11 t/ha of WITA 9 in Côte d'Ivoire. The economic analysis of the zootechnical results obtained at the end of the experiments shows that the use of complementary feeds (ASF and AC) leads to an economic gain thanks to better growth performance and feed utilisation. During the adult fish production phase, the use of the supplementary feed (AC) resulted in respective rates of yield reduction of marketable fish reaching 300 g (threshold weight of marketable fish after 180 days) of 46% and 77% respectively for ASF and AN.The results observed could be related to the nutritional value of the feed used. According to New & Singholka (1985), the lower the nutrient quotient (Qn) of a feed, the higher the yield of feed consumed and the lower the production cost of feedIn terms of yield, the rice-fish combination increased yield at maintenance costs (herbicides, insecticides and fertilisers) by 17.37% and 50.96% at grow-out compared with the control structures. Our results corroborate those of Gupta (1997). This author observed an increase in yield of between 14 and 48% in rice-fish culture in the Philippines. Similar results (18%) were obtained by Paradis (2017) in Madagascar during studies of the effect of management and stocking of rice-fish areas. Our results are similar to those of Bouet *et al.* (2015). These authors obtained a 31.78% increase in yield of *Oryza sativa* variety WITA 9 in Côte d'Ivoire.

CONCLUSION

The results of the present study show that growth performance and production of tilapia *Oreochromis niloticus* and rice are significantly higher in treatments fed AC and ASF diets, compared with the treatment fed the natural diet. Similarly, the AC diet containing both low-grade rice meal and other agricultural by-products (maize bran, cottonseed cake and soya) gave tilapia O. niloticus and "Gbêbi" rice the best growth and production performance compared with the diet containing only rice meal. Considering feed as the main production cost in fish farming, the use of exogenous diets despite their high cost price per kilogram can be justified by the savings resulting from the better production and growth performance obtained in fish and rice compared with the AN diet, and the contribution to sustainable aquaculture by the substitution of fishery products (mainly fish meal) by agricultural by-products. The zootechnical parameters of the fish show that it is possible to obtain marketable tilapia under rice-fish farming conditions.

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