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RESEARCH ARTICLE

Effects of Broken Rice Flour Feeding Strategies on Water Quality, Growth Performance and Production Costs of Nile Tilapia (*Oreochromis niloticus* Linnaeus, 1758) Reared in Fish Pens

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Abstract

Background and Objective: The increasing cost of commercial aquafeeds has prompted fish farmers to incorporate agricultural by-products into fish diets as cost-effective alternatives. In Côte d'Ivoire, broken rice flour is among the most commonly used agricultural by-products in small-scale aquaculture. This study evaluated the effects of different feeding strategies incorporating broken rice flour on water quality, zootechnical performance, and the economic viability of Nile tilapia (*Oreochromis niloticus*) cultured in fish pens.

Materials and Methods: A total of 240 Nile tilapia were reared in fish pens for 56 days under four feeding strategies: Commercial Feed (CF), Commercial Feed plus Broken Rice Flour (CFBR), Broken Rice Flour alone (BR) and a Double Ration of Broken Rice Flour (2BR). Water quality, growth performance, survival, feed utilization, and production costs were assessed throughout the experimental period.

Results: Dissolved oxygen concentrations ranged from 5.03-7.50 mg/L, with the lowest value recorded in the 2BR treatment. Despite this, the 2BR treatment achieved the highest survival rate (86.67%, $p<0.05$). Fish fed the CF diet exhibited the greatest weight gain (36.77 g), significantly exceeding those fed the CFBR (24.63 g), 2BR (25.63 g), and BR (16.80 g) diets. Voluntary feed intake (4.98-5.15% body weight/day) and condition factor values ($K>1$) indicated good diet acceptability and satisfactory physiological status of the fish across all treatments. Economic analysis showed that the production cost of the CFBR feeding strategy (1,788.7 XOF) was nearly twice that of the 2BR strategy (993 XOF), despite producing a comparable weight gain.

Conclusion: Feeding Nile tilapia with a double ration of broken rice flour (2BR) represents a technically and economically favorable strategy, providing the highest survival rate while substantially reducing production costs compared with feeding strategies incorporating commercial feed.

INTRODUCTION

Aquaculture is an important sector for food security and economic development worldwide. It has experienced rapid growth and is now one of the fastest-growing food production sectors, making a significant contribution to reducing the global animal protein deficit[1]. In Côte d'Ivoire, despite considerable aquatic resources, including 150,000 ha of lagoons, 350,000 ha of lakes and four major rivers, national aquaculture production remains limited to approximately

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10,000 t in 2024[2]. As the annual demand for fish exceeds 700,000 t, the country relies heavily on fish imports, resulting in a substantial trade deficit[3]. To address this challenge, the Government of Côte d'Ivoire has identified aquaculture as a national priority through several strategic programs, including the National Policy for the Development of Livestock, Fisheries and Aquaculture (PONADEPA, 2022 to 2026), the Project for the Development of Competitive Value Chains in Aquaculture and Sustainable Fisheries (ProDeCAP) and the Project for the Revitalization of Inland Fish Farming (PREPICO 2). These initiatives aim to increase national aquaculture production to 150,000 tons by 2030[3].

The Nile tilapia, (*Oreochromis niloticus* Linnaeus, 1758), is the principal species targeted for aquaculture development in Côte d'Ivoire because of its rapid growth, adaptability and high market demand. Global production of Nile tilapia has increased from approximately 380,000 t in 1990 to more than 7 million tons in 2022[1]. Despite this growth, the expansion of the aquaculture sector remains constrained by the high cost and limited availability of quality commercial feeds, which account for more than 50-60% of total production costs[4]. Consequently, many fish farmers use agricultural by-products as low-cost feed alternatives. Among these, broken rice flour produced by artisanal rice mills is widely used, whereas only a small proportion of farmers rely on locally produced extruded feeds[5]. The widespread use of broken rice flour is mainly attributed to its low price, easy availability and the high level of domestic rice production, particularly in urban and peri-urban aquaculture systems[6]. However, the use of this by-product as the sole feed source often results in poor growth performance, low production efficiency and extended production cycles[6,7].

To improve fish growth while reducing feeding costs, some producers combine commercial feed with broken rice flour[8,9]. Although, this feeding strategy can reduce feed expenses, excessive use of broken rice flour may deteriorate water quality through nutrient enrichment and eutrophication, thereby adversely affecting fish health and production performance[10]. Therefore, optimizing the use of broken rice flour in feeding strategies is essential for improving both production efficiency and environmental sustainability. The present study evaluated the effects of different feeding strategies incorporating broken rice flour on water quality and the zootechnical performance of Nile tilapia (*Oreochromis niloticus*) reared in fish pens.

MATERIALS AND METHODS

Experimental infrastructure and fish: The experiment was conducted at the Aquaculture Experimental Station of the Centre for Oceanological Research, located along the Abidjan to Dabou road, approximately 40 km from Abidjan and 5 km from Dabou, Côte d'Ivoire (5°19 30.69"N, 4°18 45.90"W). The hydroclimatic conditions of the site are strongly influenced by its proximity to the outlet of the Ebrié Lagoon and the Agnéby River[11].

The experimental system consisted of 12 rectangular fish pens, each with a surface area of 0.8 m^2 (1.0 m $\times$ 0.8 m) and a mean water depth of 0.5 m. The pens were constructed from mosquito netting and installed in earthen ponds.

A total of 240 juvenile Nile tilapia (*Oreochromis niloticus*) with an average body weight of 37$\pm$5 g were used in the experiment. The fish were obtained from the production ponds of the Aquaculture Experimental Station.

Feeding methods: Two feed types were evaluated in this study: A commercial feed and broken rice flour. Four feeding strategies were tested:

- Commercial Feed Only (CF)
- Commercial feed Combined with Broken Rice Flour (CFBR)
- Broken rice Flour Only (BR)
- Double ration of Broken Rice flour (2BR)

Experimental conditions: The 240 fish were randomly allocated to four treatment groups, with 20 fish stocked in each pen. Each treatment was conducted in triplicate. Fish were fed daily at a rate equivalent to 4% of the total biomass. The daily ration was divided into two equal meals and offered at 08:00 and 16:00 h.

Before each feeding, water physicochemical parameters were measured using a multiparameter water quality meter. Fish growth was monitored weekly. During each sampling, 10 fish were randomly selected from each pen, individually weighed and measured to evaluate growth performance.

Zootechnical parameters: Survival Rate (SR), Daily Weight Gain (DWG), Specific Growth Rate (SGR), Voluntary Ingesting (VI), Feed Conversion Ratio (FCR), condition factor (K) were calculated as follows:

- **Survival Rate (SR):**

$$\text{SR}(\%)=\frac{\text{Final number of fish}}{\text{Initial number of fish}}\times 100 \tag{1}$$

- **Daily Weight Gain (DWG):**

$$\text{DWG}(\text{g / day})=\frac{\text{Final weight} - \text{Initial weight}}{\text{Duration of the experiment (days)}} \tag{2}$$

- **Specific Growth Rate (SGR):**

$$\text{SGR}(\%/\text{day}) = \frac{\text{Ln(Final weight)} - \text{Ln(Initial weight)}}{\text{Duration of the experiment (days)}} \times 100 \quad (3)$$

- **Voluntary Intake (VI):**

$$\text{VI}(\%/\text{day}) = \frac{\text{D} \times [(\text{Bi} + \text{Bf})/2]}{\text{Duration of the experiment (days)}} \times 100 \quad (4)$$

D : Cumulative quantity of feed distributed (g)
Bi and Bf : Initial and final biomasses (g)

- **Feed Conversion Ratio (FCR):**

$$\text{FCR} = \frac{\text{Quantity of feed distributed}}{\text{Fish biomass produced}} \quad (5)$$

Condition factor (K):

$$\text{K} = \frac{\text{Body weight}}{\text{Length}^3} \times 100 \quad (6)$$

Economic evaluation: Production cost was estimated by multiplying the cost of 1 kg of feed by the Feed Conversion Ratio (FCR), where FCR was calculated as the ratio of feed consumed to body weight gain. This approach was used to compare the economic efficiency of the different feeding strategies.

Statistical analysis: Statistical analyses were performed using STATISTICA software (version 7.1). Data were analyzed using one-way analysis of variance (ANOVA) to determine the effect of the different feeding strategies. When significant differences were detected ($p<0.05$), treatment means were compared using Tukey's *post hoc* test.

RESULTS

Rearing water quality: The physicochemical characteristics of the rearing water are presented in Table 1. Water temperature, pH, salinity and transparency ranged from 29.89-29.97°C, 7.06-7.11, 0.10-0.13 ppt and 0.32-0.45 m, respectively. No significant differences were observed among the feeding methods for these parameters ($p>0.05$).

In contrast, dissolved oxygen concentration differed significantly among the feeding methods ($p<0.05$). The lowest dissolved oxygen level (5.03 mg/L) was recorded in the 2BR treatment (Fig. 1), whereas the CF, CFBR and BR treatments maintained dissolved oxygen concentrations of approximately 7 mg/L.

Zootechnical parameters: The survival rates of Nile tilapia at the end of the experimental period are presented in Fig. 2. Survival varied significantly among the feeding methods ($p<0.05$). The highest survival rate (86.67%) was recorded in the 2BR treatment, whereas the lowest survival rate (63.33%) was observed in the CF treatment.

Changes in fish body weight and total length throughout the experiment are illustrated in Fig. 3. Body weight increased similarly in all treatments during the first 14 days. Thereafter, growth patterns differed according to the feeding method. Fish length showed a similar trend among treatments until day 21. From this point onward, fish fed the BR and 2BR diets exhibited comparable growth patterns until the end of the experiment.

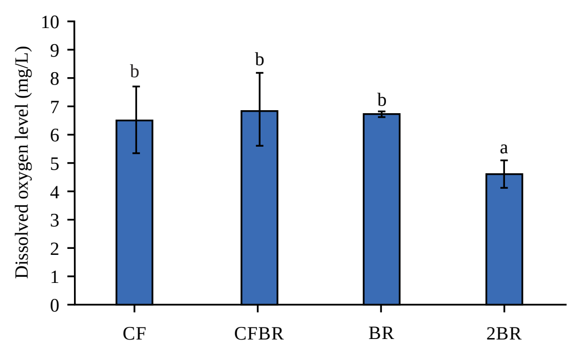

Fig. 1: Variation in dissolved oxygen levels depending on the rationing method

Table 1: Physicochemical parameters of the water in pond

	Rationing methods			
Parameters	CF	CFBR	BR	2BR
Temperature (°C)	29.96±0.51[a]	29.90±0.48[a]	29.89±0.49[a]	29.97±0.59[a]
PH	7.08±0.25[a]	7.06±0.25[a]	7.09±0.25[a]	7.11±0.23[a]
Salinity (ppt)	0.13±01[a]	0.10±00[a]	0.11±0.01[a]	0.13±0.01[a]
Transparency (m)	0.45±0.21[a]	0.39±0.19[a]	0.35±0.24[a]	0.32±0.26[a]

Data are mean values±SD (n = 3), means in the same row with the same superscript were not significantly different ($p>0.05$). CF: Commercial Feed, CFBR: Commercial Feed-Broken Rice flour combination, RB: Broken Rice and 2RB: Double ration of broken rice flour

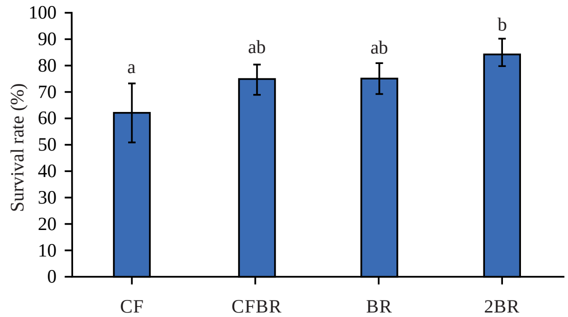

Fig. 2. Fish survival rate at the end of the experiment

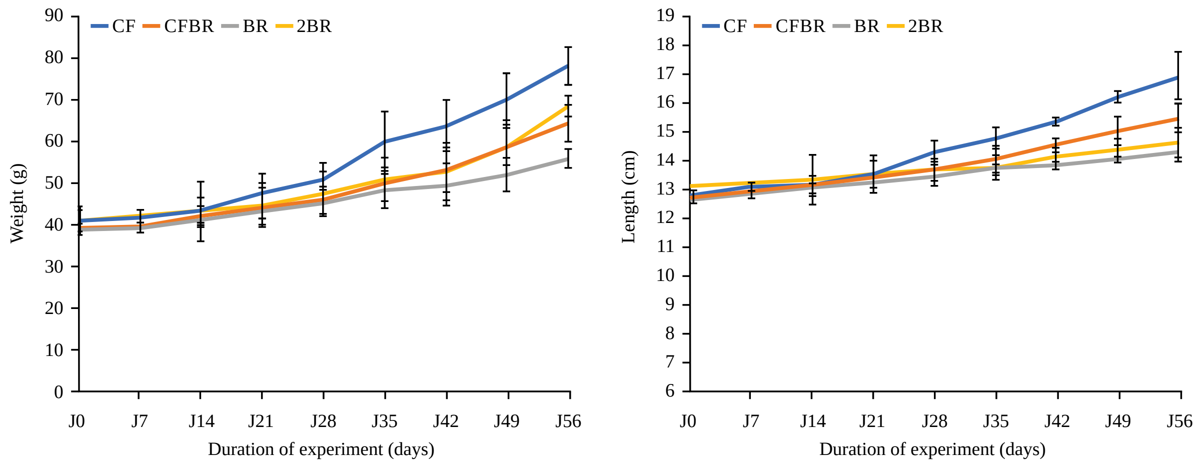

Fig. 3(a-b): Evolution in weight and length of fish during the experiment

Table 2: Fish growth parameters during the 56 days experiment

	Rationing methods			
Parameters	CF	CFBR	BR	2BR
W_i (g)	41.00±3.37	39.58±1.26	38.94±1.05	40.55±1.93
L_i (cm)	12.86±0.13	12.75±0.14	12.72±0.10	13.19±0.12
W_f (g)	77.77±4.55^c	64.21±4.44^b	55.74±2.21^a	68.18±2.44^b
L_f (cm)	17.00±0.87^b	15.56±0.51^a	14.40±0.35^a	14.70±0.52^a
WG (g)	36.77±2.19^c	24.63±3.35^b	16.80±3.24^b	25.63±3.45^a
LG (cm)	4.14±0.98^c	2.81±0.43^b	1.68±0.36^{ab}	1.51±0.42^a
DWG (g/day)	0.66±0.04^c	0.44±0.06^b	0.30±0.06^a	0.46±0.06^b

Data are mean values±SD (n = 3), means in the same row with the same superscript were not significantly different (p 0.05). CF: Commercial feed; CFBR: Commercial feed-broken rice flour combination, BR: Broken rice flour, 2BR: double ration of broken rice flour, W_i: Initial weight, W_f: Final weight, L_i: Initial length, L_f: Final length, WG: weight gain; LG: length gain and DWG: Daily weight gain

The growth performance of fish is summarized in Table 2. Weight gain ranged from 16.80-36.77 g, while daily weight gain varied from 0.30-0.66 g/day. Fish fed the Commercial Feed (CF) achieved the highest weight gain (36.77 g) and daily weight gain (0.66 g/day), both of which were significantly higher than those of the other treatments ($p<0.05$).

The Specific Growth Rate (SGR) during the experimental period is presented in Fig. 4. SGR varied significantly among the feeding methods ($p<0.05$). The highest SGR (1.14%/day) was obtained in the CF treatment, whereas the lowest value (0.64%/day) was recorded in the BR treatment.

The condition factor (K) is shown in Fig. 5. Significant differences were observed among the feeding methods ($p<0.05$). Fish fed the 2BR diet exhibited the highest condition factor (2.09), whereas those fed the CF diet had the lowest value (1.61).

Table 3: Feed conversion ratio and voluntary intake according to rationing method

	Rationing methods			
Parameters	CF	CFBR	BR	2BR
FCR	3.43±0.30[a]	4.77±0.76[ab]	7.12±1.78[b]	6.64±0.58[b]
IV (%/d)	5.15±0.24[a]	4.98±0.20[a]	5.42±0.52[a]	4.98±0.53[a]

Data are mean values±SD (n = 3), means in the same row with the same superscript were not significantly different (p>0.05). CF: Commercial feed, CFBR: Commercial feed-broken rice flour combination, BR: Broken rice flour, 2BR: Double ration of broken rice flour, FCR: Feed conversion ratio and VI: Voluntary intake

Table 4: Cost of production of fish

Methods	Price of one kg of feed (X 0 F)	FCR	Cost of production of one kg of fish (X 0 F)
CF	600	3.43	2058
CFBR	375	4.77	1788.75
BR	150	7.12	1068
2BR	150	6.64	993

CF: Commercial Feed, CFBR: Commercial feed-broken rice flour combination RB: Broken rice flour, 2BR: Double ration of Broken Rice Flour and XOF: West African CFA franc

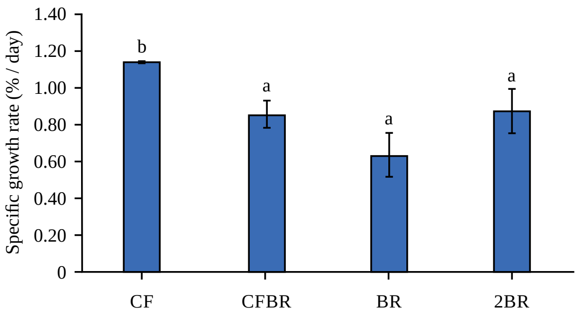

Fig. 4: Specific growth rate of fish during the experiment

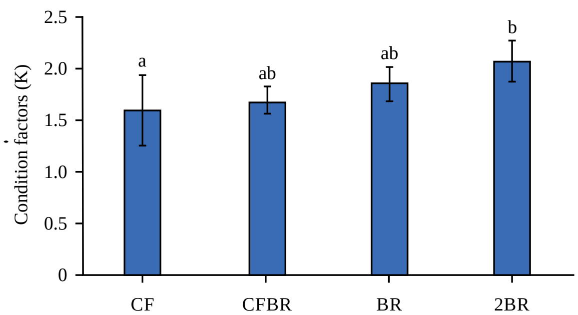

Fig. 5: Fish condition factor at the end of the experiment

Feed utilization parameters: Feed utilization parameters are presented in Table 3. Feed Conversion Ratio (FCR) differed significantly among the feeding methods (p<0.05). The lowest FCR (3.43), indicating the most efficient feed utilization, was recorded in the CF treatment. Voluntary intake (VI) ranged from 4.98-5.42% body weight/day, with no significant differences among treatments (p>0.05).

Economic evaluation: The estimated production cost for 1 kg of fish under each feeding strategy is presented in Table 4. The highest production cost was recorded for the CF treatment (XOF 2,058/kg), followed by the CFBR treatment (XOF 1,788.7/kg). The BR and 2BR treatments resulted in the lowest production costs, amounting to XOF 1,068/kg and XOF 993/kg, respectively.

DISCUSSION

The physicochemical characteristics of the rearing water, including temperature, pH, salinity and transparency, remained stable throughout the experiment and were within the optimal ranges reported for the growth and survival of *Oreochromis niloticus* under tropical conditions[12]. The absence of significant differences among the feeding treatments indicates that the inclusion of broken rice flour, even at the highest feeding level, did not affect the overall physicochemical stability of the rearing environment.

In contrast, dissolved oxygen concentration was significantly lower in the 2BR treatment (5.03±0.59 mg/L). This reduction is likely associated with the decomposition of excess organic matter resulting from the higher quantity of broken rice flour. Because broken rice flour is rich in starch and fiber but has poor water stability compared with extruded pellets, it disperses and dissolves rapidly in water[13]. The decomposition of uneaten feed by microorganisms increases Biochemical Oxygen Demand (BOD), thereby reducing dissolved oxygen levels. Nevertheless, the observed dissolved oxygen concentration remained above the critical threshold of 3 mg/L required to prevent hypoxic stress in Nile tilapia[14,15]. These findings suggest that prolonged overfeeding with broken rice flour may increase the risk of eutrophication and oxygen depletion in pond culture systems[12].

Survival rates ranged from 63.33-86.67% among the feeding treatments. Fish fed the double ration of broken rice flour (2BR) exhibited the highest survival rate (86.67%), whereas those receiving commercial feed (CF) had the lowest survival rate (63.33%) ($p<0.05$). Two factors may explain this result. First, broken rice flour may enhance the natural productivity of the culture environment by acting as an organic fertilizer[9]. Its partial decomposition provides nutrients that stimulate the growth of phytoplankton, zooplankton and benthic organisms, which serve as natural food for Nile tilapia. Owing to its omnivorous and filter-feeding habits, *O. niloticus* can efficiently utilize these natural food resources, thereby reducing nutritional stress and improving survival[16]. Second, the feeding method may influence fish behavior. Commercial feed is highly palatable and concentrated in nutrients, which can increase competition for feed and promote social dominance among fish. Such competition may increase stress, aggression and mortality[17]. In contrast, broken rice flour disperses widely throughout the water, making feed more accessible to all fish and reducing competitive interactions.

The highest growth performance, including weight gain (36.77 g), daily weight gain (0.66 g/day), specific growth rate (1.14%/day) and the lowest feed conversion ratio (3.43), was obtained in fish fed the commercial feed. These results are consistent with the balanced nutritional composition of commercial extruded diets, which are formulated to satisfy the protein and energy requirements of juvenile tilapia and provide high nutrient digestibility[18]. In comparison, fish fed broken rice flour alone exhibited the poorest growth performance, with a weight gain of 16.80 g and an FCR of 7.12. This reduced performance is likely due to the low protein content (8 to 14%), poor balance of essential amino acids and relatively high fiber content of broken rice flour[19].

Increasing the amount of broken rice flour (2BR) improved weight gain compared with the standard broken rice flour treatment (BR). Fish receiving the 2BR diet gained 25.63 g, whereas those fed the BR diet gained only 16.80 g. This improvement suggests that a greater supply of carbohydrates provides additional non-protein energy, allowing dietary protein to be utilized more efficiently for growth rather than for energy production[20]. Furthermore, fish in the 2BR treatment exhibited the highest condition factor ($K = 2.09$), indicating good body condition and greater accumulation of energy reserves, particularly as visceral fat and liver glycogen.

Voluntary feed intake remained similar among the feeding treatments, ranging from 4.98-5.52% body weight/day. This finding indicates that broken rice flour was readily accepted by the fish and that differences in growth performance were primarily related to its nutritional quality rather than feed palatability. The use of locally available feed ingredients may therefore improve feed acceptance while minimizing stress associated with dietary changes[21].

The economic analysis demonstrated a clear difference between biological performance and production cost. Although, the commercial feed treatment produced the greatest growth, it also resulted in the highest production cost (XOF 2,058/kg of fish) because of the high market price of commercial feed (XOF 600/kg). In contrast, the 2BR treatment reduced production costs by more than 50% (XOF 993/kg of fish) while maintaining intermediate growth performance and the highest survival rate. These findings support the economic potential of broken rice flour as an alternative feed ingredient for small-scale and peri-urban fish farming systems in Côte d'Ivoire, where financial resources are often limited[5,6]. The combined commercial feed and broken Rice Flour Treatment (CFBR) produced an intermediate production cost (XOF 1,788.7/kg of fish), suggesting that a co-feeding strategy, such as providing commercial feed in the morning and broken rice flour in the afternoon, may offer a practical balance between fish growth and production costs.

CONCLUSION

The results of this study demonstrate that commercial feed remains the most effective feeding strategy for maximizing the growth performance of *Oreochromis niloticus*. However, under low-input aquaculture conditions, feeding fish a double ration of broken rice flour (2BR) represents a technically and economically viable alternative. This feeding strategy achieved the highest survival rate (86.67%) while reducing production costs to XOF 993/kg of fish. Therefore, the 2BR feeding strategy may provide a practical and cost-effective option for small-scale fish farmers seeking to reduce feed costs without substantially compromising production performance.

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