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Assessment of relative contributions of natural and artificial feed in *Oreochromis niloticus* according to growth stage in integrated rice–fish farming systems in Côte d'Ivoire

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Abstract

Rice–fish farming, which combines rice cultivation with fish rearing in the same environment, represents a promising agroecological solution for sub-Saharan Africa in response to growing food and economic challenges. Although this integrated system enhances the use of natural resources, quantitative data on the dietary intake of natural and artificial feed in *Oreochromis niloticus* remain limited, particularly across different growth stages. This study aims to address this gap by evaluating the nutritional contributions of both feed types in juvenile and adult fish, with the goal of optimising feeding strategies in rice–fish systems. The experiment was carried out at the Bonoufla-Kouadiokro site in Côte d'Ivoire, using nine earthen ponds. Fish were provided with a practical diet formulated from soybean meal, cottonseed meal, rice bran, and maize bran. Individuals were classified into two weight categories: juveniles (26.58–28.15 g) and adults (246.58–251.32 g). Stomach contents were analysed over two 24-hour cycles, taking into account nycthemeral rhythms and growth phases. Results revealed a strong reliance on natural resources, with Euglenophytes and Rotifers dominating the diet. Among juveniles, the distribution between natural and artificial feed was balanced (≈47–53%), whereas artificial feed predominated in adults (≈67%). Cycle 2 was characterised by higher total intake, improved utilisation of artificial rations (up to 72.93% consumed), and reduced waste. These findings underscore the importance of adjusting feed rations according to physiological stage to enhance feeding efficiency and sustainability in integrated rice–fish farming systems.

Keywords: Tilapia; Integrated aquaculture; Feeding behaviour; Stomach content; Endogenous resources; Formulated diet

1. Introduction

Rice–fish farming, which integrates rice cultivation with fish rearing in a shared environment, constitutes an innovative agroecological strategy particularly suited to the socio-economic contexts of sub-Saharan Africa. It enables the integrated management of natural resources while addressing the growing nutritional needs of rural and urban populations, for whom rice and fish are primary sources of calories and protein [1, 2]. In Côte d'Ivoire, annual consumption exceeds 1.5 million tonnes of rice and 300,000 tonnes of fish, yet domestic production remains insufficient, with import rates estimated at 60% for rice and 90% for fish [2]. Despite this, the country possesses significant hydrological potential, including over 1,000 water reservoirs, 64,000 hectares of lowlands, and a lagoon network covering 1,200 km^2—favourable conditions for implementing rice–fish systems [2]. This production model relies on

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functional synergy between its two components: fish contribute to biological pest control and organic fertilisation of rice plots, while rice paddies provide a nutrient-rich habitat teeming with aquatic microorganisms [3]. However, one of the main constraints to aquaculture development remains the high cost of artificial feed, which can account for up to 60% of production expenses [4]. In rice ponds, the availability of natural feed sources such as phytoplankton, zooplankton, and organic detritus offers a valuable nutritional resource for fish, particularly *Oreochromis niloticus*, an omnivorous species widely used in tropical aquaculture [5, 6]. Assessing the relative contributions of natural and artificial feed in these integrated systems is therefore essential to optimise rations, reduce costs, and improve profitability. Yet, quantitative data on the respective consumption of these two feed sources by *O. niloticus* in rice–fish environments remain scarce, especially across different developmental stages [7]. This study seeks to fill that gap by evaluating the nutritional contributions of natural and artificial feed in fry, juvenile, and adult *O. niloticus* reared in rice ponds, with the aim of refining feeding strategies and enhancing the efficiency of rice–fish systems in West Africa.

2. Materials and methods

2.1. Experimental setup and fish rearing conditions

The experiment was conducted at the rice–fish farming site of Bonoufla-Kouadiokro (N 7°11’40.03’’; W 6°31’39.03’’), located 11 km from the village of Bonoufla, in the sub-prefecture of Vavoua (Figure 1). The facility comprised seventeen rectangular earthen ponds, nine of which were designated for experimental trials. These ponds ranged in size from 200 to 675 m², with three ponds allocated to each growth phase. Each pond was gravity-fed from a one-hectare retention dam, ensuring a constant flow rate of 15 L/min and continuous water renewal. A refuge basin, 60 cm deep and covering 5% of the pond surface area, was constructed in each pond to provide shelter for fish during episodes of thermal or hydric stress. The hydraulic system included opposing water inlets and outlets within the rice-growing area, along with a drainage channel leading to the refuge basin. This configuration enabled precise control of water levels, which were maintained at one-fifth the height of the rice plants [8]. Mesh screens with 1 mm openings were installed to protect the pipes from intrusion and leakage.

The experimental fish were *Oreochromis niloticus*, divided into two weight classes: juveniles (26.58–28.15 g) for the pre-grow-out phase, and adults (246.58–251.32 g) for the grow-out phase. Fish were fed a powdered diet containing 25% crude protein, formulated to meet the nutritional requirements of semi-intensive systems. This locally produced feed was composed of raw materials including soybean and cottonseed cakes, maize bran, and low-grade rice flour. The proximate composition of the experimental diet was analysed in Côte d’Ivoire by the Central Laboratory of Analysis (LCA) at Nangui ABROGOUA University, using standard analytical procedures as outlined by the AOAC [9]. The ingredient profile and proximate composition of the experimental diet are presented in Table 1.

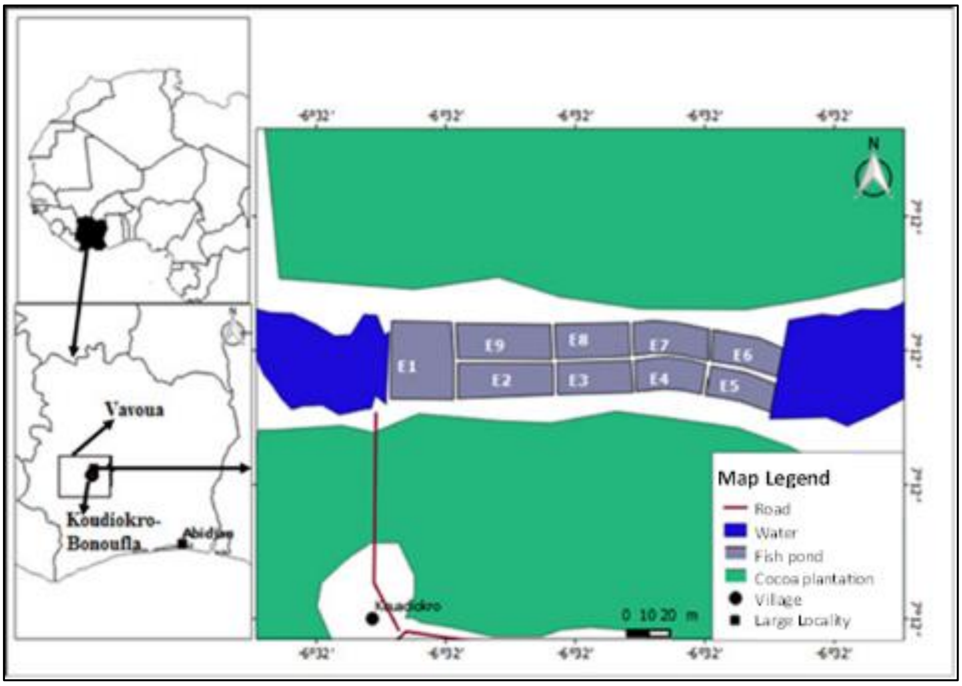

Figure 1 Location of the Kouadiokro–Bonoufla rice–fish farm and sampling points [10]

Table 1 Composition of the formulated diet (g/100 g of feed as distributed) and proximate composition of experimental diet (% dry matter)

Raw materials	Inclusion level of ingredients in the diet (g /100 g of diet as fed)
Ingredients (% as-fed basis)	
Rice bran	27
Soybean meal	25
Cottonseed meal	22
Maize bran	22
Sodium chloride	1,5
Shell meal	1
Palm oil	1,5
Proximate Composition (% DM)	
Dry matter	87.63
Crude protein	25.08
Lipids	9.31
Ash	7.55
Crude fibre	12.16

DM : dry matter

2.2. Fish rearing and sampling procedures

In this study, fish were hand-fed twice daily at 09:00 and 15:00, in accordance with semi-intensive aquaculture practices [11]. Feed rations were adjusted based on developmental stage: juveniles received 5% of their body weight, while adults were fed 3%, reflecting stage-specific metabolic requirements [12]. Stocking densities were maintained at 12 fish/m^2 during the pre-grow-out phase and reduced to 1.5 fish/m^2 in the grow-out phase, in line with recommended thresholds for *Oreochromis niloticus* under semi-intensive conditions [13].

To estimate daily ration and analyse the relative contributions of natural and artificial feed in the fish diet, an intensive sampling protocol was implemented following the methodology described by Bamba et al. [14]. The experiment was conducted over two nychthemeral cycles, with samples collected every three hours over a 24-hour period. The first sampling occurred approximately 30 minutes after the initial feeding. At each interval, fifteen fish were collected per growth phase (pre-grow-out and grow-out), with five individuals sampled from each of the nine earthen ponds. This setup enabled the collection of 120 specimens per cycle and per growth stage.

Fish were individually weighed on site and then dissected to extract the digestive tract. Stomachs were isolated, fixed in 5% formalin solution, and stored separately for laboratory analysis. This method, based on the work of Richter and Focken [15] and Bamba et al. [14], allows for examination of stomach content variations in relation to feeding rhythm and trophic behaviour. It provides a structured approach for quantifying hourly intake and determining daily ration, while distinguishing between natural feed from the environment and formulated feed.

2.3. Stomach content analysis of *Oreochromis niloticus* in rice–fish farming system

In the laboratory, fish stomachs were opened longitudinally and their contents carefully extracted. Food matter was weighed using a high-precision analytical balance (SARTORIUS, sensitivity 0.001 g), and particles were identified and sorted using a binocular magnifier (OLYMPUS SZ 30) and an optical microscope (OLYMPUS BX 40, magnification 40× to 100×), following protocols established by Focken et al. [16], Bamba et al. [14] and Azim et al. [6]. Feed items were then classified into two distinct categories: exogenous (formulated) and endogenous (naturally occurring), and quantified separately according to the methodology described by Bamba et al. [14].

The data obtained enabled estimation of the daily ration based on weight variations in stomach contents observed in the fish [17, 14, 18]. The respective proportions of natural and artificial feed were calculated and expressed as percentages of total intake, providing a solid quantitative basis for evaluating nutritional efficiency within an integrated rice–fish farming system.

3. Results

3.1. Planktonic diet of *Oreochromis niloticus* in integrated rice–fish farming according to growth stage

Stomach content analysis of *Oreochromis niloticus* (Tables 2 and 3) revealed a diet dominated by phytoplanktonic and zooplanktonic organisms, with distribution varying according to growth stage. During the pre-grow-out phase, the main phytoplankton groups identified were Euglenophytes (33% in Cycle 1 and 39% in Cycle 2), followed by Chlorophytes (24% in both cycles), Bacillariophytes (24% and 23%), and Cyanobacteria (19% and 14%). In the grow-out phase, Euglenophytes became predominant (55% and 45%), while Chlorophytes (29% and 33%), Bacillariophytes (12% and 15%), and Cyanobacteria (4% and 7%) remained present but in reduced proportions.

Zooplankton also constituted a significant portion of the diet. Among juveniles, Rotifers were dominant (39% and 42%), followed by Cladocerans (25% and 23%), Copepods (21% and 24%), and other miscellaneous elements (15% and 11%). In adults, Rotifers remained dominant (42% and 46%), accompanied by Cladocerans (28%), Copepods (17% and 15%), and other components (13% and 11%). These results indicate a strong dependence on natural environmental resources, with trophic variation linked to developmental stage.

Table 2 Distribution of phytoplankton (%) in stomach contents

Phytoplankton Group	Pre-grow-out Cycle 1	Pre-grow-out Cycle 2	Grow-out Cycle 1	Grow-out Cycle 2
Euglenophytes	33	39	55	45
Chlorophytes	24	24	29	33
Bacillariophytes	24	23	12	15
Cyanobacteria	19	14	4	7

Table 3 Distribution of zooplankton (%) in stomach contents

Zooplankton Group	Pre-grow-out Cycle 1	Pre-grow-out Cycle 2	Grow-out Cycle 1	Grow-out Cycle 2
Rotifers	39	42	42	46
Cladocerans	25	23	28	28
Copepods	21	24	17	15
Other Elements	15	11	13	11

3.2. Nycthemeral variations in natural and artificial feed intake of juvenile and adult *Oreochromis niloticus* in integrated rice–fish farming system

Figure 2 illustrates the proportions of natural and artificial feed found in the stomach contents of *Oreochromis niloticus* over two 24-hour cycles, according to growth stage. Histogram analysis reveals a cyclical feeding pattern, marked by nychthemeral fluctuations in endogenous and exogenous intake. Ingestion profiles were comparable between juveniles and adults. Within the rice–fish farming context, intake quantities varied according to time of day, feed type, and physiological stage.

Among juveniles in the pre-grow-out phase, natural feed intake reached 0.17 g at 06:00 and 0.21 g at 12:00 in Cycle 1, compared to 0.24 g and 0.23 g respectively in Cycle 2. Artificial feed was primarily consumed at 09:00 (0.35 g in Cycle 1; 0.37 g in Cycle 2) and at 15:00 (0.36 g; 0.42 g). At 12:00, natural intake exceeded artificial intake, with 0.21 g versus 0.05 g in Cycle 1. Intake quantities declined towards the end of the day, reaching 0.018 g (artificial) and 0.02 g (natural) at 24:00 in Cycle 1.

In adults during the grow-out phase, intake volumes were higher. Natural feed was consumed at 06:00 (0.33 g in Cycle 1; 0.30 g in Cycle 2), 09:00 (0.71 g; 0.71 g), and 15:00 (0.50 g; 0.57 g), with minimum values at 24:00 (0.07 g; 0.07 g). Artificial feed intake was concentrated at 09:00 (2.03 g in Cycle 1; 2.19 g in Cycle 2) and 15:00 (1.63 g; 1.69 g), with no intake recorded at 06:00 in either cycle. Overall, juveniles consumed approximately 53% artificial feed and 47% natural feed, while adults consumed 67–68% artificial and 32–33% natural feed. Cycle 2 showed higher intake values and a more consistent hourly distribution between the two feed types.

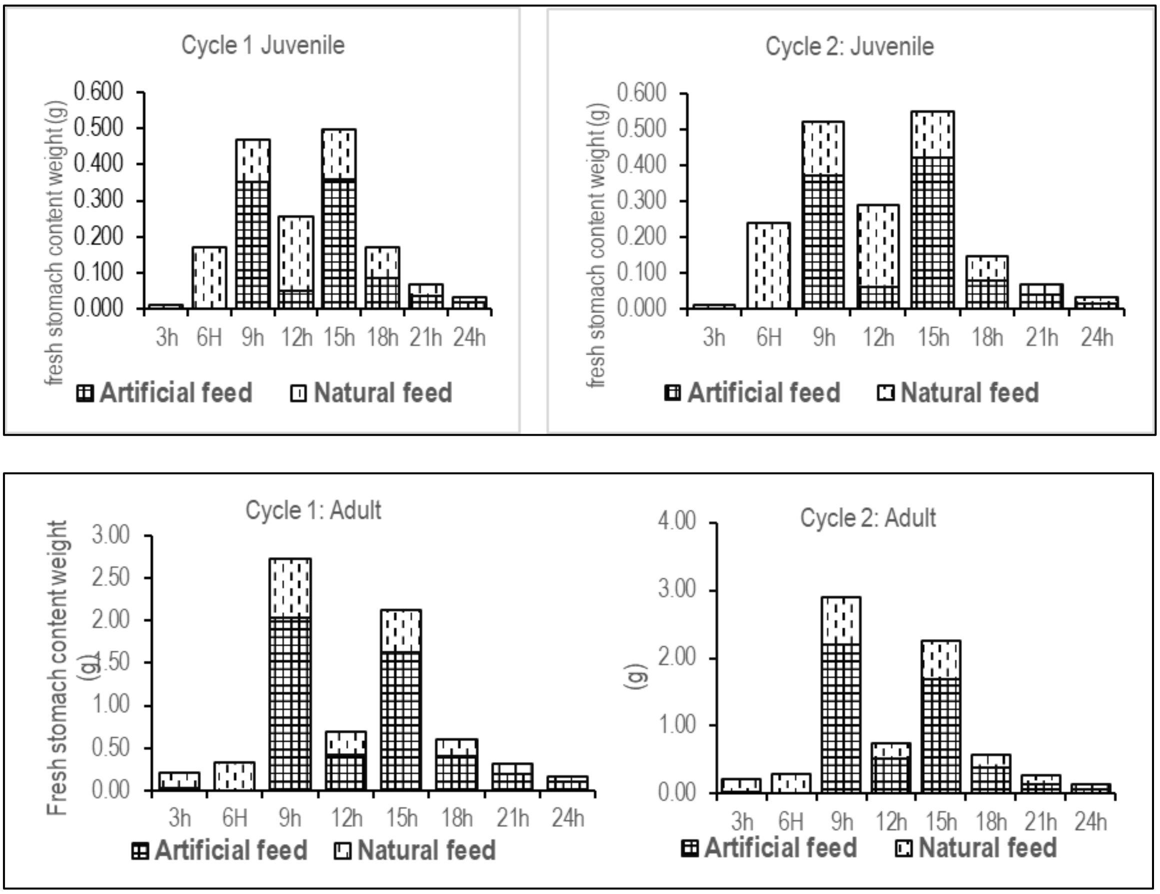

Figure 2 Nychthemeral variation in the proportions of natural and artificial feed in the stomach contents of *Oreochromis niloticus* according to developmental stage over two 24-hour cycles in an integrated rice–fish farming system

3.3. Parameters and variations in natural and artificial feed intake in juvenile and adult *Oreochromis niloticus* over 24 hours in an integrated rice–fish farming system

The analysis of *Oreochromis niloticus* feed intake over two 24-hour cycles (Table 4) reveals variations linked to growth stage, type of feed consumed, and ingestion efficiency. During the pre-grow-out phase, juveniles with an average weight of 28.15 ± 11.04 g in Cycle 1 and 26.58 ± 11.60 g in Cycle 2 received an exclusively artificial ration of 1.41 g/fish and 1.33 g/fish respectively, corresponding to 5% of body weight. Total daily intake reached 1.63 g in Cycle 1 and 1.85 g in Cycle 2, distributed between 0.85–0.97 g of artificial feed and 0.78–0.88 g of natural feed. Relative to live weight, this equates to 3.03% to 3.65% for artificial feed and 2.77% to 3.31% for natural feed, resulting in an overall estimated ration of 5.80% in Cycle 1 and 6.96% in Cycle 2. The consumption rate of artificial feed improved between cycles, rising from 60.3% to 72.93%, with a reduction in feed loss from 39.7% to 27.07%. The distribution of feed sources remained relatively balanced, with a slight predominance of artificial feed (52.15% in Cycle 1; 52.43% in Cycle 2) over natural resources (47.85%; 47.57%).

In the grow-out phase, adults exhibited higher intake volumes, with an average weight of 251.32 ± 35.46 g in Cycle 1 and 246.58 ± 21.05 g in Cycle 2. The distributed ration was mixed, comprising 7.54 g/fish in Cycle 1 and 7.40 g in Cycle 2, corresponding to a rationing rate of 3%. Total intake was 7.18 g and 7.40 g respectively, including 4.80–5.00 g of artificial feed and 2.38–2.40 g of natural feed. Relative to live weight, the consumed ration represented 2.87% in Cycle 1 and 3.00% in Cycle 2, with artificial feed accounting for 1.90% to 2.03% and natural feed remaining stable at 0.97%.

The consumption rate of artificial feed increased from 63.7% to 67.6%, while feed losses decreased from 36.3% to 32.43%. Feed distribution showed a clear dominance of artificial feed in adults, representing 66.85% of the total ration in Cycle 1 and 67.57% in Cycle 2, compared to 33.15% and 32.43% for natural resources.

In contrast to adults, juvenile specimens exhibited a more balanced intake between natural and formulated feed sources. Cycle 2 showed a slight increase in total intake, better use of artificial feed, and lower feed losses in both growth stages.

Table 4 Consumption parameters and daily feed ration of *Oreochromis niloticus* over 24 hours (Cycles 1 and 2) in an integrated rice–fish farming system

Phase	Cycle	Mean weight (g)	Feed type	Feed distributed (g/fish)	Rationing rate (% body weight)	Feed consumed (g/fish)	estimated daily ration (% body weight)	Feed Not consumed (g)	% Feed not consumed	% Feed consumed	Proportion of feed consumed (%)
Pre-grow-out	1	28.15 ± 11.04	Artificial	1.41	5	0.85	3.03	0.56	39.7	60.3	52.15
			Natural	—	—	0.78	2.77	—	—	—	47.85
			Total	*1.41*	*5*	*1.63*	*5.80*	*0.56*	*39.7*	*60.3*	*100*
	2	26.58 ± 11.60	Artificial	1.33	5	0.97	3.65	0.36	27.07	72.93	52.43
			Natural	—	—	0.88	3.31	—	—	—	47.57
			Total	*1.33*	*5*	*1.85*	*6.96*	*0.46*	*34.6*	*65.4*	*100*
Grow-out	1	251.32 ± 35.46	Artificial	7.54	3	4.80	1.90	2.74	36.3	63.7	66.85
			Natural	—	—	2.38	0.97	—	—	—	33.15
			Total	7.54	3	7.18	2.87	2.74	36.3	63.7	100
	2	246.58 ± 21.05	Artificial	7.40	3	5.00	2.03	2.40	32.43	67.6	67.57
			Natural	—	—	2.40	0.97	—	—	—	32.43
			Total	*7.40*	*3*	*7.40*	*3.00*	*2.40*	*32.43*	*67.6*	*100*

4. Discussion

The dietary analysis of *Oreochromis niloticus* within an integrated rice–fish farming system revealed a clear interaction between growth stage, feed type (natural versus artificial), and rearing cycle. These findings align with previous work [19], which demonstrated that such systems optimise resource use through the synergy of exogenous inputs and naturally available environmental resources.

In the pre-grow-out phase, juveniles exhibited a balanced intake between natural and artificial feed, with natural sources accounting for approximately 48% and artificial feed for 52% across both cycles. Daily intake ranged from 1.63 g to 1.85 g per fish. This balance reflects the availability and diversity of planktonic organisms—particularly Euglenophytes (33–39%), Chlorophytes (24%), and Rotifers (39–42%)—which are indicative of a productive aquatic environment. These observations are consistent with findings in [20- 22], which emphasised the role of natural productivity in supporting fish growth under semi-intensive conditions. Mixed feeding regimes have been shown to enhance nutrient assimilation and reduce feed conversion ratios in juvenile tilapia [18, 23], underscoring the importance of maintaining ecological balance in integrated systems.

As fish progressed to the grow-out phase, a dietary shift was observed, with artificial feed comprising over two-thirds of total intake (66.85% in Cycle 1; 67.57% in Cycle 2), while natural feed declined accordingly. This transition coincided with a shift in planktonic composition, marked by increased Euglenophyte dominance and reduced Cyanobacteria presence. Such trophic specialisation reflects physiological adaptation to formulated diets, as noted in [24, 25], which highlighted the enhanced capacity of adult tilapia to utilise high-protein artificial feeds. Supporting studies [26, 27] further confirm that dietary reliance on artificial feed in grow-out systems can improve growth performance when nutritional profiles are well balanced.

Feeding rhythms followed a distinct nycthemeral pattern, shaped by both physiological stage and environmental conditions. Juveniles showed peak natural intake at 06:00 and 12:00, while artificial feed was primarily consumed at 09:00 and 15:00. Notably, natural intake exceeded artificial intake at midday, suggesting autonomous foraging and active exploitation of endogenous resources. Intake declined towards the evening, consistent with findings in [24] on diel feeding behaviour.

Adults displayed higher overall intake, with artificial feed concentrated at 09:00 and 15:00, and natural feed remaining secondary. Despite the absence of artificial feed at 06:00, natural consumption persisted, indicating sustained endogenous trophic activity. These patterns are influenced by feeding schedules, photoperiod, and ecological structuring, as demonstrated in [28], which reported that tilapia exhibit rhythmic feeding behaviour modulated by light cycles and feed composition.

Recent research has further elucidated the physiological basis of these rhythms. Studies [29, 30] showed that digestive enzyme activity and gene expression in *O. niloticus* follow circadian patterns, with peak responses during the dark phase, particularly under biofloc conditions. Feeding frequency and timing significantly affect growth and feed conversion, reinforcing the need to align feeding strategies with biological rhythms.

Comparative analysis between rearing cycles revealed that Cycle 2 was more efficient, with higher intake in both juveniles (1.85 g vs 1.63 g) and adults (7.40 g vs 7.18 g). Artificial feed consumption increased (72.93% vs 60.3% in juveniles; 67.6% vs 63.7% in adults), while feed losses declined. This improvement is attributed to better synchronisation between feeding schedules and fish metabolic rhythms, as supported by [19]. These results are consistent with [31], who found that structured feeding protocols and ecological optimisation in rice–fish systems promote regular intake and reduce waste. Reference [32] also emphasised the role of habitat design and plankton availability in modulating feeding rhythms, with activity peaks linked to plankton density. Further evidence from [33], using stable isotope analysis, demonstrated that fish in integrated systems exhibit trophic plasticity, adapting their feeding behaviour to resource availability over time. The FAO [34] advocates for integrated aquaculture approaches that leverage natural productivity, minimise external inputs, and enhance system resilience. Collectively, these findings highlight the importance of synchronised feeding regimes, ecological design, and adaptive management in improving feed utilisation and supporting sustainable aquaculture. The trophic transition observed in *Oreochromis niloticus*, from a mixed diet in juveniles to artificial feed specialisation in adults, reflects behavioural adaptation to feeding protocols and environmental conditions. Cycle 2 demonstrated greater efficiency, with improved intake, reduced losses, and more stable feed distribution. These outcomes reinforce the value of feeding strategies tailored to physiological stage, in line with the principles of integrated aquaculture and international sustainability standards.

5. Conclusion

This study demonstrates that *Oreochromis niloticus* adapts its feeding behaviour according to growth stage, with juveniles consuming a nearly balanced mix of natural (47.85–47.57%) and artificial feed (52.15–52.43%), while adults show a clear preference for artificial feed (66.85–67.57%). The complementary nature of natural planktonic resources, rich in Euglenophytes, Chlorophytes, and Rotifers, and formulated diets supports efficient nutrient assimilation and growth. Cycle 2 showed improved feed utilisation, with higher intake and reduced losses, highlighting the benefits of synchronized feeding schedules. Integrated rice–fish systems thus offer a resilient, resource-efficient model that enhances zootechnical performance while reducing dependence on external inputs.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

Author contributions

This study was conducted through joint efforts and active collaboration among all authors.

- BZ: Conceptualisation of the study, experimental design, data collection, statistical analysis, and manuscript drafting.
- YB: Coordination of fieldwork, sampling procedures, laboratory analysis, and critical revision of the manuscript.
- YD: Data processing, interpretation of results, preparation of figures and tables, and literature review.
- KAD contributed to rice transplanting, data collection and manuscript correction.
- A O: Technical support during fish rearing trials, feed formulation, and logistical management of the experimental site.

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