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Effect of a diet based on jackfruit seeds (*Artocarpus heterophyllus*) on the morphometrical growth of tilapia (*Oreochromis niloticus*) at the Milasoa Center fish station in Andranovelona, Analamanga Region, Madagascar

[Effet d'un régime alimentaire à base de graines de jacquier (*Artocarpus heterophyllus*) sur la croissance morphométrique du tilapia (*Oreochromis niloticus*) à la station piscicole du Centre Milasoa d'Andranovelona, Région Analamanga, Madagascar]

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Abstract

The surge in aquaculture feed costs constitutes a major constraint to the development of fish farming in Madagascar. This study evaluates the effect of an alternative diet based on jackfruit seed meal on tilapia growth. Over a period of 100 days, two diets were tested on 390 tilapias with an initial weight of 30±2,45g: a control diet (R0) and an experimental diet (RI) containing 28,60% jackfruit seed meal, at the Milasoa fish farming center of Andranovelona. After stocking, five morphometric parameters were measured every 20 days: weight, total length, standard length, headless length, and height. The results indicate that fish fed the RI diet showed higher growth than those in the R0 group, with a survival rate of 100% in both groups. The specific growth rate was 0,875%/day for R0 and 0,924%/day for RI, in an environment favorable to fish development (RI: K = 2,078±0,035 vs. R0: K = 2,122±0,033). The population exhibited "negative allometric" growth in the R0 group and "isometric" growth in the RI group. Furthermore, fish fed the RI diet showed the best feed conversion ratio throughout the trial, with a peak value of 2,73 at the second sampling, and achieved a reduction in production costs of 8,32%. The evolution of the effects of the different tested diets on tilapia allowed a better evaluation of the effectiveness of the jackfruit seed–based diet on performance and feed cost reduction. A complementary study on the organoleptic quality of the flesh will follow the present study.

Keywords: Sustainable aquaculture, alternative feed, *Artocarpus heterophyllus*, growth, *Oreochromis niloticus*, Madagascar.

Résumé

La hausse des coûts des aliments aquacoles constitue une contrainte majeure au développement de la pisciculture à Madagascar. La présente étude évalue l'effet d'un régime alimentaire alternatif à base de farine de graines de jacquier (Artocarpus heterophyllus) sur la croissance du tilapia (Oreochromis niloticus). Sur une période de 100 jours, deux régimes alimentaires ont été testés sur 390 tilapias présentant un poids initial de 30 ± 2,45 g : un régime témoin (R0) et un régime expérimental (RI) contenant 28,60 % de farine de graines de jacquier, au centre piscicole Milasoa d'Andranovelona. Après l'empoissonnement, cinq paramètres morphométriques ont été mesurés tous les 20 jours : poids, longueur totale, longueur standard, longueur sans tête et hauteur corporelle. Les résultats indiquent que les poissons nourris avec le régime RI ont présenté une croissance supérieure à celle du groupe R0, avec un taux de survie de 100 % dans les deux groupes. Le taux de croissance spécifique était de 0,875 %/jour pour R0 et de 0,924 %/jour pour RI, dans un environnement favorable au développement des poissons (RI : K = 2,078 ± 0,035 contre R0 : K = 2,122 ± 0,033). La population a présenté une croissance allométrique négative dans le groupe R0 et une croissance isométrique dans le groupe RI. Par ailleurs, les poissons nourris avec le régime RI ont enregistré le meilleur indice de conversion alimentaire tout au long de l'essai, avec une valeur maximale de 2,73 lors du deuxième échantillonnage, ainsi qu'une réduction des coûts de production de 8,32 %. L'évolution des effets des différents régimes testés sur le tilapia a permis une meilleure évaluation de l'efficacité du régime à base de graines de jacquier en termes de performance zootechnique et de réduction des coûts alimentaires. Une étude complémentaire portant sur la qualité organoleptique de la chair est prévue à la suite du présent travail.

Mots-clés : Aquaculture durable, aliment alternatif, *Artocarpus heterophyllus*, croissance, *Oreochromis niloticus*, Madagascar.

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1. Introduction

Inland fisheries and aquaculture constitute major components of food security and socio-economic development in Madagascar. With an annual production estimated between 28.000 and 30.000 tonnes, the sector provides a substantial share of the animal protein consumed by households (Razafindralambo, 2008). However, despite this potential, Malagasy quaculture continues to face numerous structural constraints that limit its expansion, notably the overexploitation of natural resources, the lack of adequate infrastructure, and the widespread use of poorly optimized farming practices (PNVBV, 2020).

Among the factors limiting productivity, the cost of feed inputs plays a predominant role. In Africa, as in many other developing countries, feed accounts for 50 to 80% of operating expenses according to FAO in 2013.

This burden is exacerbated by dependence on imported ingredients such as fish meal, protein concentrates, and certain cereals, whose prices fluctuate widely on international markets. Madagascar is not exempt from this issue: access to commercial feeds remains limited and costly for the majority of small-scale fish farmers, who therefore resort to artisanal diets that are often unbalanced and poorly suited to the nutritional requirements of fish (FAO, 2022). This situation leads to suboptimal growth, prolonged production cycles, and reduced profitability.

In response to these challenges, the valorization of local agricultural by-products appears to be a strategic and sustainable pathway. Numerous studies conducted in Africa and Asia have explored the use of by-products such as copra meal, cocoa residues, oil palm shells, and legume flours. These studies demonstrate that partial substitution of fish meal is feasible, provided that good digestibility is ensured and antinutritional factors are reduced through appropriate processing methods.

In this context, jackfruit (*Artocarpus heterophyllus*), a fruit tree widely found in Madagascar, offers particularly interesting potential. Its seeds, often considered waste, nevertheless exhibit a favorable nutritional composition, containing between 10,09% and 30,84% protein and a high content of complex carbohydrates (Kamdem Bemmo et al., 2023). Several recent studies on tilapia have shown that jackfruit seeds, when processed through dehulling, cooking, extrusion, or decortication, can replace a significant portion of fish meal without causing a reduction in growth performance (Cuevas-Rodríguez et al., 2024). Some studies even suggest the possibility of substitution levels reaching 40–50%, with performance comparable to that obtained using conventional diets (Niang et al., 2022).

The use of jackfruit seeds in aquafeeds therefore represents a dual opportunity: to reduce production costs by replacing an expensive input, and to valorize an abundant and still underexploited local resource. Such an approach aligns with principles of sustainability, circularity, and the strengthening of the economic resilience of Malagasy fish farming systems (Jatta et al., 2022).

The present study aims to evaluate the effect of incorporating jackfruit seeds into tilapia diets on morphometric performance. More specifically, it seeks to:

(1) compare the growth of fish fed a traditional diet with that of fish fed a jackfruit seed-enriched diet;

(2) analyze the economic profitability of this alternative feed.

Two hypotheses guide this work:

H1: the incorporation of processed jackfruit seeds does not result in a significant reduction in tilapia growth performance;

H2: this incorporation reduces feed cost per kilogram of fish produced.

2. Material et methods

2.1. Study Site and Duration

The experiment was conducted at the Milasoa Center fish station in Andranovelona (figure 1), over a period of 100 days from November 4, 2024, to February 17, 2025.

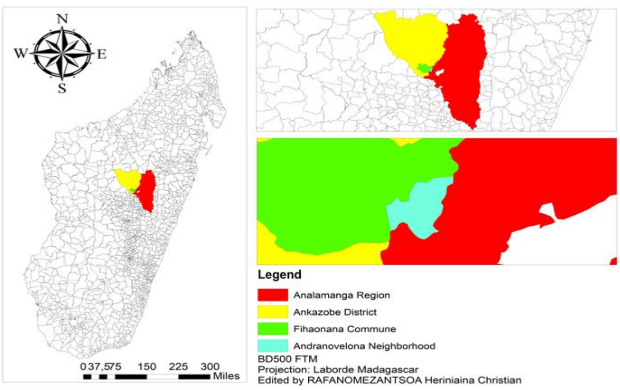

Figure 1. Location of the study site (Source: BD500FTM, 2025)

2.2. Biological Material

A stock of 390 unsexed Oreochromis niloticus juveniles, with an initial average weight of 30±2,45g, was used (Pompa & Masser, 1999; El-Sayed, 2006). The fish came from the Milasoa Center fish farm, guaranteeing a homogeneous genetic strain.

2.3. Animal Feeding

Daily feed distribution was carried out twice a day (09:00 and 15:00), at a rate of 4% of the total biomass (Pompa & Masser, 1999; FAO, 2020). The amount of feed distributed was readjusted every 20 days based on the average weight of the fish, determined during control weighings (Billard, 1995).

The feed ration formulation was performed by linear programming using the Solver add-in in Excel, taking into account the nutritional requirements of the studied animals (NRC, 2011). The nutritional composition of the different experimental diets is presented in table I.

Tableau I. Nutritional value of the different experimental diets per 100 kg of feed

Composition (/100g)	R_0	R_I	*R_0: Habitual feed, RI: Feed with 29% jackfruit seed meal*
Crude Protein (%)	34,30	36,00	
Fat (%)	2,92	2,92	
Ash (%)	4,78	5,04	
Fiber (%)	2,66	2,00	
Lysine (%) *	1,84	0,30	*(%) *: % of total nitrogenous matter*
Methionine (%) *	0,83	0,14	*(%) *: % of total nitrogenous matter*
Ca (%)	0,70	0,70	
Phosphorus (%)	0,40	0,40	
Energy			
Crude Energy (Mj/100g)	2,61	2,77	***Mj:** Megajoule*

2.4. Experimental Design

A completely randomized design was set up with 02 treatments (R0 and RI), randomly distributed in each lot to guarantee group homogeneity (figure 2).

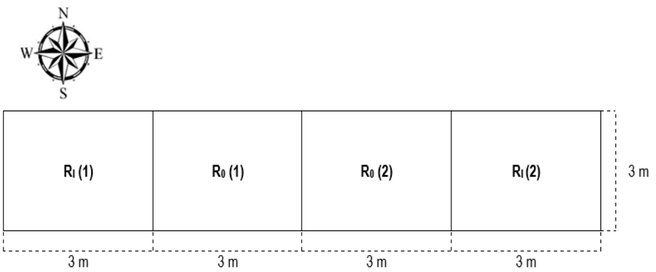

Figure 2. Experimental design

With:

R0 : Local ration

RI : Ration with 28,60% jackfruit seed meal

Four 9m³ tanks were each stocked with 90 tilapia, corresponding to a stocking density of 10 fish/m3, in accordance with the recommendations of Mengistu et al., (2020).

2.5. Measurement of monitoring indicators

2.5.1. Measurement of fish growth performance

Five morphometric parameters were measured every 20 days: weight, total length, standard length, headless length, and height (figure 3.), according to the method of Mainguy et al., (2023).

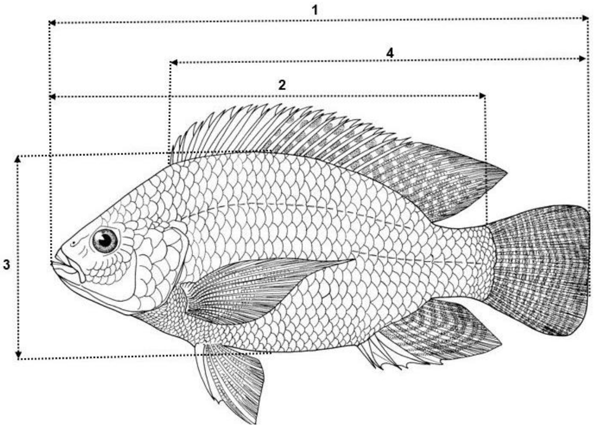

Figure 1. Main measurements taken on Tilapia

1. Total length : Total Length: distance between the tip of the snout and the tip of the caudal fin lobe;
2. Standard length: Standard Length: distance between the tip of the snout and the end of the caudal peduncle;
3. Body height: Body Height: distance between the dorsal contour and the ventral contour of the body;
4. Headless length: Headless Length: distance between the base of the dorsal fin and the tip of the caudal fin lobe.

2.5.2. Measurement of water physico-chemical parameters

As tilapia are ectothermic or poikilothermic animals, variations in the physico-chemical parameters of water, particularly temperature, directly influence their feeding behavior (Hamed et al., 2024). Three parameters were measured daily: pH, water temperature (°C), and dissolved oxygen concentration (mg/l).

1. Measurements were conducted at a depth of 30 cm;

2. Measurements were taken at a fixed and unchanged location in each tank;

3. Measurements were systematically repeated three times per day according to the predefined schedule.

2.6. Performance Indices

2.6.1. Average Daily Gain

The Average Daily Gain (ADG) represents the average daily weight gain obtained during the rearing period (Elegbe et al., 2015). It is given by (1)

$$\text{Average Daily Gain (g/day)} = \frac{\text{Final Weight (g)}}{\text{Rearing duration in days (days)}} \quad (1)$$

2.6.2. Specific Growth Rate

The Specific Growth Rate (SGR) allows appreciation of the fish's growth speed or evaluation of the rate of weight gain by individuals during the rearing period (Elegbe et al., 2015). It is expressed in (2).

SGR = [(lnFW - lnIW) / t] x 100 (2)

Where: - SGR: Specific Growth Rate

- lnIW: Natural logarithm of initial weight
- lnFW: Natural logarithm of final weight
- t: Rearing duration in days (days)

2.6.3. Survival Rate

The Survival Rate (SR) represents the rate of individuals that survived until the end of the (Arrignon, 1998), expressed by the relation (3).

SR (%) = [Number of individuals at end of trial / Initial number of individuals] x 100 (3).

2.6.4. Condition Factor

The condition factor (K) as an indicator of the physiological state of the fish (health, well-being and growth) for estimating the ecological state of the environment (habitat quality, water quality, feeding activity of the species and availability of trophic resources) (Ricker, 1975; Fréon, 1979) according to Fulton's equation (1911) (4).

2.6.5. Allometric Relationship

The allometric relationship translated by the length-weight relationship was chosen to inform the state of the ponderal and corporal growth of the fish, namely the shape, plumpness and variations during growth and also to identify possible differences likely in the individuals treated with the different rations (Ricker, 1975; Froese, 2006). An equation (5) was proposed by Le Cren in 1951.

W = a (TL) b (5)

Where:

- W: Live weight of the fish (g)
- LT: Total Length (cm)

This exponential relationship was transformed into linear form according to equation (6) :

Log W = Log a + b Log (TL) (6)

2.6.6. Feed Conversion Ratio

The Feed Conversion Ratio (FCR) evaluates the efficiency of the feed used for fish growth. It was calculated according to the following formula (7) (Cho & Kaushik, 1985).

FCR (g/g) = feed distributed (g) / weight gain (g) (7)

2.7. Economic Analysis

A profitability analysis was performed by comparing production costs between the two rations, focusing on feed costs which represent nearly 70% of total costs (Willy et al., 2024).

2.8. Data Processing and Analysis

The collected data were recorded in an Excel 2013 spreadsheet and then statistically analyzed using RStudio version 2025.09.2+418. The analysis involved checking the data distribution, and when it followed a normal distribution, the appropriate parametric tests were performed. In cases of non-normality, non-parametric tests were used (table II).

Table II. Statistical Test Selection for One-Sample and Two-Sample Mean Comparisons

Test objective	Parametric test	Non-parametric test
Compare a mean to a reference value (one sample)	Student's t-test	Wilcoxon test
Compare two means (two samples)	Student's t-test	Mann-Whitney test

Differences observed between groups were considered statistically significant when the p-value was less than or equal to the significance threshold α = 0,05. In addition to significance analyses, estimates of biological parameters were presented with their 95% confidence intervals to assess the precision of the means and quantify the uncertainty associated with the obtained values.

3.1.1. Water pH

Figure 3 shows the daily mean variation of water pH for the two treatments, R0 and RI.

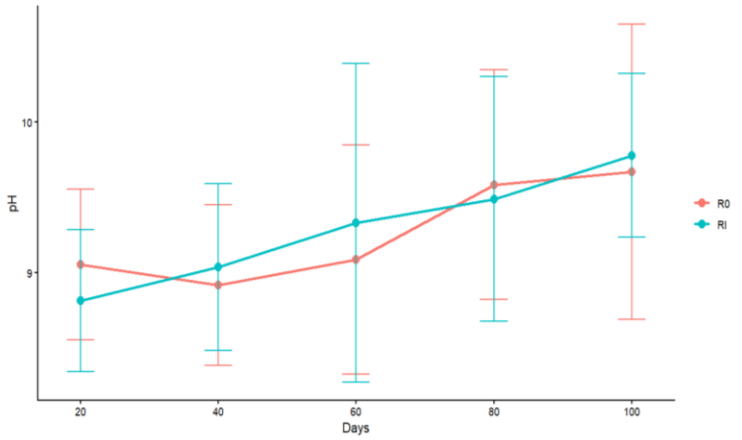

Figure 3. Daily mean variation of water pH

R0: Control diet ; RI : Diet with jackfruit seeds.

Figure 3 illustrates the daily mean variation of water pH for both treatments. For the control diet (R0), pH ranged from 8,915 to 9,670, with a mean of 9,27±0,71. For the jackfruit seed–based diet (RI), pH ranged from 8,811 to 9,780, with a mean of 9,29±0,69. These results indicate that pH remained relatively stable during the experiment for both treatments and that the inclusion of jackfruit seeds did not cause any significant pH variation, remaining within a slightly basic range suitable for tilapia farming.

3.1.2. Water temperature

Figure 4 shows the daily mean variation of water temperature for treatments R0 and RI.

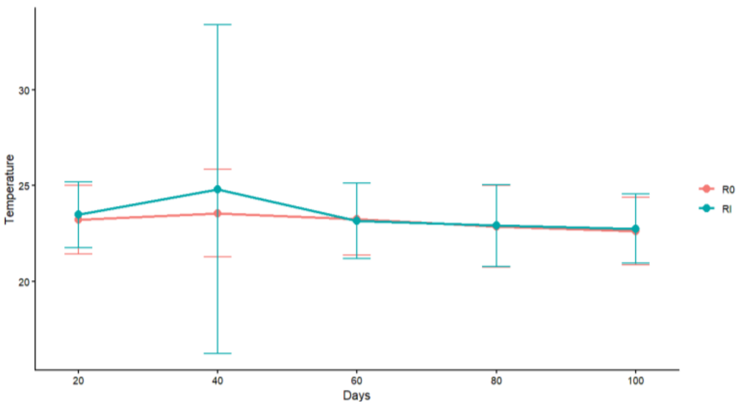

Figure 4. Daily mean variation of water temperature

R0: Control diet; RI: Diet with jackfruit seeds

Figure 4 illustrates the daily mean variation of water temperature for both treatments. For the control diet (R0), temperature ranged from 22,641 to 23,560°C, with a mean of 23,09±1,99°C. For the jackfruit seed–based diet (RI), temperature ranged from 22,759 to 24,811°C, with a mean of 23,63±3,40°C. These results indicate that water temperature remained generally stable for both treatments, without excessive fluctuations, and that the inclusion of jackfruit seeds did not cause any significant variation

3.1.3. Dissolved oxygen in water

Figure 5 shows the daily mean variation of dissolved oxygen in water for the different diets.

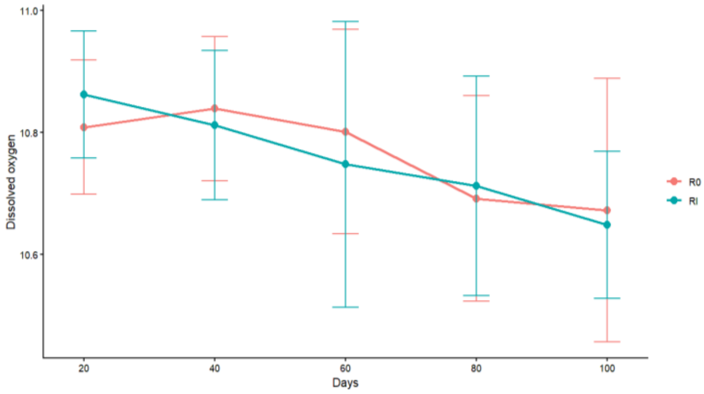

Figure 5. Daily mean variation of dissolved oxygen in water

R0: Control diet; RI: Diet with jackfruit seeds

Figure 5 illustrates the daily mean variation of dissolved oxygen for both treatments. For the control diet (R0), dissolved oxygen ranged from 10,673 to 10,839 mg/l, with a mean of 10,78±0,16 mg/l. For the jackfruit seed–based diet (RI), values ranged from 10,649 to 10,862 mg/l, with a mean of 10,76±0,14 mg/l. These results indicate that dissolved oxygen content remained relatively stable during the experiment for both treatments and that the inclusion of jackfruit seeds did not lead to any significant variation

3.2. Average Daily Gain

Table III presents the cumulative Average Daily Gain of tilapia treated with the two different feed rations.

Table III. Cumulative Average Daily Gain (ADG) produced by the two types of feed (R0 and RI)

Feed	IW (g)	FW (g)	Weight Gain	Rearing Duration (days)	ADG (g/day)
R_0	30,00	71,97	41,97	100	0,42
R_I	30,00	75,56	45,56	100	0,46

R0: Control ration; RI: Jackfruit seed-based ration; IW: Initial Weight; FW: Final Weight; ADG: Average Daily Gain.

The results presented in Table 2 show a positive evolution of the average daily gain (ADG) in tilapia fed with both types of rations. The ADG obtained with the experimental ration based on jackfruit seeds (RI) is slightly higher (0,46 g/day) than that recorded with the control ration (R0) which is 0,42 g/day. This difference suggests that the incorporation of jackfruit seeds in the feed formulation had a beneficial effect on fish growth. Indeed, the RI ration allowed a total weight gain of 45,56 g compared to 41,97 g for the control ration, translating to better feed conversion efficiency and satisfactory valorization of this local alternative ingredient.

The temporal evolution of the average weight of tilapia fed with the two types of feed is presented in figure 5 to more clearly illustrate the growth dynamics observed during the experiment.

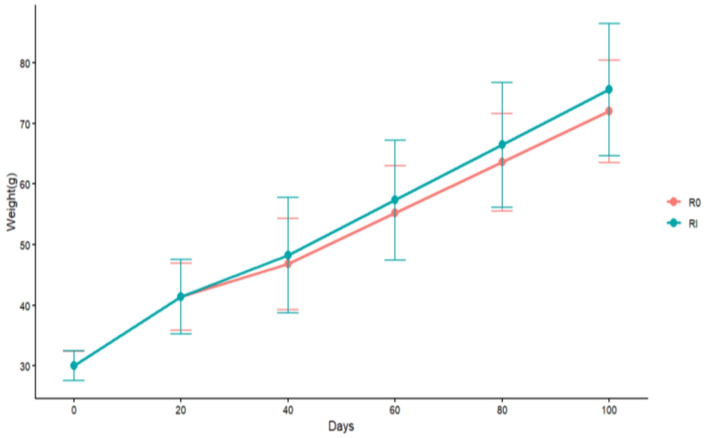

Figure 5. Evolution of the average weight of tilapia fed with the two experimental feeds

R0: Control ration; RI: Jackfruit seed-based ration

The evolution of the average weight shows a regular and continuous growth of tilapia for both diets. The fish fed with the jackfruit seed-based ration (RI) show slightly higher weights than those of the control lot (R0), indicating a moderate improvement in growth performance. The parallel progression of the curves confirms the homogeneity of the rearing conditions, suggesting that the observed difference primarily results from the type of ration. These results confirm the nutritional potential of the RI ration as a viable alternative for tilapia feed.

3.3. Specific Growth Rate

Table IV highlights the specific growth rate of the studied animals in relation to the different dietary treatments.

Table IV. Specific Growth Rate (SGR) produced by the 2 feeds

Specific Growth Rate	Complete Cycle
Feed R_0	0,875
Feed R_I	0,924
p-value	<0,0001

The results presented in Table 3 show that the specific growth rate (SGR) of tilapia fed with feed RI (0,924 %/day) is significantly higher than that obtained with feed R0 (0,875 %/day). The p-value (< 0,0001) indicates a highly significant difference between the two treatments, reflecting the positive effect of feed RI on fish growth. This improvement suggests that the incorporation of the alternative material in the formulation of feed RI contributed to better nutrient utilization and, consequently, increased growth performance.

3.4. Survival Rate

In the context of this experiment, all individuals survived until the end of the study, regardless of the pond and diet used. The survival rate of the tilapia was thus 100% for all four ponds and for both types of feed tested (R0 and RI). These observations indicate that the tilapia optimally tolerated the eco-climatic conditions of the study area as well as the implemented farming practices, notably the stocking density and feeding methods adopted. This maximum survival constitutes a reliable indicator of the viability of the experimental diets and provides a favorable context for the subsequent evaluation of their impact on growth, zootechnical performance, and the health status of the fish.

3.5. Environmental Condition

Table V presents the condition of the environment for the tilapia according to the different dietary treatments.

Table V. Condition factor "K" of the population treated with the different feed rations (R0 and RI)

Ration	Number	Minimum	Maximum	Mean ± Standard deviation
R_0	180	2,059	2,162	2,122 ± 0,033
R_I	180	2,007	2,127	2,078 ± 0,035

The condition factor (K) reflects the body shape and nutritional status of the fish. The mean values obtained (2,122±0,033 for R0 and 2,078±0,035 for RI) indicate good physical condition in both treatments. The slight decrease observed with the experimental ration (RI) remains non-significant, indicating performance comparable to that of the control ration. Thus, the incorporation of jackfruit seeds did not alter the body condition of the tilapia, confirming its harmlessness and potential as an alternative source in their feed.

3.6. Growth Status

The results on the growth status of tilapia treated with the different feed rations used are presented in Table VI.

Table VI. Equations of the weight-length relationship lines of tilapia treated with ration R0 and

Ration	Allometric Equations	R^2	Standard deviation	p-value	n	Nature of Growth
R_0	LogW = 2,821Log (LT) – 1,463	0,986	0,007	<1‰	180	Negative Allometric
R_I	LogW = 3,066Log (LT) – 1,760	0,987	0,006	<1‰	180	isometric

The established weight-length relationships show a very satisfactory fit, with high coefficients of determination (R^2 = 0,986 for R0 and R^2 = 0,987 for RI), indicating a strong correlation between the two variables. In fish fed the control ration (R0), the allometric exponent (b = 2,821) is less than 3, indicating negative allometric growth, where the increase in weight is slightly less than that in length. In contrast, the experimental ration (RI) presents an exponent close to 3 (b = 3,066), corresponding to isometric growth, characteristic of harmonious development between size and weight. These results suggest that the incorporation of jackfruit seeds does not alter the morphometrical growth of tilapia and allows for a balanced weight-length relationship.

3.6. Feed Conversion Ratio

The evolution of the feed conversion ratio of the different feeds tested on the fish is illustrated in figure 6.

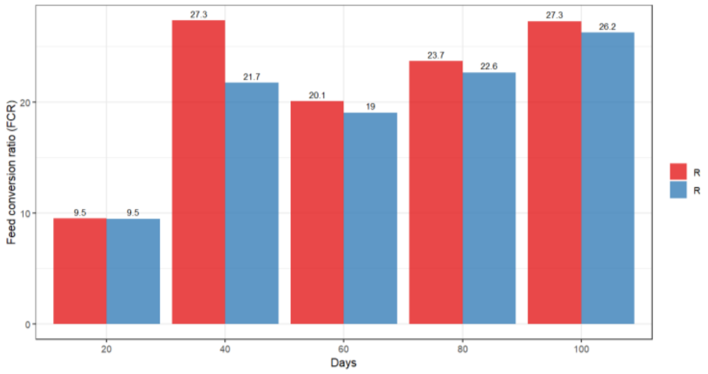

Figure 6. Evolution of the feed conversion ratio of tilapia according to the feed rations used

The evolution of the feed conversion ratio (FCR) shows similar efficiency for both diets at day 20 (9,5). At day 40, the FCR of R0 was 27,3, higher than that of RI (21,7), indicating better feed conversion for the jackfruit seed–based diet. At day 60, FCR values were close (20,1 for R0 and 19,0 for RI), and at day 80 (23,7 for R0 versus 22,6 for RI) as well as at day 100 (27,3 for R0 and 26,2 for RI), RI remained slightly more favorable. Overall, the RI diet allowed slightly more efficient feed conversion than R0 throughout the experimental period.

3.7. Economic Analysis

Table VII presents the costs and production expenses of fish according to the different diets used during the trial.

Table VII. Costs and production expenses of tilapia fed R0 and RI diets during the experiment

Variables	R_0		R_I	
	R_0	***R_I***	***R_0***	***R_I***
*Day (1) **	*0.108*	-	*0.086*	*0.022*
*Day (2) **	*0.108*	-	*0.065*	*0.043*
*Day (3) **	*0.108*	-	*0.043*	*0.065*
*Day (4) **	*0.108*	-	*0.022*	*0.086*
*Day (5) **	*0.108*	-	-	*0.108*
*Quantity offered (kg)**	*0.540*	-	*0.261*	*0.324*
*Feed offered (kg)***	*80.058*		*82.665*	
Feed price (MGA/100kg)	338,100		311,139	
Feed cost (MGA)	77,014		73,183	
Labor (MGA/100 days)	700,000		700,000	
Total cost (MGA)	777,014		773,183	
Total production (kg)	13,600		12,955	
Production cost per kg of fish (MGA/kg)	18,513		16,972	
Tilapia selling price (MGA/kg)	20,000		20,000	
Total revenue (MGA)	259,100		272,00	
Gross margin (MGA)	182,086		198,817	
Net margin (MGA)	-517,914		-501,183	
Profit per kg (MGA/kg)	1,487		3,028	
Break-even price (MGA/kg)	59,978		56,852	
Unit variable cost (MGA/kg)	5,945		5,381	
Break-even quantity (kg)	14,055.268		14,618.897	
** During the transition phase ; ** During the 100-day experimental period*				

The results show that the RI diet is generally more advantageous than the R0 diet from an economic perspective. Although the quantities of feed distributed are similar, RI has a slightly lower feed cost, which reduces the total production cost. Despite a slightly lower total production than R0, the RI diet shows a lower production cost per kilogram (16,972 vs. 18,513 MGA/kg).

Both treatments generate a negative net margin, indicating that the production obtained does not cover fixed costs. However, RI remains more efficient: it provides a higher gross margin, greater unit profit, and a lower variable cost per kg. Thus, across all evaluated economic parameters, the RI diet is more efficient and profitable than the R0 diet, although neither diet achieves net profitability at this production level.

4. Discussion

4.1. Physical-chemical parameters of tank water

4.1.1. Water pH

The mean daily variation in pH showed comparable chemical stability between the two treatments. The values observed for R0 (8,92–9,67; 9,27±0,71) and RI (8,81–9,78; 9,29±0,69) indicate a slightly alkaline environment, with no notable difference related to the incorporation of jackfruit seeds. Similar results were reported by Wachira et al., (2021), with a mean pH close to 8,9 in tilapia ponds receiving alternative feeds. In contrast, Makori et al., (2017) reported lower values (6,35–6,87) in extensive Kenyan systems. At slightly higher levels, Rebouças et al., (2016) indicated that pH values between 8,5 and 9,5 remain compatible with the growth of Oreochromis niloticus. These results confirm the adaptability of tilapia to moderately alkaline conditions.

4.1.2. Water temperature

Water temperature remained relatively stable between the two treatments, with mean values of 23,09±1,99°C for R0 and 23,63±3,40°C for RI, indicating thermal conditions favorable for tilapia culture. These values are comparable to those reported by Chepkirui et al., (2021), who observed temperatures ranging from 22,5 to 23,3°C in similar experimental systems. At lower levels, Harrison et al., (2004) showed that temperatures below 20–22°C lead to reduced growth and metabolic activity in *Oreochromis niloticus*. Conversely, higher temperatures, between 28 and 30°C, have been associated with enhanced growth, as reported by Hamed et al., (2024). The present results confirm that the incorporation of jackfruit seeds did not affect the thermal stability of the environment, which remained compatible with the physiological requirements of tilapia.

4.1.3. Dissolved oxygen in water

The mean daily concentration of dissolved oxygen remained stable and comparable between the two treatments, with 10,78±0,16 mg/l for R0 and 10,76±0,14 mg/l for RI, reflecting a well-oxygenated environment favorable to the respiratory functions of tilapia. These values are close to those reported by Mohammad et al., (2024), who observed concentrations ranging from 7,1 to 10,7 mg/l in similar culture systems. At lower levels, Kamau et al., (2023) reported concentrations between 4,0 and 5,3 mg/l, often associated with reduced zootechnical performance. Conversely, higher concentrations, reaching 11,0–11,5 mg/l, were reported under intensive aeration by Cruz et al., (2024). These results indicate that the incorporation of jackfruit seeds did not affect water oxygenation, which remained close to saturation and compatible with the physiological requirements of tilapia.

4.2. Average Daily Gain

The analysis of the Average Daily Gain (ADG) of tilapia shows that the inclusion of jackfruit seeds in the ration (RI) slightly improved fish growth compared to the control ration (R0) (0,46 g/day vs 0,42 g/day). These results indicate that jackfruit seeds can constitute an interesting alternative nutritional source, without compromising growth performance.

Comparatively, previous studies report higher ADGs in other species (chickens), ranging from 33 to 62g/day (Eburuaja et al., 2019; Adamu et al., 2024), while values close to 43,5 g/day have been observed using alternative experimental diets (Zendesha et al., 2024). These differences can be explained by the initial weight of the fish, rearing duration, stocking density, or the nutritional composition of the rations.

4.3. Specific Growth Rate

The Specific Growth Rate (SGR) obtained with the experimental feed RI (0,924 %/day) is significantly higher than that of the control diet R0 (0,875 %/day) ($p < 0,0001$), indicating better nutrient utilization and increased feed efficiency.

This result falls within the range reported by Rita et al., (2017) (0,81–1,20 %/day), confirming the consistency of the observed performance. Higher values have been noted by Muin et al., (2017) (2,43 %/day) and Houndonougbo et al., (2017) (7,25–7,60 %/day), differences probably related to the initial size of the fish, rearing duration, and protein content of the feeds. Conversely, some studies have reported slightly lower SGRs (~0.81 %/day) under semi-intensive conditions (Rita et al., 2017).

Thus, the SGR of 0,924 %/day obtained with feed RI ranks within the average of reported values, demonstrating the good nutritional quality of the experimental ration and the potential of local raw materials to improve tilapia growth.

4.4. Environmental Condition

The 100% survival rate observed for all treatments (R0 and RI) indicates excellent tolerance of the tilapia to the rearing conditions and the quality of the dietary regimes. This result aligns with those of Ahir et al., (2023) and Eze and Avwemoya, (2019), who also reported maximum survival with feeds enriched with local proteins. Similarly, Mansyur et al., (2022) and Nairuti et al., (2021) showed that the incorporation of Azolla or insect meals does not affect survival. Conversely, Santiago et al., (1987) noted a drop to 53% under low ration, highlighting the importance of adequate feeding. Thus, the total survival obtained confirms the viability of the tested diets and the good control of rearing conditions.

4.5. Growth Status

The condition factor (K) obtained in tilapia fed the control diet R0 (2,122±0,033) was slightly higher than that of the group receiving the jackfruit seed–based diet RI (2,078±0,035), although both values remained high (K>2), indicating good physiological condition of the fish. These results fall within the range reported by Nguyen et al., (2023), who obtained K values between 1,80 and 2,20 in tilapia fed alternative plant-based ingredients, confirming the consistency of the observed performance. Comparable values were also reported by Rostro et al., (2024), with coefficients ranging from 1,70 to 2,10 depending on the level of protein substitution. In contrast, some experimental studies have reported slightly lower values (1,60–1,80) in fish subjected to less balanced diets or fluctuating environmental conditions (Cadorin et al., 2022).

Thus, the K values obtained in the present study are in the upper range of those reported in recent literature, demonstrating that the incorporation of jackfruit seeds into tilapia diets does not impair body condition and confirms the good nutritional potential of this local ingredient.

4.6. Feed Conversion Ratio

The feed conversion ratio (FCR) reflects the efficiency with which fish convert ingested nutrients into biomass (Kumar et al., 2018). In this study, tilapia fed the experimental jackfruit seed–based diet (RI) exhibited slightly better feed conversion than those receiving the control diet (R0) throughout the experimental period. This trend, which became pronounced from day 40 (FCR = 21,7 for RI versus 27,3 for R0), suggests more efficient utilization of the alternative diet. Comparable results were reported by Cuevas-Rodríguez et al., (2024), where the incorporation of processed jackfruit seeds improved digestibility and reduced feed losses. Similarly, Fan et al., (2020) indicated that moderate inclusion of local plant-based ingredients in aquafeeds can optimize feed conversion without compromising growth. These observations confirm that the use of jackfruit seeds represents a sustainable and economically advantageous option for tilapia feeding.

4.7. Economic Analysis

The results show that the production cost per kilogram of tilapia was 18.513 MGA for R0 and 16.972 MGA for RI, with a selling price of 20.000 MGA/kg. Although the gross margin was positive, the net margin remained negative, indicating that fixed and feed costs exceeded total revenues.

Comparatively, these unit costs are higher than those reported in optimized intensive systems (4.000 MGA/kg) (Lazard, 2009), likely due to the experimental scale of the tanks and high fixed costs. However, they are close to values observed in similar experimental studies, where net profitability may remain limited (Burad-Méndez et al., 2023).

The RI diet reduced production costs and increased profit per kilogram compared to R0, suggesting relatively higher economic performance. These results highlight the importance of optimizing input management and labor to improve net profitability in local semi-intensive systems

5. Conclusion

This study highlights that the incorporation of jackfruit seed meal into tilapia diets does not lead to a significant alteration in morphometric growth performance, thereby confirming the technical feasibility of this alternative feed source. Economic results indicate a reduction in feed costs of 8.32%, reflecting a potential gain in profitability without zootechnical compromise. From a practical perspective, the use of jackfruit seeds represents an accessible and economically advantageous option for fish farmers, particularly in areas where this resource is abundant and underutilized, thereby contributing to the sustainability and resilience of aquaculture production systems. However, further research is necessary to: (1) optimize seed processing methods, (2) assess their effects on the organoleptic and nutritional quality of the flesh, and (3) conduct larger-scale economic analyses that incorporate the technical and commercial constraints of fish farming operations.

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Conflicts of Interest

The authors declare that they have no conflicts of interest related to this research. No specific funding or external influence affected the collection, analysis, or interpretation of the data presented in this article.

Ethical Considerations

This study was conducted in strict accordance with the ethical principles of scientific research, emphasizing the utilization of locally available resources, with the aim of contributing to the sustainable development of the aquaculture sector in Madagascar and, more broadly, at a global level.

Author's contributions

R.H.C: designed the study, carried out the experiments, performed data collection and statistical analyses, interpreted the results, and drafted the manuscript as part of his PhD research.

R.J.N.M: contributed to data interpretation and reviewed the manuscript.

R.R.B: provided scientific supervision and performed the final revision.

MT.P. and N.K.N.: participated in data analysis and interpretation as well as in the critical revision of the manuscript.

R.J.M: supervised the research, contributed to the study design, and critically revised the manuscript.

All authors contributed equitably to the conceptualization, execution, and writing of this study. They jointly participated in the validation and interpretation of the data. Teamwork was central at every stage of the project, with responsibilities shared in a collaborative and horizontal manner. The manuscript was prepared with equal involvement from all authors, and this cooperative approach strengthened the scientific rigor and quality of the work. Each author has reviewed and approved the final version of the article.

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