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Research Article

Comparison of carp aquaculture in ponds and basins in Antsirabe Vakinankaratra Madagascar: effect of food and environmental parameters

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Résume

Pour améliorer la production de carpe, quatre régimes expérimentaux formulés à partir de matières premières disponibles localement et incorporant différentes proportions de farine de banane ont été évalués. Chaque régime a été normalisé pour contenir 36 % de protéines brutes et 8 % de lipides. Les aliments ont été administrés à des carpes communes (Cyprinus carpio) avec un poids moyen initial de 9 g. Après un essai d'alimentation de 50 jours mené à la fois dans les systèmes d'élevage d'étangs et de réservoirs, des performances de croissance comparables ont été observées dans tous les traitements. Le gain de poids final (WG) variait de 120,88 g à 125,08 g, tandis que le gain de poids quotidien (DWG) variait entre 2,21 g/jour et 2,31 g/jour. Le taux de croissance spécifique (SGR) est resté cohérent entre les traitements, allant de 2,46 % à 2,49 %. Les taux de conversion des aliments (FCR) étaient tout aussi efficaces dans les deux systèmes, allant de 1,15 à 1,16, et la survie a atteint 100 % dans tous les cas. Bien que les étangs aient démontré un avantage marginal dans le DWG, les systèmes de réservoirs ont compensé grâce à un contrôle plus strict des régimes d'alimentation et de la qualité de l'eau. Dans l'ensemble, les résultats démontrent qu'une gestion efficace peut garantir des niveaux de performance similaires dans les deux environnements d'élevage. Ces résultats mettent également en évidence le potentiel d'incorporation de la farine de banane dans les formulations d'aliments pour carpes en tant que stratégie viable dans le cadre de systèmes d'aquaculture durables

***Mots clés* : Cyprinus carpio, nourriture, pisciculture, aquaculture, étang, bassin, Antsirabe.**

Abstract

To enhance carp production, four experimental diets formulated from locally available raw materials and incorporating varying proportions of banana flour were evaluated. Each diet was standardized to contain 36% crude protein and 8% lipids. The feeds were administered to common carp (Cyprinus carpio) fingerlings with an initial mean weight of 9 g. After a 50-day feeding trial conducted in both pond and tank rearing systems, comparable growth performances were observed across treatments. Final weight gain (WG) ranged from 120.88 g to 125.08 g, while daily weight gain (DWG) varied between 2.21 g/day and 2.31 g/day. The specific growth rate (SGR) remained consistent across treatments, ranging from 2.46% to 2.49%. Feed conversion ratios (FCR) were similarly efficient in both systems, ranging from 1.15 to 1.16, and survival reached 100% in all cases. Although ponds demonstrated a marginal advantage in DWG, tank systems compensated through tighter control of feeding regimes and water quality. Overall, the findings demonstrate that effective management can ensure similar levels of performance across both rearing environments. These results also highlight the potential of incorporating banana flour into carp feed formulations as a viable strategy within sustainable aquaculture systems.

Keywords*: Cyprinus carpio, *food, fish farming, aquaculture, pond, basin, Antsirabe.

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1. Introduction

Aquaculture plays a significant role in the economy of various regions of Madagascar, serving as an important source of animal protein for local communities. In Antsirabe-a city situated in the central highlands-common carp (Cyprinus carpio) farming has become increasingly prominent, supported by abundant water resources and a favorable temperate climate (FAO, 2022). The growing adoption of carp aquaculture is largely driven by its potential to strengthen food security and provide income in an area where agricultural production is often constrained by climatic and geographical limitations.

Located at an elevation of approximately 1,500 meters, the Antsirabe region benefits from relatively stable temperatures that are well suited for carp culture. Despite these advantages, the success of aquaculture in this context depends on several key factors, including water quality, stock management, and feeding practices. Carp is particularly suitable for local production due to its robustness, adaptability to diverse aquaculture systems-from ponds to tank-based systems-and its tolerance of variable water conditions. In addition to its suitability for local farming, carp represents an important species for national and regional markets (Hossaine, 2011).

Recent studies indicate that carp production in Madagascar offers both nutritional benefits and strong economic potential. However, the sector's development remains limited by insufficient data on farm management practices and the environmental impacts of existing production systems. Rakotondrabe (2016), for example, emphasizes the need to better understand local production constraints in order to optimize yields while ensuring responsible use of water resources. Such research is essential for establishing sustainable aquaculture systems capable of meeting rising demand for fish in Madagascar.

Moreover, carp farming in ponds and tank systems in Antsirabe may contribute to enhanced local biodiversity and could serve as a reference model for aquaculture in regions with low rainfall or restricted water availability (Raharimanana, 2019). Nevertheless, the expansion of this sector will depend not only on technical improvements but also on addressing socio-economic barriers that influence adoption. Ramasindrazana (2017) highlights the importance of considering community perceptions and local constraints to support long-term resilience within the sector. Integrating aquaculture within broader agroecological frameworks remains a key priority for promoting sustainable agricultural and aquaculture practices in the region.

2. Materials and Methods

2.1. Experimental procedure

This study was implemented across two aquaculture environments: hapas deployed in an open-circuit pond in Verezambola and four open-circuit basin systems in Tomboarivo. Both study sites are located in the District of Antsirabe I in the Vakinankaratra Region, situated on Madagascar's central highlands.

Table 1 : Characteristics of the pond

Location	Surface area (m2)	Dam height (cm)	Dam thickness (cm)	Depth (m)	Slope (%)
Verezambola	123	50	60	60-120	10

Table 2 : characteristics of the basin

Location	Surface area (m2)	Height (cm)	Thick-ness (cm)	Depth (m)	Slope (%)
Tomboa-rivo	23	50	50	60-150	10

The study sites included ponds situated in a low-lying area, which allowed for efficient water regulation, and four adjacent basins positioned near a well serving as the primary water source. Both systems benefit from high sunlight exposure, slight slope, and protection against flooding.

Four isoproteic (36% crude protein) experimental diets—AC0, AC1, AC2, and AC3—were formulated for the pre-fattening stage of common carp using traditional raw ingredients (Table 3). Banana flour was incorporated into three of the diets at increasing inclusion levels of 3%, 6%, and 10%, respectively (Table 4). Raw ingredients were sourced locally, then ground and sieved using a 400 µm mesh prior to formulation. Each diet was prepared by weighing and mixing the ingredients until a uniform meal was obtained, followed by the addition of vegetable oil and a mineral–vitamin premix (CMV). Water was then incorporated at approximately 60% of the dry matter to obtain a malleable dough, which was extruded into 1.2 mm filaments and subsequently cut into granules. The pellets were dried for 45 minutes, packaged, and stored at room temperature until use.

Common carp (Cyprinus carpio) juveniles were used for the feeding trial, with an initial mean weight of 9.44 ± 0.86 g and 9.40 ± 0.39 g (mean ± SE). A total of 800 individuals were individually weighed and randomly assigned to four hapas (20 m² each) and four ponds (23 m² each), corresponding to 100 fish per treatment. This experimental layout resulted in four replicated treatments, each receiving one of the test diets. Stocking took place 10 days prior to the start of the trial to allow fish to acclimate to the rearing conditions.

Table 3 : Biochemical composition of ingredients

Ingredient	Protein	Lipids	Carbo-hy-drates	Humi-dity	Ash
Fish meal	58.2	5.02	0.23	8.20	28.35
White horse	61.26	2.07	5.61	11.92	19.14
Peanut cakes	43.01	13.82	27.37	10.23	4.57
Corn flour	8.95	4.02	74.86	11.16	1.01
Cassava flour	1.4	0.59	97.9	1.8	0.019
Banana flour	5.18	0.69	81.78	9.49	2.86

Table 4: Formulation and biochemical composition of diets for pre-fattening carp fry

Ingredient	AC0	AC1	AC2	AX3
Fish meal	14.5	15	14.5	
White horse	14.5	15	14.5	
Peanut cakes	30	30	30	
Corn flour	22	22	18	
Cassava flour	14	11	11	unknown
Banana flour	3	6	10	
Peanut oil	1.5	1.5	1.5	
CMV [1]	0.5	0.5	0.5	
Nutritional value	AC0	AC1	AC2	AX3
Protein	36.26	36.65	36.4	36.39
Carbohydrate	36.91	36.64	36.79	37.26
Lipid	8.48	8.27	8.83	8.47
Ash	9.84	9.49	9.07	8.78
Humidity	8.57	8.95	8.91	9.1
Energy in Kcal	369	367.59	372.23	370.83

Mineral and Vitamin Supplement Vitamin (mg or IU. Kg-1): Vit A, 250,000 IU; Vit D3, 62500 IU; Vit K3, 100 mg; Vit B1, 412 mg; Choline, 2500 IU. Minerals (mg. Kg-1): Fe, 1.5 g; Cu, 0.2 g; Mn, 1.75 g; Zn, 1.25 g; I, 0.01 g; Se, 0.0075 g; Co, 0.008 g; P, 0.082 g; Ca , 0.24 g; Na, 0.35 g.

Throughout the experiment, the pond received water from a source located approximately 50 m away, while the basins were supplied by a well situated 5 m from the facility. The flow rate exceeded 5 L/min, ensuring a complete water renewal at least once per hour and maintaining dissolved oxygen levels above 80% saturation. Fish were hand-fed the experimental diets three times daily at 09:00, 12:00, and 15:00, seven days per week. Feeding continued until the fish no longer responded to the pellets, which was considered the point of satiation. Feeding rates were adjusted to 2.8%, 2.4%, and 2.1% of total biomass depending on water temperature. Every ten days, fish were individually measured, and the tanks were rotated to minimize positional or environmental bias within the system.

2.2. Biochemical analyses

Biochemical analyses-including crude protein, lipid content, moisture, crude fiber, and ash-were performed in duplicate following standard analytical procedures at the National Center for Environmental Research (CNRE). These analyses were applied to both the raw ingredients and the four experimental diets.

- **Crude protein (% N × 6.25)** was quantified using the Kjeldahl method with a Kjel-Foss automatic analyzer.
- **Lipid content** was determined using a hot extraction method (Soxhlet apparatus) with hexane as the solvent, followed by distillation.
- **Moisture content** was measured as the mass loss after drying samples for 24 hours in a forced-air oven at 105 °C.
- **Ash content** was assessed after incinerating samples in a muffle furnace at 550 °C for 12 hours.
- Carbohydrate content was estimated by difference, calculated from the remaining proportion after accounting for protein, lipid, moisture, ash, and fiber values.

2.3. Statistical analysis

For statistical analysis, biometric data from each replicate were treated as individual observations. Differences between treatments were assessed using a one-way analysis of variance (ANOVA) performed in Microsoft Excel, following verification of normality and homogeneity of variance assumptions. When the ANOVA indicated significant effects, Tukey's post hoc test was applied to compare treatment means. In the results, treatments sharing the same superscript letter (e.g., *a*, *b*, or *c*) are considered statistically similar, indicating no significant difference between their means. A significance level of 5% ($p < 0.05$) was applied for all analyses.

2.4. Monitoring water quality:

The rearing environment was monitored by measuring key physicochemical parameters of the water, including pH, dissolved oxygen, conductivity, salinity, and temperature. pH and temperature were measured daily at 08:00 and 14:00, respectively, using a pH meter and a thermometer. The remaining parameters were recorded every three days at 08:00 with a multiparameter oximeter and thermometer.

2.5. Expression of results:

The settings the following zootechnical parameters were determined:

- Weight Gain (WG, g) = Final Weight (g) – Initial Weight (g);
- Daily Weight Gain (DWG, g) = (Final Weight (g) – Initial Weight (g)) / Number of days of follow - up;
- Specific Growth Rate (SGR, %/d) = [(Fw (Final Weight (g)) – Iw (Initial Weight (g))] / Number of days of follow-up) x 100;
- Survival Rate (SR, %) = 100 x Final Number of fish / Initial number of fish
- Apparent Food Conversion Index (CI) = Quantity of Food Distributed (g) / Weight Gain (g);
- Condition factor (K)= 100 x Final weight (g) / (Standard Length (cm)) $^{3.}$

3. Results

3.1. Water quality

Table 5 presents the mean values of the water quality parameters recorded in the rearing systems. Water temperature averaged 24.83 ± 1.15 °C in hapas and 24.63 ± 0.66 °C in ponds. Dissolved oxygen concentrations were 6.14 ± 0.20 mg/L in hapas and 5.38 ± 0.24 mg/L in ponds, while pH values averaged 6.53 ± 0.18 and 6.29 ± 0.10, respectively. Water transparency measured using a Secchi disk was 41.61 ± 2.37 cm in hapas and 42.42 ± 2.24 cm in ponds. Conductivity values averaged 98–99 µS/cm, with salinity around 0.55‰ across both systems. No significant differences ($p > 0.05$) were detected among treatments for any of the monitored physicochemical parameters.

Table 5: Average values of temperature, dissolved oxygen and pH, conductivity, salinity, water clarity recorded during breeding

Settings	Food treatments (ponds)				Food treatments (basins)			
	AC0	AC1	AC2	AX3	AC0	AC1	AC2	AC3

Tempe-rature (°C)	*24.83±1.15*	*24.63±0.66*
Oxygen (mg/L)	*6.14±0.20*	*5.38±0.24*
pH	*6.53±0.18*	*6.29±0.12*
Con-ducti-vity (µS/cm)	*99±1.35*	*98±1.6*
Salinity (ppm)	*55.11±1.47*	*55.15±1.33*
Secchi disk (cm)	*41.61±2.37*	*42.42±2.24*

3.2. Zootechnical parameters

Tables 6 and 7 summarize the zootechnical performance and feed utilization efficiency of *C. carpio* fry after 50 days of rearing. Survival reached 100% in all treatments for both hapas and ponds. Feed treatments produced slight differences in the condition factor, ranging from 2.47 to 2.49 in hapas and 2.46 to 2.48 in ponds. Fish receiving diets AC0 and AC2 showed the lowest and highest condition factors, respectively. A significant difference was observed among treatments for this parameter (p < 0.05). Despite similar initial mean weights across groups, final mean weights differed among treatments. Final weights ranged from 129.37 ± 1.02 g to 134.23 ± 1.30 g in hapas, and from 130.29 ± 1.24 g to 134.66 ± 1.72 g in ponds. Across both rearing systems, fish fed diet AC0 consistently recorded the lowest final weight, whereas those fed AC2 achieved the highest.

Table 6 : *Zootechnical parameters in juveniles of C. Carpio subjected to different forms of food presentation for 50 days* in a pond

Zootech-nical para-meters	Food (pelvis)			
	AC0	AC1	AC2	AX3
IAG (g)	9.22 ±	9.56 ± 0.1	9.71 ±	9.14 ±
FAW (g)	0.73 ^{a}	^{b}	0.49 ^{b}	0.52 ^{a}
WG (g)	129.37 ±	130.92 ±	134.23 ±	130.7 ±
DWG	1.02 ^{a}	1.17 ^{b}	1.3 ^{c}	1.46 ^{b}
(g/d)	120.15 ±	121.36 ±	124.52 ±	121.56 ±
SGR	1.33 ^{a}	1.27 ^{b}	1.71 ^{c}	2.41 ^{b}
(%/d/g)	2.21 ±	2.23 ±	2.29 ±	2.24 ±
CI	0.47 ^{a}	0.43 ^{b}	0.49 ^{c}	0.46 ^{b}
SR (%)	5.13 ±	5.08 ±	5.10 ±	5.17 ±
K	0.26	0.32	0.41	0.03
	1.16	1.15	1.15	1.15
	100	100	100	100
	2.47	2.48	2.49	2.48

On each line, the values (averages± ESM, n = 3) assigned by different letters (a, b, c), are significantly different (P < 0.05), Tukey test. The presence of the same letter on the same line indicates no significant difference (P>0.05).

Weight gain ranged from 120.15 to 124.52 g in tanks and from 120.88 to 125.08 g in ponds. Specific growth rate (SGR) and daily weight gain (DWG) also varied among treatments, with values ranging from 5.08 to 5.17% per day in tanks and 5.09 to 5.17% per day in ponds, while DWG fluctuated between 2.21 and 2.29 g/day in tanks and 2.22 to 2.31 g/day in ponds. Fish receiving diets AC2 and AX3 consistently showed the highest values for these growth indicators, whereas those fed AC1 exhibited the lowest performance. Fish fed AC0 also demonstrated reduced growth relative to AC1, AC2, and AX3. Unlike survival and condition factor results, significant differences (p < 0.05) were observed among treatments for growth performance. As shown in Figure 2, the growth curves of all groups were similar during the first 10 days in both rearing systems. From day 10 onward, however, differences in weight gain became increasingly noticeable, irrespective of whether fish were reared in ponds or tanks. Feed conversion index (FCI) values ranged from 1.15 to 1.16 across both environments. No significant differences were detected among fish fed AC1 and AX3 in ponds, nor among AC1 to AX3 in tanks. The highest FCI values were recorded for fish fed AC2 in ponds and AC0 in tanks, indicating comparatively lower feed efficiency in those treatments. Feeding-related parameters also differed significantly among groups ($p < 0.05$). The condition factor (K) ranged from 2.46 to 2.49 across treatments, with AC2 yielding the highest value and AC0 the lowest.

Table 7*: Zootechnical parameters in juveniles of C. Carpio subjected to different forms of 50-day feed presentation in pond*

Zoo-technical parameters	Food (pond)			
	AC0	AC1	AC2	AX3
IAW (g)	9.41 ±	9.23 ±	9.58 ±	9.55 ±
FAW	0.54 ^{a}	0.12 ^{a}	0.79 ^{a}	0.64 ^{a}
(g)	130.29 ±	131.7±	134.66±	131.33 ±
WG (g)	1.24 ^{a}	1.44 ^{b}	1.72 ^{c}	2.47 ^{b}
DWG	120.88 ±	122.47 ±	125.08 ±	121.78 ±
(g/d)	1.42 ^{a}	1.21 ^{b}	2.78 ^{c}	2.73 ^{b}
SGR	2.22 ±	2.26 ±	2.31 ±	2.24 ±
(%/d/g)	0.51 ^{a}	0.45 ^{b}	0.50 ^{c}	0.41 ^{b}
CI	5.10 ±	5.17 ±	5.13 ±	5.09 ±
SR (%)	0.03	0.51	0.34	0.03
K	1.16	1.15	1.16	1.15
	100	100	100	100
	2.46	2.47	2.49	2.47

On each line, the values (averages± ESM, n = 3) assigned by different letters (a, b, c), are significantly different ($P < 0.05$), Tukey test. The presence of the same letter on the same line indicates no significant difference ($P>0.05$).

DISCUSSION

4.1. Physicochemical parameters

The temperatures recorded in ponds (24.83 ± 1.15 °C) and tanks (24.63 ± 0.66 °C) align well with the thermal requirements of common carp. According to FAO (2022), the optimal temperature range for carp growth is 23–30 °C. Within this interval, metabolic activity is maximized, resulting in improved feed intake and conversion efficiency. Rahman (2020) demonstrated that growth decreases markedly below 20 °C, while temperatures exceeding 30 °C may induce thermal stress and compromise health. Similarly, Das (2012) reported that temperatures near 25 °C support optimal nutrient assimilation and the highest growth rates. The temperatures observed in this study therefore appear favorable and likely contributed to the satisfactory rearing outcomes. The pH of the rearing water remained within suitable limits, measuring 6.53 ± 0.18 in ponds and 6.29 ± 0.12 in tanks. The recommended range for carp culture is 6.5–8.5 (Swann, 1997). Values below 6 may reduce nutrient availability and induce physiological stress (Meade, 1989). Boyd and Tucker (1998) note, however, that carp tolerate slightly acidic water when dissolved oxygen is sufficient. Although the tank pH approaches the lower limit, it did not appear to impair performance during the experimental period. Nevertheless, routine monitoring and corrective measures—such as agricultural liming—may be beneficial if acidity persists. Dissolved oxygen concentrations were 6.14 ± 0.20 mg/L in ponds and 5.38 ± 0.24 mg/L in tanks, remaining within acceptable limits for carp. Boyd (2019) suggests that concentrations above 5 mg/L are necessary to prevent stress, while Avnimelech (2009) reports improved feeding efficiency at levels approaching 6 mg/L. Concentrations below 4 mg/L have been associated with reduced growth and elevated mortality risk (Fisher et al., 2006). Although oxygen concentrations in tanks were slightly lower than in ponds, they remained adequate. Supplemental aeration could further stabilize oxygen levels, particularly under higher stocking densities. Conductivity values averaged 99 ± 1.35 µS/cm in ponds and 98 ± 1.60 µS/cm in tanks. Although suitable for freshwater aquaculture, these values are slightly below the commonly recommended 100–500 µS/cm range for carp (Teichert-Coddington, 2000). Low conductivity may indicate limited mineral availability (Boyd, 2019), and modest mineral supplementation or partial water exchange with more mineralized water could potentially enhance growth performance. Salinity values (~0.55‰) confirmed that the systems functioned under true freshwater conditions. Carp can tolerate salinity up to 5 ppt, but growth is generally optimal in low-salinity environments (Boyd & Tucker, 1998). Hossain (2011) reported that salinity above 500 ppm may negatively affect physiological processes and growth. In this case, the recorded salinity falls well within the ideal range and is unlikely to present constraints for production.

Figure 1: Evolution of physicochemical parameters of the pond

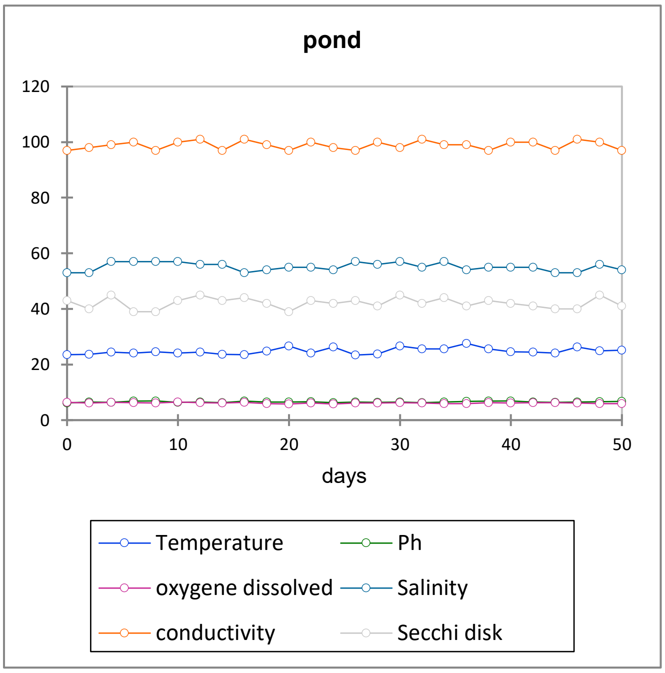
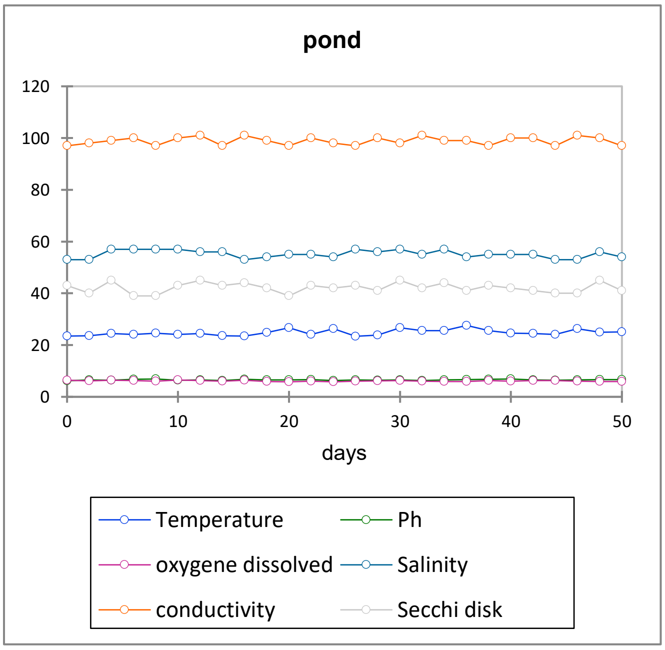


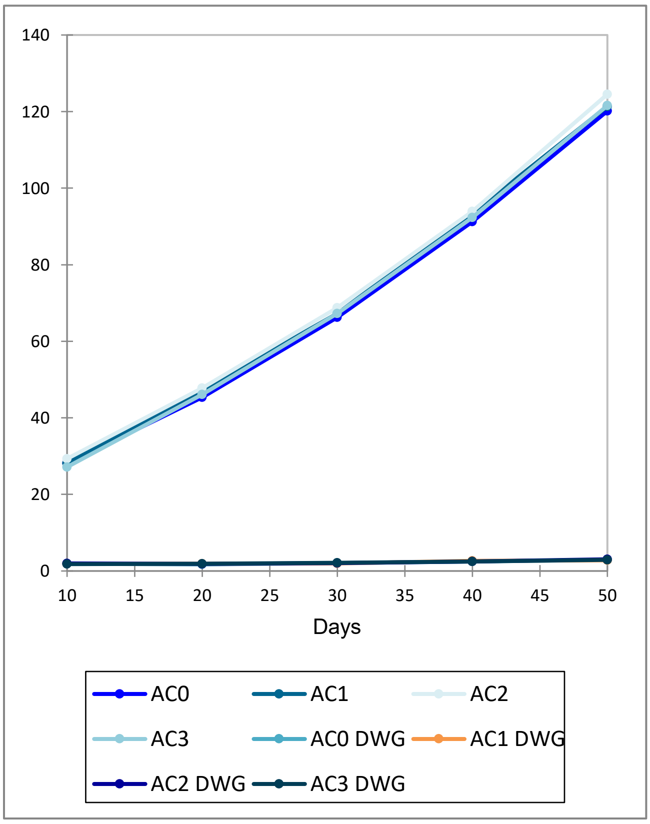
Figure 2:_Evolution of physicochemical parameters of the basins



Water transparency averaged 41.61 ± 2.37 cm in ponds and 42.42 ± 2.24 cm in tanks. These values fall within the optimal range for carp culture. Transparency between 30 and 50 cm is considered suitable, as it supports adequate phytoplankton development, which serves as an important natural food source for carp (Boyd, 2019). Das (2002) similarly reported that transparency values near 40 cm help maintain an appropriate balance between turbidity and primary productivity, thereby supporting favorable growth conditions. The transparency levels recorded in this study therefore reflect well-managed water quality and satisfactory biological productivity within the culture systems.

4.2. Technical zoo parameters

The initial mean weight (IAW) of the fry ranged from 9.22 to 9.71 g. This uniformity at stocking is important for maintaining consistent growth dynamics. Boyd (2015) emphasized that homogeneous initial weights help reduce competition and promote more uniform size distribution throughout the rearing period. At the end of the trial, final mean weight (FAW) ranged from 130 to 134 g in ponds and from 130.92 to 134.23 g in tanks, values that are consistent with expected growth performance in semi-intensive carp culture systems (Chowdhury et al., 2017, p. 146). Differences observed between culture systems may be partly attributed to environmental and nutritional factors. Ponds generally support faster growth due to the presence of natural food sources such as phytoplankton and zooplankton, whereas tanks rely exclusively on formulated feed and controlled inputs (Milstein et al., 2006, p. 205). This difference in supplementary nutrition may explain the slightly higher growth values recorded in pond environments. Weight gain (WG) ranged from 120.88 to 125.08 g in ponds and from 120.15 to 124.52 g in tanks. Daily weight gain (DWG) varied between 2.22 and 2.31 g/day in ponds and 2.21 to 2.29 g/day in tanks. According to Das (2012), WG and DWG values within this range are typical when diets contain high-quality protein sources such as fishmeal, peanut cake, and peanut oil (p. 321). These ingredients are well documented for their positive effects on carp muscle development and metabolic efficiency (Milstein et al., 2016, p. 77). The slightly higher WG and DWG observed in ponds support the assumption that natural productivity contributes to enhanced dietary efficiency. Feed conversion ratio (FCR), or feed conversion index (CI), reflects the efficiency with which fish convert feed into biomass. The measured FCR values ranged from 1.15 to 1.16 in both ponds and tanks, which aligns with optimal standards reported for well-managed intensive and semi-intensive carp systems (Boyd & Tucker, 2012). FCR values close to 1.0–1.2 indicate efficient feed utilization, whereas higher values may result from suboptimal aeration, poor feed quality, or excessive stocking densities. In this study, the narrow range of FCR values suggests that both culture systems maintained stable environmental and nutritional conditions throughout the trial.



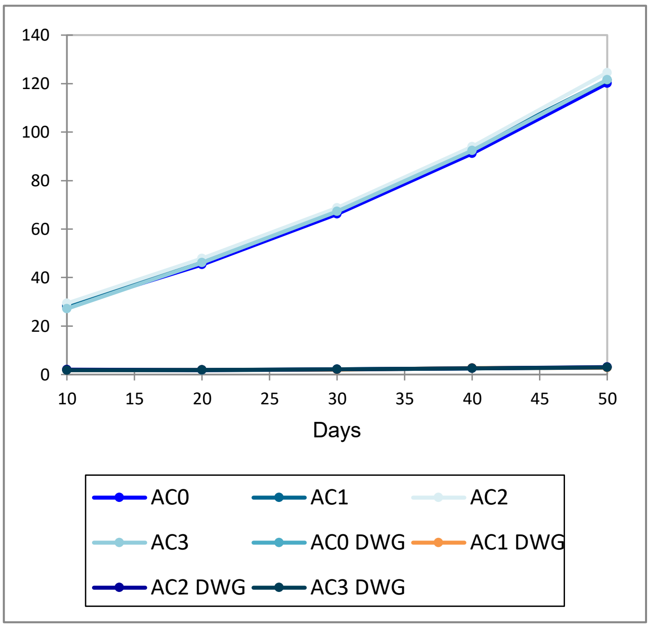


Figure 3: A: Evolution of weight gain and daily weight gain. A: basins, B: pond

The differences observed between treatments may also be associated with the availability of natural food in ponds, which likely enhanced feeding efficiency. In contrast, tank systems rely entirely on formulated feed, resulting in more stable feed conversion indices but requiring stricter feeding and environmental management (Timmons et al., 2002).

A 100% survival rate was recorded across all treatments, reflecting optimal culture conditions and effective management of both feed and water quality. High survival rates are critical for the economic performance of carp production systems. Chowdhury (2017) notes that survival rates exceeding 95% are typically achieved in well-managed systems with nutritionally balanced diets rich in protein, carbohydrates, and lipids. Differences in survival between rearing systems are often linked to environmental stability. Natural pond ecosystems may buffer fluctuations in water quality more effectively; however, well-managed tank systems—with regulated temperature, pH, and hardness—can also achieve comparable results (Rahman et al., 2018).

Specific growth rate (SGR) values ranged from 5.08 to 5.17%/day in ponds and from 5.08 to 5.13%/day in tanks.

These values align with expectations for nutritionally balanced diets containing fishmeal, peanut cake, and other high-quality protein sources (Ali et al., 2011, p. 184). Slight differences between systems may be attributed to the supplemental contribution of natural food in ponds, which can reduce reliance on formulated feeds and improve nutrient assimilation.

The condition factor (K), an indicator of body condition and overall health, ranged from 2.46 to 2.49 across treatments. According to Froese (2006), values close to 2 reflect healthy growth dynamics, balancing somatic weight gain and structural development. The slightly higher values observed in fish fed diets AC2 and AX3 suggest efficient nutrient utilization and energy deposition, likely supported by appropriate protein-to-lipid ratios in these formulations (Ng et al., 2002).

CONCLUSION

Carp aquaculture in Antsirabe, Madagascar, demonstrates strong potential to contribute to local food production. The environmental parameters measured during the study-including temperature, dissolved oxygen, salinity, and water transparency-were generally within the optimal ranges for carp culture, supporting favorable growth performance. These conditions are particularly advantageous given the adequate temperature and dissolved oxygen levels observed, both of which align with the physiological requirements of *Cyprinus carpio*. Despite these positive outcomes, further improvements in management practices could enhance production efficiency. Increasing aeration, particularly in pond-based systems, may help stabilize dissolved oxygen concentrations and consequently improve feed conversion efficiency and growth. Likewise, closer monitoring and regulation of pH and conductivity would help minimize environmental stress and support more consistent growth responses. Continued refinement of feeding strategies, stocking densities, and water management-while adapting these practices to local environmental constraints-will be essential for strengthening the sustainability and productivity of carp farming in Madagascar. Such improvements will support healthier fish, faster growth rates, and greater economic viability for aquaculture in the region.

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