

USE OF 3D PRINTER WASTE IN FILTRATION SYSTEMS FOR FRESHWATER ANGELFISH CULTURE

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ABSTRACT

Recirculating Aquaculture Systems (RAS) are extensively utilised in aquarium for both aquaculture and ornamental fishkeeping. In the context of ornamental aquaculture, RAS can be implemented in urban areas due to their high productivity and efficient utilisation of space and water resources. This study evaluated the performance of 3D printer waste as biological media for freshwater angelfish (*Pterophyllum scalare*) culture in RAS. The experimental design was completely randomised, with two treatments and four replicates, using biological media composed of ceramic rings (CR) and 3D printer waste (PLA). For 51 days, the biofilters underwent a maturation process. After system stabilization, juvenile *P. scalare* (0.1 g and 1.7 cm) were stocked in the experimental units (1.5 ind L⁻¹) and reared for 31 days. During this period, the fish were fed a specific commercial diet (47% crude protein) twice daily at 20–10%. Water quality parameters and production performance indices of *P. scalare* were evaluated during the study. The results showed a shorter maturation period in the biofilters of the CR treatment (33 days), while in the culture, higher total ammonia concentrations and lower pH were reported in the PLA treatment ($P \leq 0.05$). All assessed water quality parameters, alongside the productive performance indices, remained within the optimal ranges reported in the literature for *P. scalare* culture. Therefore, under the conditions evaluated in this study, 3D printer waste can be utilised in RAS as biological media, representing a sustainable alternative for solid waste management and for reducing production costs in ornamental aquaculture.

Keywords: solid waste, sustainability, aquaculture, ornamental fish, RAS.

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1. INTRODUCTION

Ornamental aquaculture is an economically important sector at the global scale, generating approximately USD 15–30 billion annually (EVERS; PINNEGAR; TAYLOR, 2019). The industry is characterised by the production of various species and strains of ornamental fish, with fishkeeping and ornamental pond keeping as its primary objectives. In ornamental aquaculture, different rearing structures can be implemented according to species-specific requirements, and the main production systems are semi-intensive, intensive, and super-intensive (REZENDE et al., 2021).

In this context, recirculating aquaculture systems (RAS) represent a super-intensive rearing technology characterised by high productivity in limited spaces, control of environmental variables, biosecurity, and rational water use (GUPTA et al., 2024; BREGNBALLE, 2015; EBELLING; TIMMONS, 2012). RAS is the main technology employed in fishkeeping and, in ornamental aquaculture, is widely used in urban environments for the cultivation of species requiring strict water quality control, precise husbandry, and high commercial value, such as marine fish and freshwater fish with specific strains (REZENDE et al. 2021).

In RAS, the biological filter (biofilter) is a critical component for system operation, consisting of substrates that provide surface area for bacterial colonization and thereby promote efficient nitrification. This process involves the oxidation of ammonia excreted by cultured organisms into nitrite and subsequently into nitrate, a less toxic compound for aquatic organisms (EBELLING; TIMMONS, 2012).

The most used substrates (biological media) in biofilters include ceramic rings, expanded clay, gravel, quartz sand, and plastic media such as bioballs (DELONG; LOSORDO, 2012). Alternatives biological media have been investigated to reduce production costs and minimising environmental impacts, including natural by products such as coconut fibre (LI et al., 2025; ZHU et al., 2024) and fruit seeds (STERZELECKI et al., 2022), as well as plastic wastes made of polyethylene and polypropylene (SIKORA; NOWOSAD; KUCHARCZYK, 2020).

Recently, the expansion of 3D printing in industrial and domestic applications has raised concerns regarding solid waste management. The most common 3D printing technology is

fused deposition modelling (FDM), in which one of the main filaments used is polylactic acid (PLA) (MWEMA; AKINLABI, 2020). PLA is a thermoplastic biopolymer composed of lactic acid molecules of biological origin, derived from corn or sugarcane starch (BREMIGARTNER et. al., 2024; DANANJAYA et al., 2024). In ornamental aquaculture, the utilisation of PLA waste as biological media and in water treatment may provide an alternative to the materials currently employed in the culture of ornamental fish.

In this context, freshwater angelfish (*Pterophyllum scalare*) is a cichlid endemic to the Amazon Basin, highly popular in fishkeeping, and ranks among the ten most traded ornamental fish worldwide (CHELLAPA; YAMAMOTO; CACHO, 2020; EVERS; PINNEGAR; TAYLOR, 2019). This importance is due to its biological traits and resilience, as it adapts well to different rearing systems, such as RAS. Based on this information, the aim of this study was to evaluate 3D printer waste (PLA) as biological media in the culture of *P. scalare* in RAS.

2. MATERIAL AND METHODS

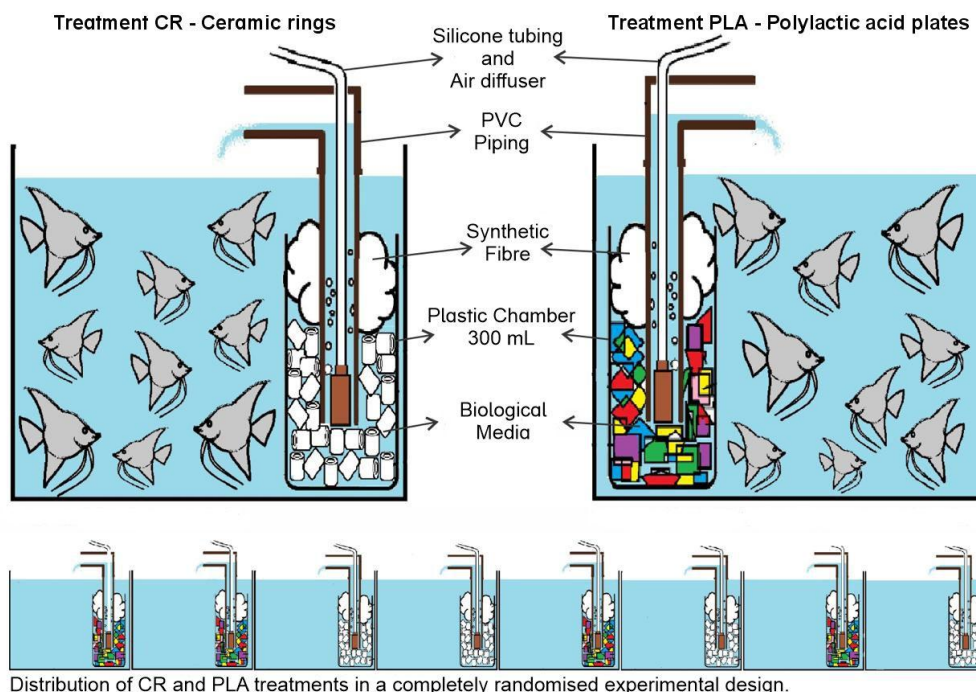
2.1. Study Site

The study was conducted at the Department of Fisheries and Aquaculture, Federal Rural University of Pernambuco (DEPAQ/UFRPE), Recife, Brazil. All experimental procedures were approved by the UFRPE Ethics Committee on the Use of Animals (CEUA No. 3172050422). The 3D printing waste used in this study was donated by the IFMaker Laboratory, Federal Institute of Education, Science and Technology of Pernambuco, Ipojuca, Brazil.

2.2. Experimental Design

The experimental design was completely randomised with two treatments and four replicates, considering the culture of freshwater angelfish (*P. scalare*) in RAS, using different biological media: CR – conventional biological media, using ceramic rings; and PLA – alternative biological media utilising 3D printing waste, consisting of polylactic acid (PLA) filaments (Figure 1).

Figure 1 – Schematic representation of the experimental design for the culture of *P. scalare*.



Source: Prepared by the authors (2023).

2.3. System Sizing and Biofilter Maturation Dynamics

Each experimental unit consisted of a 6 L glass aquarium equipped with an internal filtration system. The filters comprised a 300 mL plastic chamber containing biological media, synthetic fibre (polyester) filter media, and PVC piping. Aeration and water circulation were achieved by means of an air-lift system, supported by silicone tubing and an air diffuser stone installed within the PVC piping (Figure 1). Following system assembly and water filling, a commercial biological additive for aquarium (Stability, Seachem®, USA) was applied at a dosage of 0.8 mL per aquarium, in accordance with the manufacturer's recommendations.

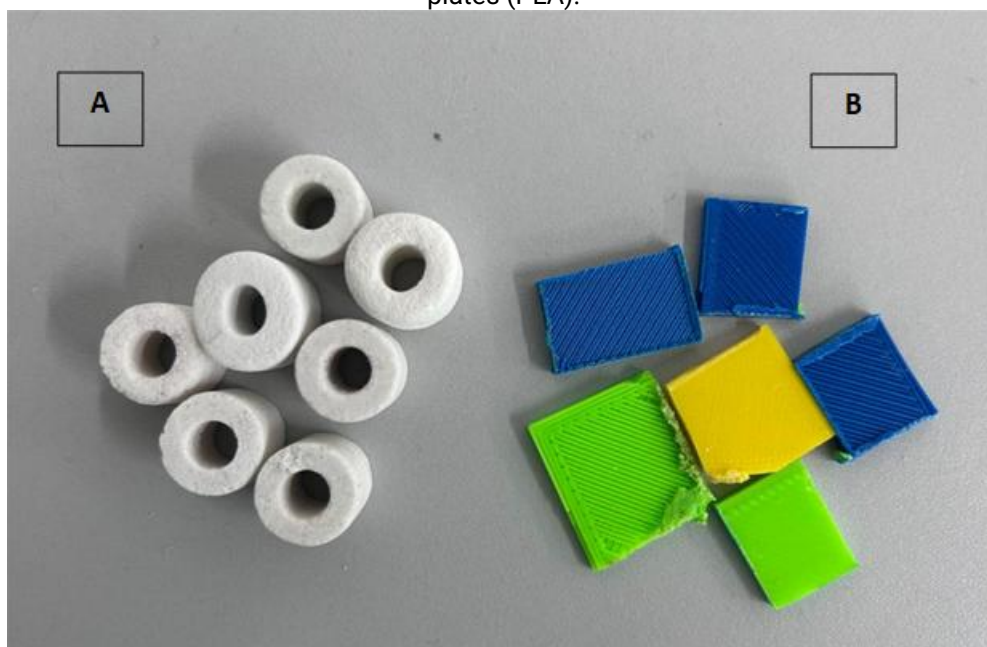
During the biofilter maturation phase, total ammonia nitrogen ($\text{NH}_3 + \text{NH}_4^+$) and nitrite (NO_2^-) concentrations were determined at two-day intervals using colourimetric test kits (Alcon, LabconTEST, Brazil). The maturation process extended over 51 days and was considered complete when both total ammonia nitrogen and nitrite concentrations reached undetectable levels. Subsequently, fish were stocked into the experimental units and reared for 31 days.

2.4. Surface Area Assessment of Biological Filter Media

The volume of biological media allocated to each filter was standardised at 212 mL, corresponding to a media column height of 7.5 cm within a 300 mL plastic chamber. In the CR treatment, this volume was filled with 40 ceramic rings (internal diameter = 0.7 cm; external diameter = 1.5 cm; mean height = 1.43 cm). The unit surface area of each ring (12.61 cm²) was estimated as the sum of the internal, external, upper, and lower surfaces, resulting in a total available surface area of 504.54 cm² per filter.

In the PLA treatment, the 3D printing waste consisted of rectangular polylactic acid plates (height = 0.30 ± 0.07 cm; length = 2.40 ± 0.41 cm; width = 1.90 ± 0.29 cm). A total of 53.3 units were introduced within the same media volume (212 mL), with a mean external surface area of 12.1 ± 2.74 cm² per unit, yielding a total surface area of 647.8 cm² per filter. The total surface area of the CR and PLA treatments was calculated without accounting for the porosity of the biological media.

Figure 2 – Biological media used in the culture of angelfish. A. Ceramic rings (CR); B. Polylactic acid plates (PLA).



Source: Prepared by the authors (2026).

2.5. Fish Stocking and Rearing Management

Seventy-two juveniles of *P. scalare* obtained from a laboratory hatchery, were randomly assigned to the experimental units at a stocking density of 1.5 ind L⁻¹. The initial mean body mass and total length were 0.12 ± 0.01 g and 1.75 ± 0.13 cm for the CR treatment, and 0.11 ± 0.02 g and 1.82 ± 0.11 cm for the PLA treatment, respectively.

To assess water quality, the variables of temperature (°C), dissolved oxygen (DO, mg L⁻¹), pH, electrical conductivity (μS cm⁻¹), and total dissolved solids (ppm) were measured once daily using an oxygen meter (MO-8920, Instrutherm, Brazil), a pH meter (AT-315, Alfakit, Brazil), and a conductivity meter (COM-80, HM, Brazil). Nitrogenous compounds, including total ammonia (TAN, mg L⁻¹) and nitrite (mg L⁻¹), were monitored weekly using colourimetric test kits (Alcon, LabconTEST, Brazil). Partial water exchanges were performed in the morning and afternoon to remove organic matter derived from feed residues and fish faeces. Water flow in the recirculating system was maintained between 400 and 600 mL min⁻¹.

Juveniles of *P. scalare* juveniles were fed twice daily with a commercial ornamental fish feed (Tetra, TetraMin, Germany), containing 47% crude protein. During the first nine days of culture, the feeding rate was set at 20% of biomass and subsequently adjusted to 10%, which was maintained until the end of the trial (PATIL et al., 2015).

2.6. Productive performance

After 31 days of culture, fish were harvested and biometric data, including body weight (g) and total length (cm), were collected using a ruler, digital calliper, and a precision digital balance (AUY220, Shimadzu, Japan) with an accuracy of 0.0001 g. Prior to measurement, the animals were anaesthetised with clove oil, following Tarkhani et al. (2017). The following performance indices were determined: survival (S), weight gain (WG), specific growth rate (SGR), mean feed intake (FI), apparent feed conversion ratio (FCR), and productivity (g m⁻³), calculated using the equations: S (%) = (Number of surviving individuals / Total number of stocked individuals) × 100; WG (g) = Final mass – Initial mass; SGR (% day⁻¹) = [(ln Final mass – ln Initial mass) / Culture period (days)] × 100; FI = Total feed offered / Culture period (days); FCR = Total feed offered / Biomass gain.

2.6. Statistical analysis

Water quality parameters, biometric data, and production performance indices were subjected to tests for normality (Shapiro–Wilk) and homogeneity of variances (Levene). Data meeting the assumptions for parametric analysis were analysed using the Student's t-test at a 5% significance level. Data that did not meet these assumptions were analysed using non-parametric methods via the Mann–Whitney U test. All statistical analyses were conducted using R software, version 4.5.1 (R CORE TEAM, 2026).

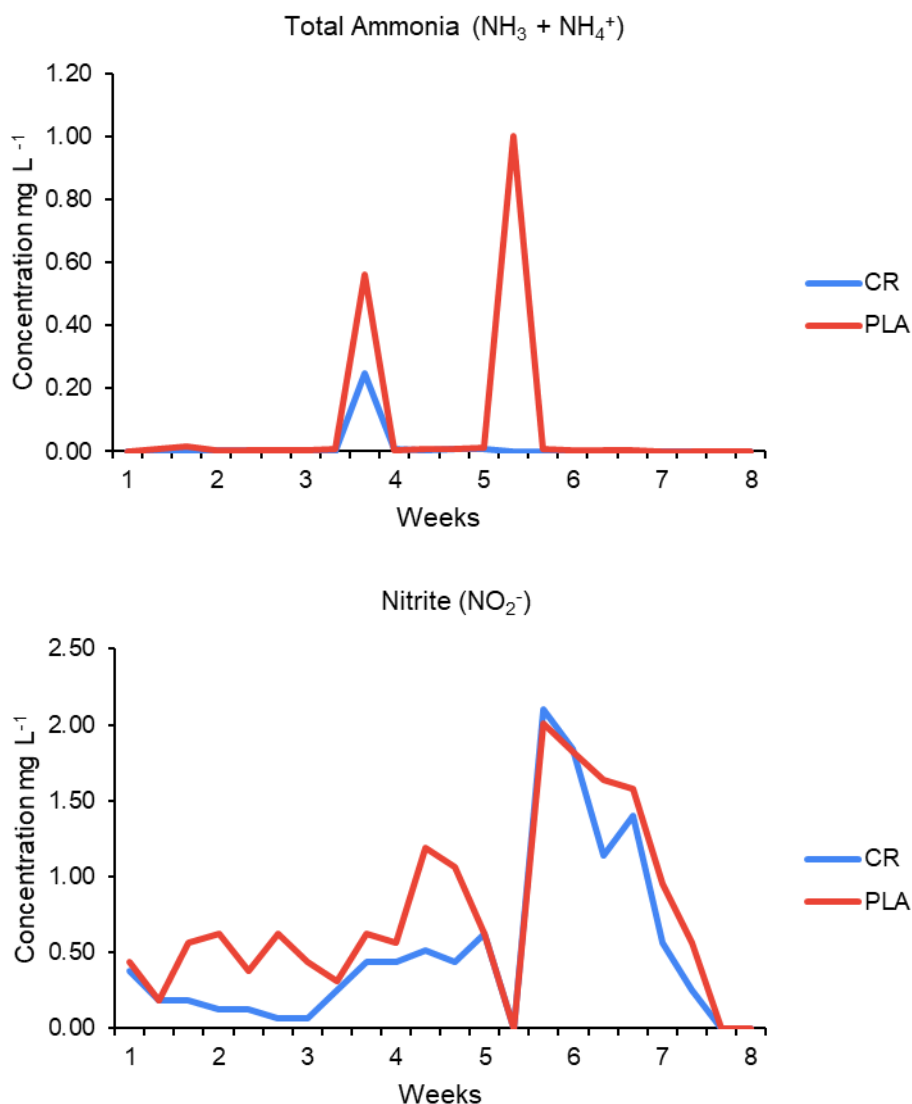
3. RESULTS AND DISCUSSION

3.1. Biofilter Maturation and Water Quality

The ceramic rings (CR treatment) were more efficient in the conversion of nitrogenous compounds, including total ammonia and nitrite, compared to the rectangular polylactic acid plates derived from 3D printing waste (PLA treatment). The superior efficiency of the CR media compared with PLA was observed both during biofilter maturation (Figure 3) and throughout the production cycle of freshwater angelfish (*P. scalare*).

During biofilter maturation, the CR and PLA treatments exhibited initial peaks in total ammonia concentration from day 19, with mean values of 0.25 mg L⁻¹ and 0.56 mg L⁻¹, respectively. In the CR treatment, system stabilization, defined as a total ammonia concentration approaching zero, was achieved by day 33. In contrast, the PLA treatment exhibited a secondary peak in total ammonia (1.0 mg L⁻¹), with stabilization attained only after day 42. For nitrite, the CR treatment demonstrated greater stability, maintaining lower concentrations compared with the PLA treatment. Both treatments reached a nitrite peak at day 33, with mean concentrations of 2.10 mg L⁻¹ and 2.01 mg L⁻¹ for CR and PLA, respectively, followed by complete system stabilization after 50 days of maturation.

Figure 3 – Concentration of nitrogenous compounds during biofilter maturation in recirculating aquaculture systems (RAS). CR – Biological media composed of ceramic rings; PLA – Biological media composed of rectangular polylactic acid (PLA) plates.



Source: Prepared by the authors (2026).

Throughout the 31-day production cycle of *P. scalare*, the CR treatment consistently exhibited lower concentrations of nitrogenous compounds, with mean total ammonia and nitrite levels of $0.02 \pm 0.08 \text{ mg L}^{-1}$ and $0.07 \pm 0.13 \text{ mg L}^{-1}$, respectively. However, the PLA treatment exhibited higher concentrations, with total ammonia at $0.32 \pm 0.38 \text{ mg L}^{-1}$ and nitrite at $0.19 \pm 0.31 \text{ mg L}^{-1}$ (Table 1). Nevertheless, in both treatments, these concentrations remained below

the lethal limits for ammonia and nitrite, reported as 0.58 mg L⁻¹ and 6.28 mg L⁻¹, respectively (SEREZLI, R.; KÜÇÜKAĞTAŞ, A.; KURTOGLU, 2016; PATIL et al., 2015).

Table 1 – Water quality parameters monitored during the culture of *P. scalare* under a recirculating aquaculture system (RAS).

Variables	CR	PLA	P-value
Temperature (°C)	26.41 ± 1.08	26.46 ± 1.09	0.753
Dissolved Oxygen (mg L ⁻¹)	7.14 ± 0.23	7.17 ± 0.29	0.217
pH	6.54 ± 0.53 ^a	6.27 ± 0.53 ^b	0.001
Electrical Conductivity (μS cm ⁻¹)	279.36 ± 56.41	270.19 ± 59.69	0.296
Total Dissolved Solids (ppm)	146.33 ± 41.11	141.87 ± 41.33	0.354
Total Ammonia (mg L ⁻¹)	0.02 ± 0.08 ^b	0.32 ± 0.38 ^a	0.001
Nitrite (mg L ⁻¹)	0.07 ± 0.13	0.19 ± 0.31	0.064

Mean ± standard deviation. CR – RAS with biological media composed of ceramic rings; PLA – RAS with biological media composed of polylactic acid (PLA) plates. Different letters within columns indicate significant differences according to the Mann–Whitney U test.

The efficiency of biological filtration in recirculating aquaculture systems (RAS) is modulated by water quality parameters (temperature, pH, dissolved oxygen, and alkalinity), light exposure (as nitrifying bacteria are photosensitive), water flow, and the characteristics of the filter media (surface area and material composition) (LI et al, 2023; GUERDAT et al., 2010). In the present study, light intensity (natural illumination) and water flow (400–600 mL min⁻¹) were maintained consistently across all experimental units. Except for pH (p = 0.001), no significant differences in water quality parameters were observed between treatments. While pH varied slightly between treatments, it remained within the optimal range for bacterial activity (6.0–8.5) (SOMERVILLE et al., 2014). The primary factor influencing filtration efficiency in this experiment was the type of filter media. Although the PLA treatment had a greater nominal surface area (647.8 cm² per filter) compared to the CR treatment (504.54 cm² per filter), the ceramic rings demonstrated superior ammonia conversion. This enhanced performance is related to differences in material porosity, which may affect bacterial colonisation and biofilm development.

Ceramic rings are highly porous, with porosity ranging from 36% to 47% (YAKUB et al., 2013), which promotes extensive colonisation by nitrifying bacteria compared to other substrate types (MNYORO et al., 2022; DELONG; LOSORDO, 2012). In contrast, PLA waste exhibits low porosity, ranging from 0.09% to 2.79% (ARDIANTO et al., 2026). Therefore, the total abundance of nitrifying bacteria may have been lower in the PLA plate filters. Despite the larger nominal surface area, the limited porosity likely constrained biofilm development, thereby reducing the efficiency of nitrogenous compound conversion.

Regarding the other water quality parameters assessed during the culture of *P. scalare* in RAS (Table 1), no significant differences were observed between the CR and PLA treatments for temperature, dissolved oxygen, electrical conductivity, or total dissolved solids, except for pH ($p = 0.001$). The measured pH values for the CR (6.54 ± 0.53) and PLA (6.27 ± 0.53) treatments remained within the recommended range of 6.0–6.9 for *P. scalare* (CHELLAPA; YAMAMOTO; CACHO, 2020).

The observed temperature and dissolved oxygen conditions are consistent with established literature. *P. scalare* can be maintained at dissolved oxygen concentrations exceeding 5.0 mg L⁻¹ (RIBEIRO et al., 2014) and within a temperature range of 24–32 °C, with 28 °C widely recognized as optimal for somatic growth and reproductive performance (ALVAREZ-LEE et al., 2023; CHELLAPA; YAMAMOTO; CACHO, 2020; RIBEIRO et al., 2012). Under natural conditions, *P. scalare* inhabits environments characterised by electrical conductivity within a range of 0.8–41.5 µS cm⁻¹ (TAVARES-DIAS; LEMOS; MARTINS, 2010). However, under intensive culture conditions, both electrical conductivity and total dissolved solids frequently exceed these values without exerting deleterious effects on survival or productive performance (GONÇALVES JÚNIOR et al., 2013).

3.2. Productive Performance

The different biological media employed in the RAS for the culture of *P. scalare* did not significantly influence production performance indices over the 31-day experimental period ($p \geq 0.05$). Furthermore, no mortality was recorded in either treatment (Table 2). The final stocking density of 1.5 ind L⁻¹ resulted in total lengths (TL) of 2.48 cm and 2.58 cm, mean body weight (BW) of 0.36 g and 0.38 g, and weight gains (WG) of 0.24 g and 0.25 g for the CR

and PLA treatments, respectively. These values are considered suitable for the species, as stocking densities of up to 1 g L⁻¹ of live biomass facilitate improved feeding management, particularly during the juvenile stage when individuals exhibit schooling behaviour (FUJIMOTO; SANTOS; MARIA, 2014).

Table 2 – Productive performance in the culture of *P. scalare* under a recirculating aquaculture system (RAS).

Productive Performance	CR	PLA	P-value
Total Length (cm)	2.48 ± 0,44	2.58 ± 0,34	0.364
Standard Length (cm)	1.70 ± 0.32	1.75 ± 0.25	0.420
Body Weight (g)	0.36 ± 0.18	0.38 ± 0.13	0.439
Weight Gain (g)	0.25 ± 0.04	0.24 ± 0.02	0.646
Specific Growth Rate (% day ⁻¹)	3.74 ± 0.30	3.63 ± 0.23	0.662
Apparent Feed Conversion Ratio	2.01 ± 0.45	1.89 ± 0.17	0.685
Mean Feed Intake (g day ⁻¹)	0.17 ± 0.03	0.14 ± 0.01	0.202
Productivity (g m ⁻³)	599.33 ± 137.07	629.75 ± 100.22	0.763

Mean ± standard deviation. CR – RAS with biological media composed of ceramic rings; PLA – RAS with biological media composed of polylactic acid (PLA) plates. No statistically significant differences were observed according to Student's t-test.

The specific growth rate (SGR) recorded in the present study averaged 3.74% day⁻¹ for the CR treatment and 3.63% day⁻¹ for the PLA treatment, exceeding the values reported by Abisha et al. (2022), Ribeiro et al. (2012), and Nagata et al. (2010) for juvenile *P. scalare* cultured under intensive systems. In these studies, the SGR ranged from 1.14 to 2.11% day⁻¹, while the apparent feed conversion ratio (FCR) varied between 1.63 and 3.90.

Studies addressing the productive performance of *P. scalare* generally do not report productivity indices, as the production cycle of the species is typically concluded when individuals reach a mean final length of approximately 2.5 cm, which is considered the optimal size for commercialisation (RIBEIRO; PRETO; FERNANDES, 2009). However, the determination of productivity indices may provide valuable insights into technical and economic feasibility, thereby supporting strategies aimed at optimising production efficiency and reducing operational costs.

4. CONCLUSION

The findings of this study demonstrated that nitrification dynamics in RAS are influenced by the type of biological media, with filters containing PLA waste exhibiting extended maturation periods. During the culture of *P. scalare*, although total ammonia concentrations were higher in the PLA treatment, all water quality parameters remained within the species optimal physiological ranges, resulting in high survival rates and robust productive performance. Under the experimental conditions evaluated, PLA waste represents a viable alternative biological media in ornamental aquaculture RAS without adversely affecting productive performance. Future investigations should assess the economic feasibility of PLA waste utilisation and its applicability in prolonged culture cycles to fully determine its operational and commercial potential.

5. REFERENCES

- ABISHA, R. et al. Performance of a bio-integrated aquaculture production system in floating net cages with angelfish, aquatic plant and leafy vegetable. **Journal of Environmental Biology**, v. 43, p. 377–384, 2022. DOI: <http://doi.org/10.22438/jeb/43/3/MRN-1929>.
- ÁLVAREZ LEE, L. et al. Thermal biology and plasticity of the thermal metabolic scope of angelfish (*Pterophyllum scalare*) acclimated to different temperatures. **International Aquatic Research**, v. 15, n. 3, p. 263–269, 2023.
- ARDIANTO, H. et al. Comprehensive material, thermal, and physical characterization of multistage recycling of PP/PLA polymers for sustainable composite matrix development. **Journal of Polymer Research**, v. 33, 127, 2026. DOI: <https://doi.org/10.1007/s10965-026-04852-3>.
- BREMGARTNER, J. L. et al. Promovendo a sustentabilidade por meio de uma oficina de reciclagem de resíduos de impressão 3D. **Revista Ibero Americana de Estudos em Educação**, Araraquara, v. 19, n. esp. 1, e024064, 2024. DOI: <https://doi.org/10.21723/riaee.v19iesp.1.18341>.
- BREGNBALLE, J. **A guide to recirculation aquaculture: an introduction to the new environmentally friendly and highly productive closed fish farming systems**. FAO and Eurofish, 2015. Available at: <https://openknowledge.fao.org/server/api/core/bitstreams/a0297773-095a-4ae7-9a89-5a3bfb48abc7/content>. Accessed on: Mar. 17, 2026.

CHELLAPPA, S.; YAMAMOTO, M. E.; CACHO, M. S. R. F. Biologia, comportamento e reprodução do peixe ornamental acará-bandeira (*Pterophyllum scalare*). In: BALDISSEROTTO, B. (org.). **Espécies nativas para a piscicultura no Brasil**. 3. ed. Santa Maria: UFSM, 2020. p. 437–446.

DANANJAYA, S. A. V. et al. 3D printing of biodegradable polymers and their composites – current state-of-the-art, properties, applications, and machine learning for potential future applications. **Progress in Materials Science**, v. 146, art. 101336, 2024. DOI: <https://doi.org/10.1016/j.pmatsci.2024.101336>.

DELONG, D. P.; LOSORDO, T. **How to start a biofilter**. Southern Regional Aquaculture Center: SRAC Publication, 2012. Available at: <https://koioorganisationinternational.org/sites/default/files/SRAC-Publication-No.-4502-How-to-Start-a-Biofilter.pdf>. Accessed on: Mar. 17, 2026.

EBELING, J. M.; TIMMONS, M. B. Recirculating aquaculture systems. In: TIDWELL, J. H. (ed.). **Aquaculture production systems**. Ames: Wiley-Blackwell, 2012. p. 245–277.

EVERS, H. G.; PINNEGAR, J.; TAYLOR, M. Where are they all from? – sources and sustainability in the ornamental freshwater fish trade. **Journal of Fish Biology**, v. 94, n. 6, p. 909–916, 2019. DOI: <https://doi.org/10.1111/jfb.13930>.

FUJIMOTO, R. Y.; SANTOS, R. F. B. S.; MARIA, A. N. Densidade de estocagem e manejo alimentar na criação de acarás-bandeira. Aracaju: Embrapa Tabuleiros Costeiros (Comunicado Técnico, 145), 2014. Available at: <https://www.embrapa.br/busca-de-publicacoes/-/publicacao/1014407/densidade-de-estocagem-e-manejo-alimentar-na-criacao-de-acaras-bandeira>. Accessed on: Mar. 23, 2026.

GONÇALVES JÚNIOR, L. P.; PEREIRA, S. L.; MATIELO, M. D.; MENDONÇA, P. P. Efeito da densidade de estocagem no desenvolvimento inicial do acará bandeira (*Pterophyllum scalare*). **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 65, n. 4, p. 1176–1182, 2013. DOI: <https://doi.org/10.1590/S0102-09352013000400033>.

MNYORO, M. S.; MUNUBI, R. N.; PEDERSEN, L.-F.; CHENYAMBUGA, S. W. Evaluation of biofilter performance with alternative local biomedica in pilot scale recirculating aquaculture systems. **Journal of Cleaner Production**, v. 366, art. 132929, 2022. DOI: <https://doi.org/10.1016/j.jclepro.2022.132929>.

MWEMA, F. M.; AKINLABI, E. T. Basics of fused deposition modelling (FDM). In: **Fused Deposition Modeling**. SpringerBriefs in Applied Sciences and Technology. Cham: Springer, 2020. p. 1–15. DOI: https://doi.org/10.1007/978-3-030-48259-6_1.

GUERDAT, T. C. et al. An evaluation of commercially available biological filters for recirculating aquaculture systems. **Aquacultural Engineering**, v. 42, n. 1, p. 38–49, 2010. DOI: <https://doi.org/10.1016/j.aquaeng.2009.10.002>.

- GUPTA, S. et al. Recent developments in recirculating aquaculture systems: a review. **Aquaculture Research**, 2024, art. ID 6096671. DOI: <https://doi.org/10.1155/are/6096671>.
- LI, T. et al. Effect of coconut waste and its biochar as hydroponics substrates on system performance and nitrogen transformation in aquaponics. **Aquacultural Engineering**, v. 109, art. 102512, 2025. DOI: <https://doi.org/10.1016/j.aquaeng.2025.102512>.
- LI, H. et al. A review of influencing factors on a recirculating aquaculture system: environmental conditions, feeding strategies, and disinfection methods. **Journal of the World Aquaculture Society**, v. 54, n. 3, p. 566–602, 2023. . DOI: <https://doi.org/10.1111/jwas.12976>.
- NAGATA, M. M. et al. Influência da densidade de estocagem no desempenho produtivo do acará-bandeira (*Pterophyllum scalare*). **Boletim do Instituto de Pesca**, v. 36, n. 1, p. 9–16, 2010. DOI: <https://doi.org/10.1590/S0102-09352013000400033>.
- PATIL, P. A. et al. Growth and survival of angel fish *Pterophyllum scalare* (Schultze, 1823) fry reared at different stocking densities. **Journal of Environment and Bio-Sciences**, v. 29, n. 1, p. 167–172, 2015.
- R CORE TEAM. **R: A language and environment for statistical computing**. Vienna: R Foundation for Statistical Computing, 2026. Available at: <https://www.R-project.org/>. Accessed on: Mar. 9, 2026.
- REZENDE, F. P. et al. Sistemas e infraestrutura de produção. In: REZENDE, F. P.; FUJIMOTO, R. Y. **Peixes Ornamentais: mercado, legislação, sistemas de produção e sanidade**. Brasília, DF: Embrapa, 2021. p. 139–226.
- RIBEIRO, F. A. S. et al. Feeding level and frequency for freshwater angelfish. **Revista Brasileira de Zootecnia**, v. 41, n. 6, p. 1550–1554, 2012. DOI: <https://doi.org/10.1590/S1516-35982012000600033>.
- RIBEIRO, F. A. S.; PRETO, B. L.; FERNANDES, J. B. Sistemas de criação para o acará-bandeira (*Pterophyllum scalare*). **Acta Scientiarum Animal Sciences**, Maringá, v. 31, n. 4, p. 431–435, 2009. DOI: <https://doi.org/10.4025/actascianimsci.v30i4.685>.
- SEREZLI, R.; KÜÇÜKAĞTAŞ, A.; KURTOGLU, I. Z. Acute toxicity of ammonia and nitrite to angel fish (*Pterophyllum scalare*, Liechtenstein 1823) and the effect of erythrocyte morphology. **Fresenius Environmental Bulletin**, v. 25, n. 8, p. 3119–3124, 2016.
- STERZELECKI, F. C. et al. Açai palm, *Euterpe oleracea*, seed for aquaponic media and seedling production. **Aquacultural Engineering**, v. 98, art. 102270, 2022. DOI: <https://doi.org/10.1016/j.aquaeng.2022.102270>.
- SOMERVILLE, C.; COLE, C.; BABY, K.; EDWARDS, P. Small-scale aquaponic food production – Integrated fish and plant farming. Rome: **Fisheries and Aquaculture Technical Paper 589**, 2014. 288 p. Available at: <https://openknowledge.fao.org/handle/20.500.14283/i4021e>. Accessed on: Mar. 23, 2026.

SIKORA, M.; NOWOSAD, J.; KUCHARCZYK, P. Comparison of different biofilter media during biological bed maturation using common carp as a biogen donor. **Applied Sciences**, v. 10, n. 2, art. 626, 2020. DOI: <https://doi.org/10.3390/app10020626>.

TAVARES DIAS, M.; LEMOS, J. R. G.; MARTINS, M. L. Parasitic fauna of eight species of ornamental freshwater fish from the middle Negro River in the Brazilian Amazon region. **Revista Brasileira de Parasitologia Veterinária**, v. 19, n. 2, p. 103–107, 2010.

YAKUB, I. et al. Porosity, flow, and filtration characteristics of frustum shaped ceramic water filters. **Journal of Environmental Engineering**, v. 139, n. 7, p. 986–994, 2013. DOI: [https://doi.org/10.1061/\(ASCE\)EE.1943-7870.0000669](https://doi.org/10.1061/(ASCE)EE.1943-7870.0000669).

ZHU, C. et al. Suitability of coconut bran and biochar as a composite substrate for lettuce cultivation in aquaponic systems. **Heliyon**, v. 10, art. e35515, 2024. DOI: <https://doi.org/10.1016/j.heliyon.2024.e35515>.