Performance Assessment of Two Biofilter Media for Ammonia Control in Freshwater Recirculating Aquaculture Systems

Indranil Bagchi[1], Anurag Sen[1], T. Ramesh[1] and P. Selvaraj[2]

[1] Centre of Advanced Study in Marine Biology, Faculty of Marine Sciences, Annamalai University, Chidambaram, Cuddalore district Tamil Nadu – 608 502

[2] Department of Biotechnology, Sri Kaliswari College (Autonomous), Sivakasi – 626130

*Corresponding author: rameshcasmb@gmail.com

Abstract

Recirculating aquaculture systems (RAS) are increasingly adopted for intensive fish farming due to their ability to conserve water and limit nutrient-rich effluents. Effective control of ammonia, the primary nitrogenous waste in aquaculture, is critical for maintaining optimal water quality and fish health. This study evaluated the performance of two commonly used biological filtration media—bio-balls and ceramic rings—in reducing ammonia concentrations within a model freshwater RAS. The system comprised eight interconnected culture tanks divided into three experimental setups: (i) control with probiotics only, (ii) probiotics plus bio-balls, and (iii) probiotics plus ceramic rings. Each tank was stocked with equal biomass and maintained for a 20-day trial, with ammonia (NH_3) levels measured twice daily following the Strickland and Parsons (1972) method. In the control, ammonia peaked at 3.5 ppm and stabilized at 2.0 ppm by day 20. Bio-balls reduced ammonia from 3.0 ppm to 0.03 ppm, while ceramic rings achieved a reduction from 2.5 ppm to 0.4 ppm over the same period. The bio-ball treatment achieved the highest removal efficiency, likely due to its greater effective surface area for nitrifying bacterial colonization. Findings indicate that bio-balls offer superior ammonia control under tropical freshwater RAS conditions, contributing to improved water quality and system sustainability.

Keywords: Recirculating aquaculture system, ammonia removal, biofilter media, bio-balls, ceramic rings, biological filtration

1. Introduction

Recirculating aquaculture systems (RAS) are designed to conserve water and minimize environmental impact by continuously reusing culture water after mechanical and biological treatment. Compared to traditional flow-through systems, RAS can reduce water consumption by up to 100-fold (Ebeling & Timmons, 2012), making them a viable solution for sustainable aquaculture under increasing resource constraints. The technology enables high-density fish culture in controlled environments, but its efficiency depends heavily on the ability to maintain optimal water quality parameters, particularly ammonia levels (Shnel et al., 2002; Piedrahita, 2003).

Ammonia is the principal nitrogenous waste produced by fish through protein metabolism (Regnault, 1987). In aquaculture systems, it originates from fish excretion, uneaten feed, and the decomposition of organic matter (Moriarty, 1997). Elevated concentrations of un-ionized ammonia (NH_3) are toxic, impairing growth, feed conversion, and immune function, and in severe cases causing mortality (Colt & Tchobanoglous, 1978; Svobodová et al., 2005). Ammonia toxicity is influenced by pH, temperature, and alkalinity, which determine the proportion of toxic NH_3 relative to its ionized form (NH_4^+) (Bower & Bidwell, 1978; Szumski et al., 1982). In RAS, ammonia is primarily removed via nitrification, a biological process in which nitrifying bacteria convert NH_3 to nitrite and then nitrate (Schreier et al., 2010).

Biological filtration media are central to nitrification efficiency. Media with high specific surface area provide more attachment sites for nitrifying biofilms, enhancing ammonia conversion rates (Xu et al., 2020). Bio-balls and ceramic rings are two widely used filtration media in freshwater aquaculture, each offering distinct structural and surface characteristics. Bio-balls are lightweight plastic spheres with grooved surfaces, while ceramic rings are porous materials with microchannels that facilitate bacterial colonization. Comparative studies under tropical freshwater RAS conditions remain scarce, particularly those involving side-by-side testing of these media under identical operational parameters (Romano et al., 2020; da Silva et al., 2022).

The present study evaluates the efficiency of bio-balls and ceramic rings in reducing ammonia concentrations in a model freshwater RAS. By maintaining identical operational conditions for both media, this study aims to provide a direct performance comparison, offering practical guidance for selecting biofilter materials to optimize water quality management in small-scale and inland aquaculture systems.

2. Materials and Methods

2.1 Experimental system

A model recirculating aquaculture system (RAS) was constructed consisting of three interconnected components: (i) fish culture tanks, (ii) a filter media tank, and (iii) a pumping tank. Eight glass culture tanks (2 × 3 × 2 ft each) were used, all connected to a central filter tank (4 × 8 ft), which contained the selected filtration media. Water from the filter tank flowed into a 20 L pumping tank equipped with a 40 W submersible motor, which recirculated water back into the culture tanks, ensuring continuous flow.

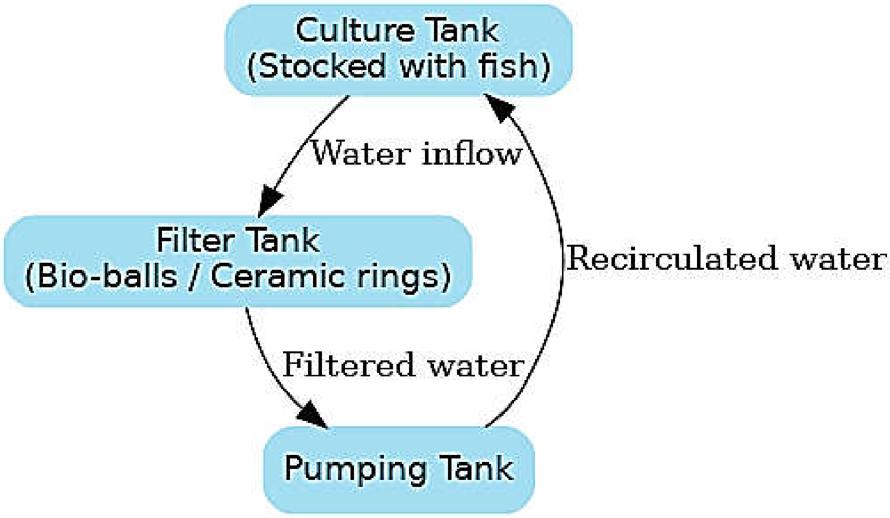

Fig. 1: Schematic representation of the freshwater recirculating aquaculture system (RAS) used in the experiment, consisting of a culture tank, filter tank (with either bio-balls or ceramic rings as media), and a pumping tank connected in a closed-loop design.

2.2 Experimental design

Three independent experiments were conducted to evaluate the effect of filtration media on ammonia removal. Each trial lasted 20 days and included 15 fish (average size: ~4 inches) per tank. Commercial fish feed was provided three times daily at recommended rations, and a commercial freshwater probiotic was added on the sixth day of each experiment.

- Experiment 1 (Control): No filtration media; only probiotic was added.
- Experiment 2 (Bio-balls): Filter tank filled with bio-balls + probiotic.

- Experiment 3 (Ceramic rings): Filter tank filled with ceramic rings + probiotic.

Table 1. Experimental treatments used in the freshwater RAS trials

Treatment	Filtration media	Probiotic use	Stocking density	Trial duration
Control	None	Yes (from day 6)	15 fish/tank (~4")	20 days
Bio-balls	Bio-balls	Yes (from day 6)	15 fish/tank (~4")	20 days
Ceramic rings	Ceramic rings	Yes (from day 6)	15 fish/tank (~4")	20 days

2.3 Filtration media

Bio-balls: Lightweight plastic spheres with grooves designed to maximize surface area for microbial colonization. Their structure allows efficient biofilm formation and contributes to maintaining neutral pH.

Ceramic rings: Porous cylinders with numerous micro-channels that provide surface area for nitrifying bacteria. They promote conversion of toxic ammonia (NH_3) and nitrite (NO_2^-) into less harmful nitrate (NO_3^-).

2.4 Probiotic application

A commercially available freshwater probiotic blend containing *Bacillus subtilis*, *Lactobacillus plantarum*, *Streptococcus thermophilus* and yeast species (*Saccharomyces cerevisiae*) was added to all treatments on day 6 of each trial at manufacturer-recommended doses.

2.5 Water quality monitoring

Ammonia (NH_3) concentrations were measured twice daily (08:00 and 17:00 h) using the colorimetric method of Strickland and Parsons (1972). Briefly, ammonia reacts with sodium hypochlorite and phenol under alkaline conditions to produce indophenol blue, with sodium nitroprusside used as a catalyst. Absorbance was read at 640 nm, and concentrations were determined against standard ammonium sulfate solutions.

3. Results

3.1 Control (Probiotic only)

In the control treatment, ammonia levels exhibited a steady increase during the first five days, reaching a maximum of 3.5 ppm (Fig. 1). Following the addition of probiotics on day 6, concentrations showed a gradual decline. From day 10 onwards, ammonia levels stabilized at 2.0–2.2 ppm and remained near this range until the end of the 20-day trial. Although some reduction was achieved, the control treatment consistently retained the highest ammonia levels among all treatments.

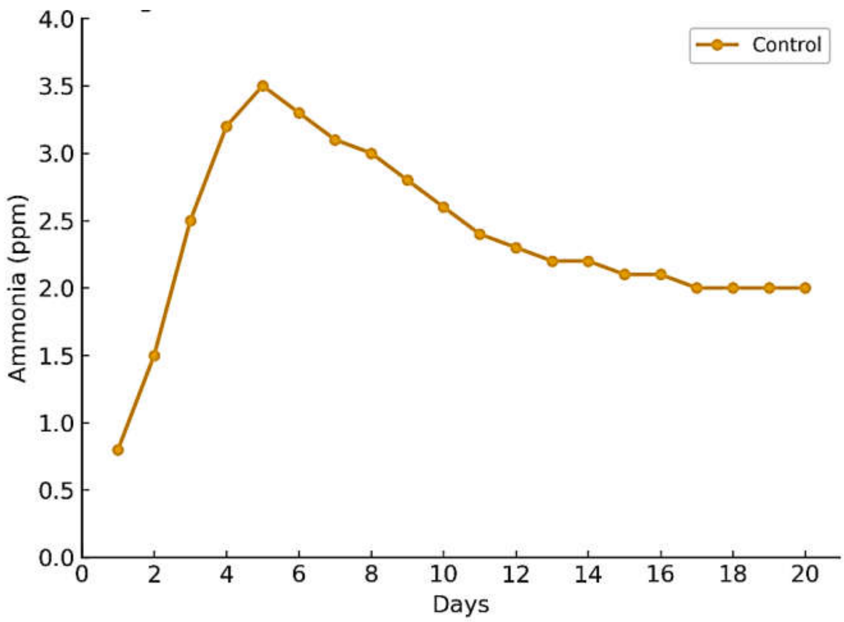

Fig. 2: Ammonia concentration (ppm) over 20 days in the control treatment (no filter media, probiotic added on day 6). Ammonia peaked at day 5 and gradually declined to ~2.0 ppm by the end of the trial.

3.2 Bio-balls

Ammonia concentrations in the bio-ball treatment increased to 2.5 ppm by day 5. After probiotic addition on day 6, levels began to decline rapidly. Between day 8 and day 15, the reduction rate averaged 0.2 ppm/day, with ammonia falling from 3.0 ppm to 0.5 ppm. By day 20, levels reached 0.03 ppm, representing almost complete removal of ammonia from the system (Fig. 2).

This trend indicates that bio-balls provided an effective surface for nitrifying bacterial colonization, accelerating ammonia oxidation once the microbial community was established. The reduction was both more rapid and more complete than in other treatments.

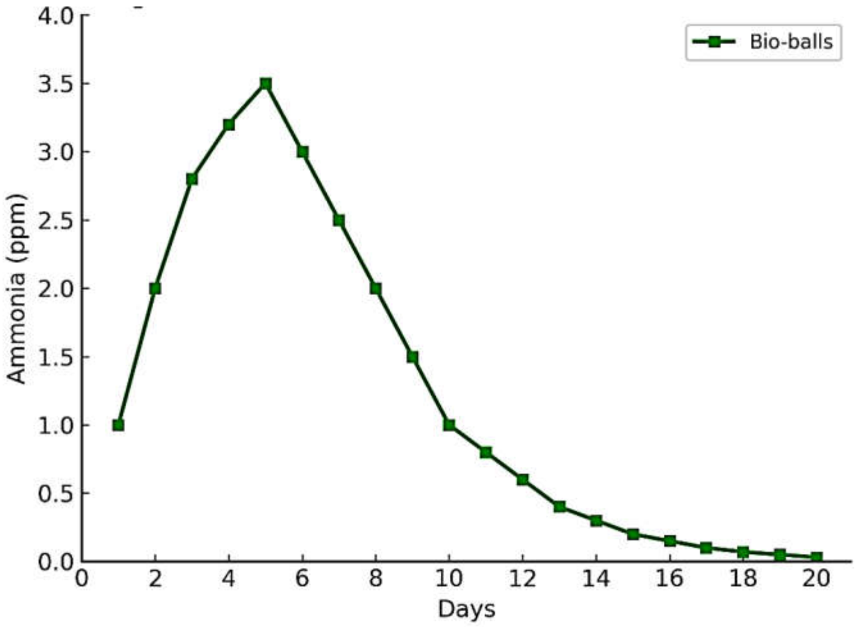

Fig. 3: Ammonia concentration (ppm) over 20 days in the bio-balls treatment. A sharp decline in ammonia levels occurred after probiotic addition, reaching near-complete removal (~0.03 ppm) by day 20.

3.3 Ceramic rings

In the ceramic ring treatment, ammonia levels rose to 3.5 ppm by day 5, similar to the control (Fig. 3). After probiotics were added, a gradual decline was observed. Concentrations decreased steadily, reaching 1.5 ppm by day 12 and 0.4 ppm by day 19. The rate of decline was slower compared to the bio-ball treatment, and ammonia concentrations never dropped below 0.4 ppm by the end of the trial.

These results suggest that although ceramic rings supported nitrifying biofilms, their efficiency in ammonia removal was lower than bio-balls under the same conditions.

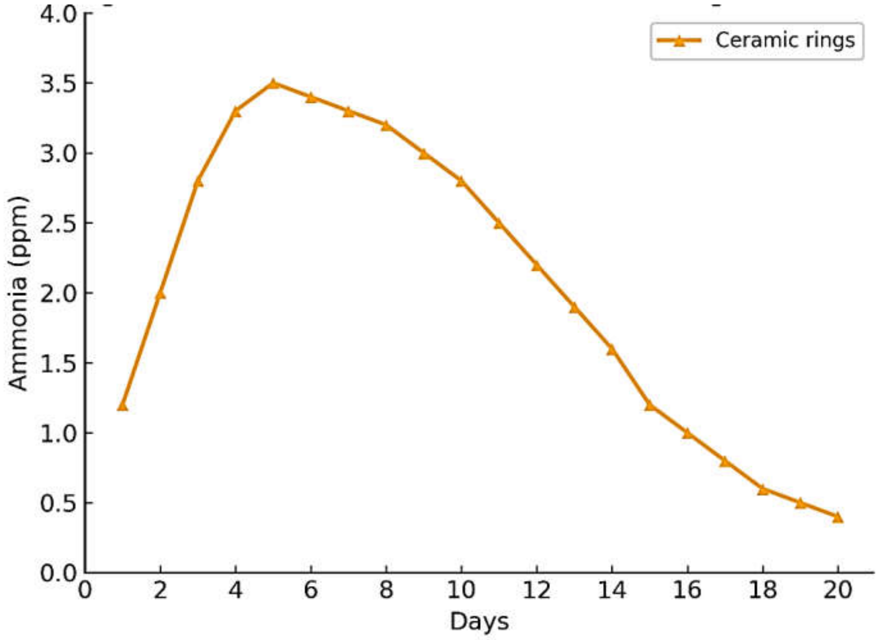

Fig. 4: Ammonia concentration (ppm) over 20 days in the ceramic rings treatment. Ammonia declined gradually, reaching ~0.4 ppm by the end of the trial.

3.4 Cross-treatment comparison

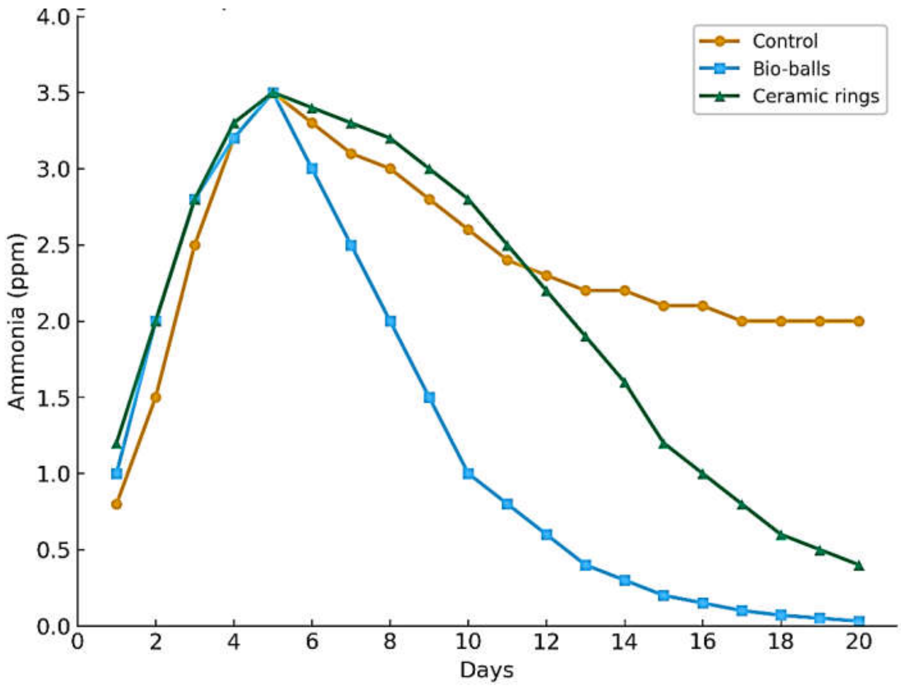

Fig. 5: Comparative ammonia concentration trends across treatments (Control, Bio-balls, Ceramic rings) over 20 days. Bio-balls achieved the fastest and most complete removal, while ceramic rings showed moderate efficiency and the control remained elevated.

Marked differences emerged between treatments after the introduction of probiotics (day 6). By day 10, ammonia in the bio-ball treatment had already declined below 2 ppm, while ceramic rings remained at 3 ppm and the control at 3.2 ppm. On day 15, ammonia was nearly eliminated in the bio-ball treatment (0.5 ppm), compared to 1.2 ppm in ceramic rings and 2.1 ppm in the control. By day 20, final concentrations were 0.03 ppm (bio-balls), 0.4 ppm (ceramic rings), and 2.0 ppm (control) (Fig. 4).

Table 2. Ammonia concentrations (ppm) at key time points in RAS treatments

Day	Control	Bio-balls	Ceramic rings
5	3.5	2.5	3.5
10	3.2	1.8	3.0
15	2.1	0.5	1.2
20	2.0	0.03	0.4

3.5 Overall performance

Bio-balls achieved the most effective ammonia removal, showing both the fastest decline and the lowest final concentrations. Ceramic rings performed moderately well but were less efficient than bio-balls, while the control treatment showed only partial reduction. These results clearly demonstrate that the choice of filtration media strongly influences ammonia dynamics in RAS and highlight the superior performance of bio-balls under the tested conditions.

Table 3. Final ammonia reduction efficiency of biofilter treatments

Treatment	Initial concentration (ppm)	Final concentration (ppm)	% Reduction
Control	3.5	2.0	42.9%
Bio-balls	3.0	0.03	99.0%+
Ceramic rings	3.5	0.4	88.6%

4. Discussion

This study demonstrated that bio-balls were more effective than ceramic rings in reducing ammonia concentrations in a freshwater recirculating aquaculture system (RAS). Ammonia levels declined from 3.0 ppm to 0.03 ppm with bio-balls, compared to 3.5 ppm to 0.4 ppm with ceramic rings, while the control treatment remained at 2.0 ppm. These results clearly indicate that the choice of filtration medium plays a decisive role in regulating nitrogenous waste in closed aquaculture systems.

The superior performance of bio-balls can be attributed to their larger effective surface area and structural design, which provide extensive colonization sites for nitrifying bacteria. Similar observations have been reported in RAS studies where increased biofilm surface area correlated with higher ammonia removal rates (Xu et al., 2020; da Silva et al., 2022). Ceramic rings, although porous and capable of supporting microbial growth, appeared less efficient in sustaining rapid nitrification under the same conditions.

The results align with earlier findings that ammonia removal in RAS depends strongly on biofilter media characteristics and operational factors. For instance, Summerfelt et al. (2014) showed that nitrification efficiency in moving bed biofilters was influenced by alkalinity and biofilm dynamics, while Peirong and Wei (2013) demonstrated that fluidized bed biofilters achieved up to 95% removal efficiency. Compared to these advanced systems, the present study shows that even relatively simple media such as bio-balls can achieve near-complete ammonia removal in small-scale freshwater systems.

The control treatment, which relied only on probiotics, showed partial reduction of ammonia, suggesting that microbial additives alone cannot substitute for the surface area provided by physical biofilters. This finding is consistent with reports that probiotics may enhance microbial activity but require stable attachment substrates for sustained performance (Schreier et al., 2010; Romano et al., 2020).

From a practical perspective, the use of bio-balls offers clear advantages for tropical freshwater aquaculture. Their low cost, durability, and ease of handling make them suitable for farmer-level applications. By maintaining ammonia at sub-toxic levels, bio-balls contribute to improved fish health and growth performance, reduce the risk of stress-induced mortality, and enhance overall system sustainability. Ceramic rings may still be useful where finer pore structures are advantageous, but under the present conditions their performance was inferior.

A limitation of the current study is the relatively short experimental duration (20 days), which may not fully capture long-term biofilm dynamics and stability. In addition, supporting water quality parameters such as pH, dissolved oxygen, and alkalinity were not monitored, which could have provided further insight into the mechanisms of ammonia removal. Moreover, microbial community analysis was not conducted, preventing identification of dominant nitrifying populations. Future studies incorporating molecular tools and longer operational periods could address these gaps and validate the scalability of the present findings.

In conclusion, this study highlights the effectiveness of bio-balls as biofilter media for ammonia removal in freshwater RAS. By providing superior nitrification compared to ceramic rings, bio-balls represent a practical option for improving water quality in small-scale and inland aquaculture systems.

5. Conclusion

This study assessed the performance of two commonly used biofilter media—bio-balls and ceramic rings—for ammonia removal in freshwater recirculating aquaculture systems (RAS). Results demonstrated that bio-balls achieved near-complete ammonia reduction (99%), while ceramic rings were moderately effective (88.6%). The control, with probiotics alone, showed only partial reduction, indicating that physical media are essential to support efficient nitrification.

The superior efficiency of bio-balls is attributed to their greater effective surface area, which promotes faster colonization and activity of nitrifying bacteria. These findings underscore the importance of selecting appropriate biofilter media in RAS design, as media type directly influences water quality and system sustainability.

Although the experiment was conducted at a small scale and over a relatively short duration, the results provide practical guidance for aquaculture operations, particularly in tropical freshwater systems. Adoption of bio-balls can help farmers maintain optimal water quality, reduce toxic nitrogen accumulation, and enhance overall culture performance. Future work should extend the study period, include detailed water quality monitoring, and investigate microbial community dynamics to strengthen understanding of biofilter performance.

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