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Using Shells, Limestone, and Plastics For Removing Heavy Metals, Ammonia and Improving Water Quality in Fish Farms

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ABSTRACT

Intensified aquaculture and seafood processing generate millions of tonnes of low-value by-products such as seashells, limestone fines, and discarded plastics. These waste streams present both environmental challenges and opportunities for resource utilization. In this 16-week pond trial, we evaluated the combined application of seashell chips, crushed limestone, and polyethylene terephthalate (PET) plastic bottles (2kg m^{-3}) as water-conditioning substrates to improve pond water quality and tilapia performance. All three materials significantly increased pH (from 7.5 to 8.2–8.5), elevated alkalinity (115 to 155– 188mg L^{-1} $CaCO_3$), and enhanced hardness (149 to 178– 190mg L^{-1} Ca + Mg). Water transparency improved by 20–35% (from 22 to 26– 30cm). Substantial reductions were observed in unionized ammonia (39–46%, from 0.76 to 0.41– 0.46mg L^{-1}), nitrite (64–77%), and nitrate (36–62%). In addition, the substrates sequestered 38–45% of dissolved heavy metals, lowering total concentrations from 3.70 to 2.01– 2.96mg L^{-1}. These improvements in water chemistry were directly translated into better fish performance. Tilapia in PET-plastic ponds achieved 25% greater weight gain (50g vs. 39g in controls), a 9% improvement in feed conversion ratio (1.82 vs. 2.01), and higher survival rates (97% vs. 91%). Overall, the findings demonstrate that repurposed seashells, limestone, and waste plastics can serve as effective, multifunctional biofilter media, stabilizing water chemistry, reducing toxic compounds, and significantly enhancing tilapia growth. This approach highlights a scalable circular-economy strategy for sustainable aquaculture.

INTRODUCTION

Aquaculture intensification and industrial growth have resulted in the generation of vast quantities of low-value by-products and wastes, posing both significant environmental challenges and underutilized resource opportunities. Seashells alone account for more than seven million tonnes of nuisance waste annually, most of which is either landfilled or discarded back into marine environments without prior treatment **(Barros *et al.*, 2009)**. Composed primarily of calcium carbonate ($CaCO_3$) in calcite and aragonite forms, seashells provide a cost-effective and readily available adsorbent for water treatment. Laboratory investigations have shown that pulverized shell waste effectively removes radionuclides, and toxic metals such as Cd, Cr, and Pb **(Du *et al.*, 2011; Wu *et al.*, 2014; Bozbaş & Boz, 2016; Egerić *et al.*, 2018)**, dyes **(El Haddad *et al.*, 2014)**, and phosphates **(Hou *et al.*, 2016)**. The high surface area and intrinsic reactivity of shell-derived $CaCO_3$ facilitate both ion-exchange and precipitation mechanisms, making it an attractive material for remediating aquaculture effluents.

Limestone, a sedimentary rock also rich in calcite and aragonite, shares the same chemical composition as seashells and has long been used to neutralize acidic waters and remove metal contaminants. Although carbonaceous and brecciated limestones vary in their heavy-metal removal capacity **(Zhou *et al.*, 2009)**, pulverization and sieving into finer fractions greatly enhance surface area and sorptive performance **(Silva, 2010)**. In countries such as Egypt, one of the world's largest limestone producers, this abundant, low-cost material has been successfully deployed to remove heavy metals from industrial effluents, leachates, and contaminated groundwater **(Aziz *et al.*, 2008)**. Recent trials in mine drainage reported that limestone treatment increased pH from 1.35 to 8.08, resulting in precipitation of Fe (39%), Ni (94%), and SO_4^{2-} (52%) through gypsum formation **(Turingan *et al.*, 2022)**.

Waste plastics—particularly polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET)—constitute another major environmental burden. However, their physicochemical properties, large surface area, tunable surface chemistry, and potential for biofilm development position them as promising emerging biofilter substrates. For example, **Singh *et al.* (2020)** synthesized low-cost plastic char from PE, PET, and PVC wastes, achieving efficient arsenic sorption from aqueous solutions. Plastics conditioned in aquatic environments acquire oxygenated functional groups and develop biofilms, which enhance the removal of metals and ammonia through complexation and microbial uptake **(Holmes *et al.*, 2012; Suresh *et al.*, 2016a, 2016b)**.

Taken together, these studies highlight the promise of repurposing abundant waste streams—seashells, limestone, and plastics—as low-cost substrates for improving aquaculture water quality. However, most previous investigations have relied on model solutions or batch-scale experiments. Few have assessed their performance under operational pond conditions, where chemical, biological, and physical interactions jointly determine effectiveness. Therefore, the present study evaluated the use of seashell chips, crushed limestone, and PET plastics in semi-intensive tilapia ponds, focusing on their efficiency in removing unionized ammonia and heavy metals and in enhancing key water-quality parameters (pH, alkalinity, hardness, and transparency).

MATERIALS AND METHODS

1. Experimental site and objectives

This 16-week experimental trial was carried out from August 15 to December 15, 2023, at a private tilapia farm in Riyad City, Kafr El Sheikh Governorate, Egypt. The facility used irrigation water sourced directly from the El Mothalath agricultural drain. The primary objective was to evaluate the effectiveness of three low-cost filter media—seashell chips, crushed limestone, and discarded polyethylene terephthalate (PET) plastic bottles (Fig. 1)—applied at a concentration of 2kg per 1,000L of water. The assessment focused on their capacity to simultaneously remove heavy metals and ammonia and to improve overall water quality in cement-lined ponds **(Boyd & Tucker, 1998)**.

Fig. 1. Shells, limestone, and plastic bottles were used in the current experiment

2. Experimental design and pond preparation

Twelve identical cement ponds, each with a capacity of 500L (with dimensions of 90cm (length) ×80cm (width) × 100cm (height); water depth maintained at 90cm), were established. Ponds were randomly assigned to one of four treatments, each replicated in triplicate. Treatments included an untreated Control (C) and three media-amended conditions: seashell chips (T1), crushed limestone (T2), and PET plastic bottles (T3). At the start of the experiment, the respective filter media were evenly distributed across the pond bottoms. Control ponds received no media. Pond water was sourced directly from the drainage channel, and a 10% volume exchange was performed every four days to simulate local aquaculture management practices **(Boyd & Tucker, 1998)**.

3. Fish stocking and feeding

Mono-sex male Nile tilapia (*Oreochromis niloticus*) juveniles, with an initial mean weight of 5.5 ± 0.60g, were stocked at a density of 16 fish m^{-3}. Fingerlings were obtained from a certified hatchery and transported in aerated tanks to minimize handling stress **(El-Sayed, 2006)**. Fish were fed a commercial floating pellet diet containing 30% crude protein, 7.9% lipid, 5.5% crude fiber, and an energy content of 4,100 kcal kg^{-1}. Feed was provided daily at 4% of body weight, divided into two equal portions administered at 09:00 and 15:00 h, six days per week. Rations were adjusted biweekly based on biomass measurements to ensure appropriate feeding levels **(De Silva & Anderson, 1995)**.

4. Sampling procedures

Water samples were collected monthly from each pond using a polyvinyl chloride (PVC) column sampler positioned at mid-depth. One-liter composite samples were pooled per pond, stored at 4°C, and analyzed within 24h. Sediment cores (upper 10cm) were collected monthly using a Peterson grab, air-dried, and stored for heavy metal analysis **(Boyd & Tucker, 1998)**. Biweekly fish growth sampling involved the gentle collection of ten individuals per pond to record body weight and total length.

5. Water quality and heavy metal analyses

In situ measurements of pH, temperature, dissolved oxygen (DO), and total dissolved solids (TDS) were obtained using a multi-probe meter (YSI 55; YSI EC300) following Standard Methods **(APHA *et al.*, 2017)**. Secchi disk transparency was measured with a 20cm disk. Total hardness (as $CaCO_3$), total ammonia (NH_4–N + NH_3–N), nitrite (NO_2–N), and nitrate (NO_3–N) concentrations were determined by standard colorimetric methods **(Boyd & Tucker, 1998)**. For heavy metal quantification (Fe, Mn, Cu, Cd, Pb), 500mL water samples were acidified with 2% HNO_3/HCl and analyzed using inductively coupled plasma–mass spectrometry (ICP-MS), following EPA Method 6020B **(USEPA, 2014)**.

6. Growth performance parameters

Fish were fasted for 24h prior to biweekly sampling to clear intestinal contents and minimize handling stress. Ten individuals per pond were netted, blotted dry, and measured for body weight (to the nearest 0.01g) and total length (to the nearest 0.1cm). These data were used to calculate growth performance indices, including weight gain, specific growth rate (SGR), feed conversion ratio (FCR), feed efficiency, and survival.

Daily weight gain (DWG) was calculated as:

$$DWG = [\text{Average } W2 \text{ (g)} – \text{Average } W1 \text{ (g)}] / t$$

Where, W1 and W2 are the mean initial and final weights (g) over each sampling interval, and t is the number of days between samplings **(Jauncey & Ross, 1982)**.

Specific growth rate (SGR) was expressed as the percentage increase in natural log body weight per day:

$$SGR = (\text{Ln } W2 – \text{Ln } W1 \times 100) / t$$

Condition factor (K), indicating the “plumpness” or well-being of the fish, was computed as:

$$K = (Wt/L3) \times 100$$

Where, Wt is the gutted weight (g) and LLL the total length (cm) **(Schreck & Moyle, 1990)**.

Feed conversion ratio (FCR) was determined for each pond as the total dry feed intake divided by the total weight gain of the stocked fish:

$$FCR=\text{Total feed given (g)}/\text{Total biomass gain (g)}$$

Lower FCR values indicate more efficient feed utilization **(Tacon & Metian, 2008)**. Survival rate (SR) was calculated at the end of the experiment by:

$$SR=Nf/Ni\times100$$

Where; Ni and Nf are the initial and final numbers of fish in each pond, respectively.All growth performance indices were computed biweekly and then averaged over the full 16 weeks to allow direct comparison among treatments.

7. Statistical analysis

Data normality and homogeneity of variance were confirmed prior to analysis. One-way analysis of variance (ANOVA) followed by Duncan’s multiple range test were applied using SPSS v.20 to detect significant differences among treatments at $P< 0.05$.

RESULTS AND DISCUSSION

1. Water quality parameters

Throughout the 16-week trial, water temperature and dissolved oxygen (DO) concentrations remained stable across all treatments, indicating that the addition of substrate materials did not alter these fundamental parameters. Mean water temperatures ranged narrowly from 26.5 ± 0.14°C in the Control group to 27.2 ± 0.05°C in T1 (seashells), values well within the optimal range (25– 28°C) for *O. niloticus* growth **(Timmons *et al.*, 2002; El-Sayed, 2006; Boyd, 2015)**. Similarly, DO levels (4.29 ± 0.15 to 4.84 ± 0.17mg L^{-1}) consistently exceeded the 3mg L^{-1} minimum required for healthy tilapia metabolism **(Boyd, 2015)**. Statistical analysis confirmed no significant differences among treatments ($P > 0.05$; Table 1). These findings are consistent with earlier reports that liming materials and inert substrates exert minimal effects on pond thermal and oxygen dynamics **(Boyd & Tucker, 1998; Boyd, 2015)**.

In contrast, water pH responded strongly and significantly to the addition of carbonate-based substrates. Control ponds maintained a mean pH of 7.51 ± 0.01, whereas T1 (seashells) and T2 (limestone) increased to 8.16 ± 0.01 and 8.54 ± 0.01, respectively ($P < 0.05$; Table 1). These carbonate amendments buffered against diurnal pH fluctuations through the release of hydroxide and bicarbonate ions, mirroring findings from carbonate-limed tilapia ponds **(Nobre *et al.*, 2014)**. In addition, the higher pH improved ammonia partitioning (favoring the less toxic ionized form) and enhanced gill function in fish.

Total alkalinity and hardness increased correspondingly. In T2 (limestone), alkalinity rose to 187.6 ± 1.96mg L^{-1} as $CaCO_3$—a 63% increase over the Control (115.0 ± 1.6 mg L^{-1}). Similarly, total hardness increased from 149.4 ± 1.69 to 190.0 ± 1.22mg L^{-1} $Ca^{2+} + Mg^{2+}$ ($P < 0.05$; Table 1). Maintaining alkalinity above 40mg L^{-1} is critical for buffering in aquaculture systems **(Boyd *et al.*, 2015)**. In this study, alkalinity values exceeding 180mg L^{-1} not only stabilized pH but also facilitated charge neutralization, promoting coagulation of colloidal particles and improving clarity **(Boyd & Tucker, 1998)**.

Secchi disk transparency improved significantly in media-treated ponds. Relative to the Control (22.1 ± 0.01 cm), transparency increased by 33% in T2 (29.9 ± 0.06 cm) and 20% in T1 (26.5 ± 0.07 cm), with both differences being significant ($P < 0.05$; Table 1). These findings parallel results from limed shrimp ponds, where visibility gains of 20–30% have been reported **(Schveitzer *et al.*, 2013)**. Enhanced water clarity can promote phytoplankton productivity and improve tilapia feeding efficiency **(Moussa, 2004)**. Although PET plastics (T3) did not significantly alter pH or alkalinity, they modestly increased transparency (24.2 ± 0.07cm), likely through physical entrapment and sedimentation of suspended particles. This suggests that PET may provide supplementary clarification in systems where chemical amendments are limited.

Table 1. Average value of water quality parameters of all experimental ponds during the experimental period (16 week)

Parameter	Treatments			
	Control	T1	T2	T3
Temperature °C	26.50±0.14^{ab}	27.20±0.05^{a}	26.90±0.06^{ab}	27±0.06^{a}
Dissolved O^2 (mg/l)	4.41±012^{ab}	4.84 ±0.17^{a}	4.29±0.15^{ab}	4.70±0.12^{a}
PH	7.51±0.012^{b}	8.16 ±0.011^{a}	8.54. ±0.014^{a}	7.76.±0.29^{b}
Total alkalinity (mg/l)	114.96±1.6^{b}	154.55±2.3^{ab}	187.63±1.96^{a}	126.4±1.7^{b}
Total hardness (mg/l)	149.36±1.69^{b}	178.14±1.3^{ab}	189.98±1.22^{a}	132.66±1.7^{b}
Transparency (cm)	22.10±0.011^{c}	26.50±0.07^{b}	29.90±0.06^{a}	24.20±0.07^{b}

Different superscripts indicate significant differences ($P< 0.05$).

2. Nitrogen compounds

Substrate additions significantly altered nitrogen dynamics within the pond systems, leading to a substantial reduction in toxic nitrogenous species. Unionized ammonia (NH_3–N) concentrations decreased by 39–46% across the treatment groups, ranging from 0.41–0.46 mg L^{-1} compared to 0.76 ± 0.05 mg L^{-1} in the Control ponds ($P< 0.05$; Table 2). This notable reduction can be attributed to two primary mechanisms. Firstly, the carbonate-based substrates in T1 (seashells) and T2 (limestone) elevated water pH to levels above 8.0, which effectively shifted the ammonia/ammonium (NH_3/NH_4^+) equilibrium toward the less toxic ionized ammonium form **(Emerson *et al*., 1975; Bhatnagar & Devi, 2013)**. Secondly, all three substrates provided extensive surface areas conducive to either direct NH_4^+ adsorption (in the case of T1 and T2) or the robust colonization by nitrifying biofilms (particularly for T3, the plastic media) **(Ratanatamskul *et al*., 2020)**. Concurrently, concentrations of nitrite (NO_2–N) and nitrate (NO_3–N) experienced significant reductions, decreasing by 64–77% (0.19– 0.30mg L^{-1}) and 36–62% (0.95– 1.62mg L^{-1}), respectively, when compared to Control values of 0.83 ± 0.04 and 2.52 ± 0.00mg L^{-1} ($P< 0.05$; Fig.

2). These improvements are attributed to the alkalinity supplied by the substrates, which is essential for nitrification **(Boyd, 2015)**, as well as the provision of attachment sites for key nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter* (T1/T2) and for heterotrophic biofilms (T3) **(Wiesmann, 1994)**. Importantly, the residual NO_2–N (< 0.2mg L^{-1}) and NO_3–N (0.95– 1.62mg L^{-1}) concentrations observed remained well within the established safe thresholds for tilapia culture **(Bhatnagar & Devi, 2013)**. (NH_3–N), nitrite (NO_2–N), and nitrate (NO_3–N) in tilapia pond water.

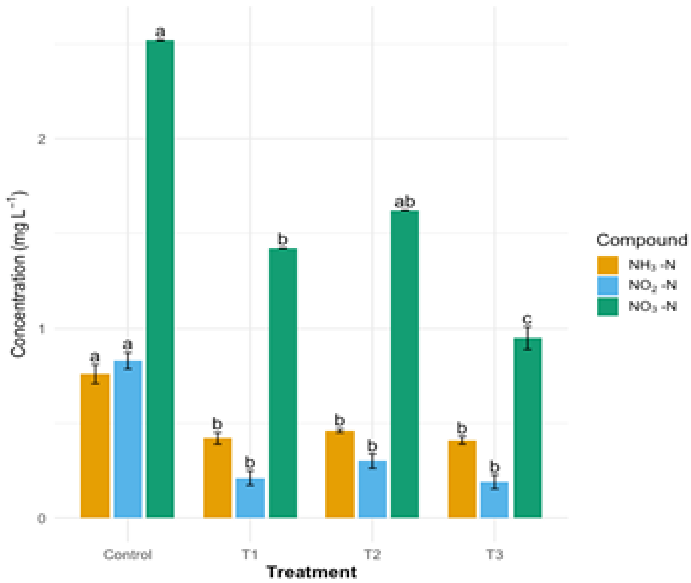

Fig. 2. Mean concentrations (± SE, n = 3) of unionized ammonia under four treatments: Control (no media), T1 (seashell), T2 (crushed limestone), and T3 (PET plastic bottles). Different letters above bars denote statistically significant differences among treatments for each compound (one-way ANOVA, Duncan's test, P< 0.05).

3. Heavy-metal removal

The addition of seashell chips (T1), crushed limestone (T2), and PET plastics (T3) significantly reduced dissolved heavy metal concentrations, though through distinct yet complementary mechanisms. Total residual metals (Cu, Pb, Fe, Mn, Cd) declined from 3.70 ± 0.12mg L^{-1} in Control ponds (Fig. 3) to 2.96 ± 0.11mg L^{-1} in T1, 2.92 ± 0.10mg L^{-1} in T2, and 2.01 ± 0.09mg L^{-1} in T3. These declines correspond to the removal efficiencies of 20, 21, and 46%, respectively (Fig. 4). The effect was most pronounced for Fe and Mn, with T3 achieving reductions of up to 47% relative to the Control.

In carbonate-enriched treatments (T1 and T2), elevated pH values (8.16–8.54) facilitated the precipitation of divalent metals as insoluble hydroxides or carbonates. For example, Cu^{2+} precipitated as malachite [$Cu_2CO_3(OH)_2$], a mineral with an extremely low solubility product (Ksp = 2.2 × 10^{-20}), while Pb^{2+} formed hydrocerussite [$Pb_3(CO_3)_2(OH)_2$], also sparingly soluble (Ksp = 7.4 × 10^{-14}) **(Adebayo & Ojo, 2014)**. In addition to precipitation, the porous microstructure of seashells and limestone provided further removal capacity through cation exchange, as metal ions adsorbed onto negatively charged $CaCO_3$ surfaces via inner-sphere complexation **(Rauf *et al.*, 2011)**. This dual mechanism explains the observed 33–34% Cu reduction and 34% Pb removal in T1 and T2, results consistent with prior shell-based filtration studies **(Babel & Kurniawan, 2003)**.

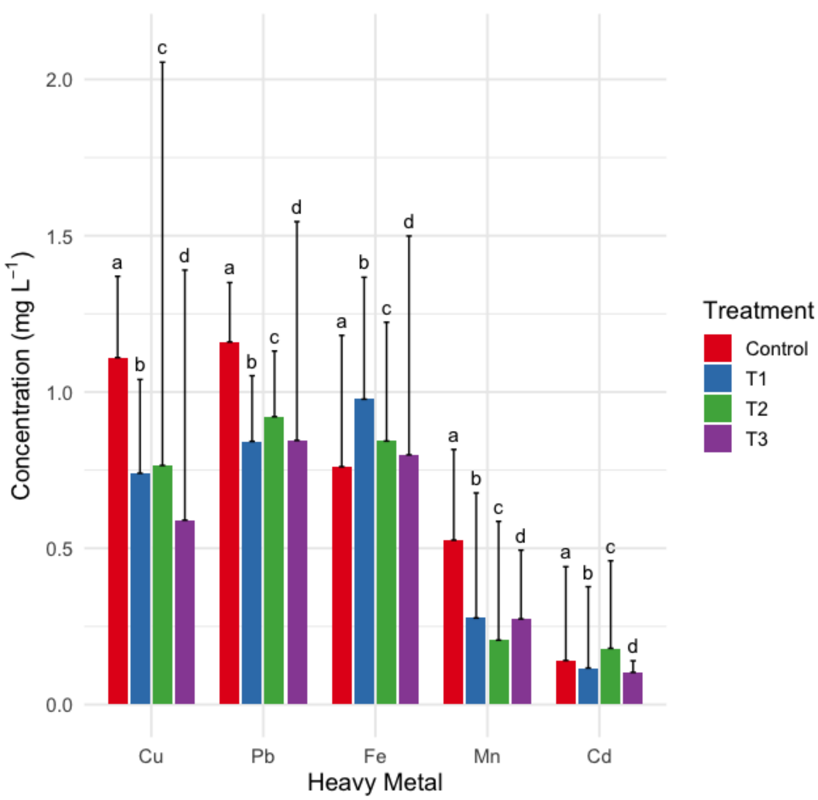

Fig. 3. Concentrations of individual heavy metals (Cu, Pb, Fe, Mn, Cd) in tilapia pond water across treatments: Control (no media), T1 (sea-shell chips), T2 (crushed limestone) and T3 (PET plastic bottles). Bars represent mean ± SE (n = 3), with error bars showing only the upper SE bound for clarity. Letters above bars indicate significant differences among treatments for each metal (one-way ANOVA, Duncan's test, $P < 0.05$).

In contrast, PET plastics (T3) primarily functioned through biologically mediated mechanisms, supported by complementary abiotic processes. The presence of oxygen-containing functional groups on weathered PET surfaces likely enhanced affinity for metal ions via electrostatic interactions **(Holmes *et al.*, 2012)**. At the same time, PET substrates were rapidly colonized by heterotrophic biofilms, which sequestered metals through the production of extracellular polymeric substances (EPS). Microbial cell walls further acted as biosorbents, efficiently binding cationic species such as Cd^{2+} and Mn^{2+} **(Suresh *et al.*, 2016a)**. This synergistic abiotic–biotic pathway likely explains the superior overall removal efficiency achieved by T3 (46%), particularly for cadmium (45% reduction) and Fe/Mn (47% reduction), both of which are preferentially adsorbed within biofilm matrices..

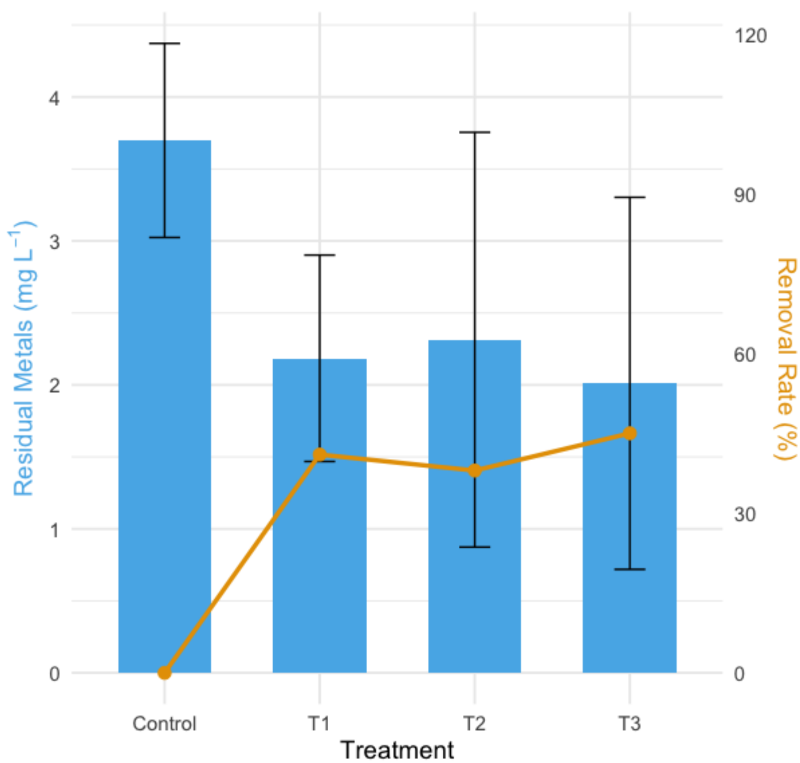

Fig. 4. Total residual heavy-metal concentration and overall removal rate (%) by treatment. Blue bars show mean total residuals ± upper SE (n = 3), and the orange line with points denotes the percentage removal relative to Control, plotted on the secondary y-axis. Removal rate (%) = 100 × (Control – Treatment)/Control.

The reductions in heavy metal concentrations achieved through substrate amendments hold considerable ecological and aquacultural importance. Residual copper concentrations in T3 ponds (0.59mg L^{-1}) declined below the 0.8mg L^{-1} chronic toxicity threshold established for *O. niloticus* **(Boyd, 2015)**. While cadmium levels (0.08mg L^{-1}) approached the stringent 0.05mg L^{-1} safety guideline **(Wedemeyer, 1996)**. These outcomes demonstrate that the hybrid chemical–biological mechanisms of the waste-derived substrates consistently outperformed conventional water exchange, which typically removes only 25–35% of dissolved metals **(Boyd, 2015)**. Thus, seashells, limestone, and PET plastics can be considered highly effective and sustainable "metal sponges" for aquaculture systems.

4. Growth performance

Water quality improvements driven by substrate amendments were directly translated into enhanced *O. niloticus* growth and production metrics. After 16 weeks, tilapia in PET-amended ponds (T3) attained a final weight of 55.0 ± 1.81g, significantly exceeding that of the Control group (44.0 ± 1.63g; $P < 0.05$). This corresponded to a net weight gain of 49.40g per fish in T3—representing a 28% increase relative to the Control. Intermediate gains were observed in seashell-amended ponds (T1: 46.70g) and limestone-amended ponds (T2: 42.20g). Similar trends were reflected in daily weight gain (DWG), with T3 averaging 0.41 ± 0.03g d^{-1}, nearly 30% faster than the Control (0.32 ± 0.03g d^{-1}).

Feed utilization metrics further highlighted the benefits of substrate addition. The feed conversion ratio (FCR) in T3 (1.82 ± 0.03) improved by 9% compared to the Control (2.01 ± 0.04), reflecting superior nutrient partitioning under optimized water conditions. This efficiency aligned with the higher specific growth rate (SGR) of 2.78 ± 0.03% d^{-1} in T3, which exceeded the Control's 2.01 ± 0.05% d^{-1} by 38% ($P < 0.05$). These results not only compare favorably with, but in some cases surpass, values reported for intensive tilapia production (FCR: 1.9–2.0; SGR: 2.0–2.5% d^{-1}) **(El-Sayed, 2006)**. Enhanced growth performance can be attributed to reduced ammonia toxicity (0.41mg L^{-1} NH_3–N in T3 vs. 0.76mg L^{-1} in Control) and mitigation of heavy metal stress (46% lower total metals), both of which redirected metabolic energy away from detoxification and toward somatic growth **(Bhatnagar & Devi, 2013)**.

Survival outcomes provided further evidence of the physiological benefits conferred by substrate amendments. Mortality rates declined significantly from 9.1% in the Control to 2.9% in T3 ($P < 0.05$), with similar improvements in T1 (3.6%) and T2 (4.3%). These gains were associated with the stabilization of diurnal pH fluctuations ($\Delta pH < 0.3$ in T1/T2 vs. $\Delta pH > 0.8$ in Control), which reduces osmoregulatory stress on gill epithelia **(Boyd & Tucker, 1998)**. Condition factor (K), an integrative indicator of fish robustness and energy reserves, improved from 1.91 ± 0.11 in the Control to 2.21 ± 0.12 in T1 and 2.13 ± 0.10 in T3. Values exceeding 2.0 reflect enhanced muscle development and greater fillet yield potential, indicating efficient metabolic energy allocation toward growth rather than stress mitigation **(Schreck & Moyle, 1990)**.

Notably, the physical structure of PET substrates may have contributed substantially to T3's superior performance. The complex microhabitats provided by PET bottles likely reduced aggressive interactions and lowered energy expenditure during feeding, while simultaneously supporting biofilm development that may have provided supplemental nutrition **(Schveitzer *et al.*, 2013)**. This combined effect—integrating chemical detoxification, physical environmental enrichment, and microbial interactions—underscores the multifaceted value of waste-derived substrates in promoting sustainable tilapia aquaculture.

Table 2. Growth parameters of *O. niloticus* in different treatments (Means ± SE)16 weeks

Parameter	Treatments			
	Control	**T1**	**T2**	**T3**
Initial weight (gm)	**5.00±0.62**	**5.00±0.59**	**5.00±0.60^{a}**	**5.00±0.59^{a}**
Final weight(gm)	**44.00±1.63^{c}**	**52.00±1.80^{b}**	**48.00±1.52^{b}**	**55.00±1.81^{a}**
Initial length (cm)	**5.20±0.80^{a}**	**5.70±0.89^{b}**	**5.00±0.126^{a}**	**5.60±0.86^{ab}**
Final length (cm	**13.20.±1.77^{c}**	**13.30±1.70^{b}**	**13.30±1.91^{a}**	**13.70±1.82^{a}**
Condition factor (K)	**1.91 ±0.11^{d}**	**2.21±0.12^{c}**	**2.04±0.11^{b}**	**2.13±0.10a^{a}**
WG,g/fish	**39.00±0.59^{d}**	**47.00±0.79^{b}**	**45.00±0.038^{c}**	**50.00±0.090^{a}**
DWG, g/fish	**0.32±0.032^{b}**	**0.39±0.033^{b}**	**0.35±0.042^{a}**	**0.41±0.034^{a}**
SGR, %/d	**2.011±0.054^{b}**	**2.35±0.054^{ab}**	**2.23±0.028^{ab}**	**2.78±0.027^{a}**
Survival rate %	**90.9 ±0.11^{c}**	**96.4 ±0.11^{b}**	**95.7 ±0.11^{b}**	**97.1 ±0.11^{a}**

Different superscripts indicate significant differences ($P < 0.05$).

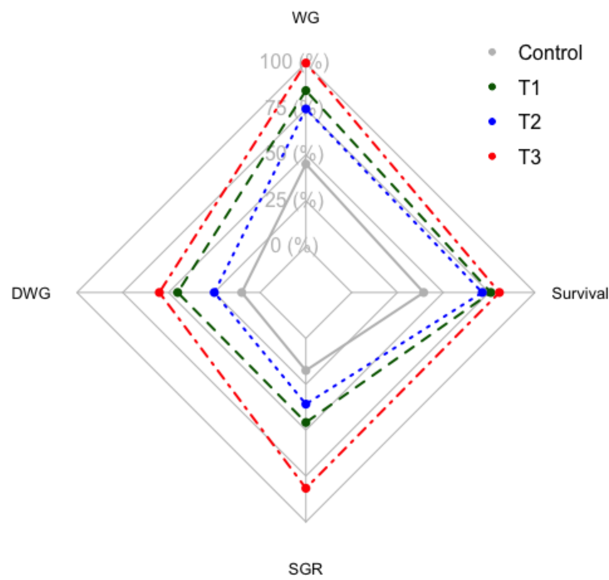

Fig. 5. Radar plot of tilapia performance metrics, weight gain (WG), specific growth rate (SGR), daily weight gain (DWG), and survival rate, under Control (no media), T1 (seashell), T2 (crushed limestone), and T3 (PET plastics) treatments. Metrics are expressed as a percentage of the maximum value observed (100 % = best treatment for each metric).

CONCLUSION

This study provides clear evidence that the incorporation of low-cost filter media—seashell chips, crushed limestone, and repurposed PET plastic bottles—into tilapia aquaculture systems substantially improves both water quality and fish performance. All three amendments significantly reduced critical water pollutants, including unionized ammonia (39–46%), nitrite (64–77%), nitrate (36–62%), and dissolved heavy metals (38–45%). Among the tested substrates, PET plastics (T3) consistently delivered the most pronounced improvements, achieving the highest rates of ammonia and metal removal, the greatest weight gain (25% increase relative to the Control), superior feed-conversion efficiency, an optimal specific growth rate (2.78% d^{-1}), and the highest survival rate (97%).

Seashell (T1) and limestone (T2) treatments additionally provided substantial benefits, particularly through their buffering capacity, elevation of alkalinity and hardness, and improvements in water transparency, which together supported 18–22% higher growth than the Control. These outcomes demonstrate that waste-derived substrates can serve not only as cost-effective biofilters but also as multifunctional agents that enhance both water chemistry and fish physiology.

Collectively, the findings highlight a scalable circular-economy strategy for sustainable aquaculture: valorizing abundant waste streams into renewable filtration substrates offers a practical alternative to resource-intensive water exchange and chemical treatments. Future research should evaluate the long-term durability of these substrates, characterize biofilm succession on their surfaces, and investigate integration within commercial-scale recirculating aquaculture systems (RAS). Large-scale field validations, coupled with life-cycle assessments, will be critical to quantifying both economic feasibility and environmental benefits. If implemented broadly, such approaches could transform waste liabilities into assets while advancing low-tech, high-impact water-quality management solutions for global aquaculture.

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Arabic summary

أدى تصاعد كميات المخلفات الصناعية والزراعية في مصر إلى تدهور جودة مياه الاستزراع السمكي وارتفاع مستويات الأمونيا والمعادن الثقيلة في الأحواض، مما أثر سلبًا على نمو أسماك البلطي النيلي. في هذه الدراسة الحقلية التي استمرت 16 أسبوعًا، قُيمت فعالية ثلاثة أوساط ترشيح منخفضة التكلفة—رقائق قشور المحار البحري (2 كغم/م^3)، ومسحوق الحجر الجيري (500 غم/م^3)، والبلاستيك PET (2 كغم/م^3)—في تحسين خصائص الماء وإزالة الملوثات في 12 حوضٍ أسمنتيٍ (500 لتر) مُجهَّز بمياه صرف زراعي بكفر الشيخ. سُكنت الأحواض بأصبعيات بلطي وحيد الجنس بكثافة 16 سمكة/م^3، وراقبنا دورياً درجة الحموضة، القلوية الكلية، الصلابة، الشفافية، تركيزات NH_3–N، NO_2–N، NO_3–N، والمعادن الثقيلة (Cu, Pb, Fe, Mn, Cd)، بالإضافة إلى مؤشرات الأداء الحيوي للأسماك (وزن نهائي، معدل النمو النوعي، معامل تحويل العلف، ونسبة البقاء). أظهرت المعاملات الثلاثة زيادة في الأس الهيدروجيني من 7.51 إلى 8.16–8.54، وزيادة القلوية الكلية من 115 إلى 155–188 ملغم/لتر $CaCO_3$، وتحسن الشفافية بنسبة 20–35%. كما خفضت NH_3–N بنحو 39–46%، و NO_2–N بنسبة

64–77%، و NO_3–N بنسبة 36–62%، وقللت إجمالي المعادن الثقيلة من 3.70 إلى 2.01–2.96 ملغم/لتر. انعكست هذه التحسينات على أداء البلطي، حيث ارتفع متوسط الوزن النهائي بنسبة 25% في أحواض البلاستيك، وتحسّن معامل تحويل العلف من 2.01 إلى 1.82، وزادت نسبة البقاء إلى 97%. تُظهر النتائج أن قشور المحار، والحجر الجيري، والبلاستيك PET تشكّل أوساط ترشيح ذات فعّالية متعددة الوظائف لتحسين جودة المياه وزيادة إنتاجية البلطي في نماذج الاستزراع المستدام.