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Preliminary study on the impact of mussel integration on qualitative changes of water in an aquaponic system

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ABSTRACT

Freshwater resource sustainability is a growing concern in modern agriculture. Aquaponic systems, which integrate fish farming and soilless plant cultivation, offer a promising solution by enabling nutrient recycling within a closed water loop. However, the accumulation of organic waste and suspended solids can challenge system stability and water quality. This study investigates the potential of the freshwater mussel *Unio crassus* as a biological filter to enhance organic waste removal and water purification in aquaponic systems.

Two system configurations were tested: the Media Bed System and the Nutrient Film Technique (NFT) system, each receiving identical daily tilapia effluent dosing, and containing identical plant cohorts (lettuce and collard greens) and *U. crassus* mussels. Over 30 days, key water quality parameters—total suspended solids (TSS), dissolved oxygen (DO), pH, and ammonia (NH_3)—were monitored, alongside plant biomass development.

Results indicated that while the media bed system achieved significantly lower TSS concentrations (14.2 ± 2.1 mg L^{-1}), the NFT system maintained higher DO levels (5.8 ± 0.6 mg L^{-1}) and supported greater plant growth. Localised zones of improved clarity were observed near mussel clusters; however, quantitative mussel-specific contributions were not measured.

Within this scope, integrating *U. crassus* may offer ecological value while warranting controlled, quantitative verification. Moreover, this approach may contribute to species conservation through practical ex situ applications. The study highlights the potential of hybrid aquaponic systems utilising both design types and nature-based filtration for sustainable food production.

Keywords: Aquaponics, Freshwater mussel, Organic waste, Water quality, NFT system, Media bed, Sustainability

Introduction

The increasing scarcity and contamination of freshwater resources, resulting from urbanisation, agriculture, and industrial activities, have driven the development of sustainable and integrated food production systems. Aquaponics, a synergistic combination of aquaculture and hydroponics, has emerged as a promising method that allows the recirculation of water and nutrients in a closed-loop system, significantly reducing water usage while supporting the simultaneous cultivation of fish and plants (Goddek et al., 2019). This system enhances resource efficiency, minimises environmental impact, and contributes to circular economy models in agriculture (Tyson et al., 2011; Yeşiltaş et al., 2025).

Aquaponics utilises the nitrogenous waste products produced by fish, which are converted by nitrifying bacteria into nutrients that are accessible to plants. In turn, plants absorb these nutrients and help to improve water clarity by reducing suspended particles in the water before it is returned to the fish tanks (Rakocy et al., 2006; Kargın & Bilgüven, 2018). This mutualistic relationship is crucial to the sustainability of aquaponic systems, eliminating the need for synthetic fertilisers and reducing extensive water inputs.

Historically, integrated farming practices can be traced back to ancient civilisations such as the Aztecs, who practised Chinampa agriculture—a floating garden system that utilised nutrient-rich lake water for crop production (Yegül et al., 2020). Contemporary aquaponic systems build upon these principles while incorporating technological advancements such as automated monitoring, energy-efficient pumps, and modular system designs (Tunçelli & Memiş, 2024).

One of the critical challenges in aquaponic systems remains the efficient removal of organic particulates and suspended solids, which can accumulate and negatively impact plant growth and fish health (Tunçelli et al., 2023). While mechanical and biological filtration methods are commonly employed, there is a growing interest in nature-based solutions to improve water quality. In this context, freshwater mussels—particularly *Unio crassus*—present a unique opportunity.

Unio crassus is an endangered species (Lopes-Lima et al., 2024) of freshwater mussel known for its ecological role as a natural biofilter (Tomović et al., 2023). These organisms are filter feeders, capable of removing fine suspended particles and microorganisms from the water column, thus enhancing water clarity and reducing total suspended solids (TSS) (Bahrioğlu, 2017). Their incorporation into aquaponic systems has the potential to complement existing filtration strategies while also providing a model for ex situ conservation of threatened mussel species.

Unio crassus was chosen because (i) it is a locally occurring unionid with recognised suspension-feeding capacity and documented water-polishing potential; (ii) its environmental requirements (cool, well-oxygenated flow over sandy–gravel substrates) can be approximated in controlled aquaponic loops with stable temperature and gentle current; and (iii) non-lethal, permit-based husbandry can contribute to ex-situ conservation and outreach while testing nature-based filtration within food-production contexts. Husbandry conditions in our systems (acclimation, continuous flow, high dissolved oxygen, shelter within perforated containers) were aligned with these requirements. In this study, mussels were acclimated and maintained under stable temperature and flow, housed in mesh containers near the return line to maximise contact with suspended solids while minimising stress.

Recent investigations have highlighted the importance of microbial community dynamics in aquaponic systems, where the presence of beneficial bacterial taxa, including Bacillus, Pseudomonas, and Serratia, facilitates enhanced nutrient cycling and inhibits the growth of opportunistic pathogens. Tunçelli et al. (2025) reported that *Bacillus spp.* may inhibit pathogenic species, such as *Aeromonas sobria*, in koi carp–parsley systems, supporting the hypothesis that native microbial communities play a role in stabilising water quality.

Despite this ecological promise, the use of freshwater mussels in aquaponic systems has been rarely explored in the scientific literature. While some studies have examined the role of unionid mussels in natural or engineered water purification contexts, very few have assessed their functionality within closed-loop aquaponic configurations. Table 1 summarises selected studies that investigated various freshwater mussel species and their contributions to water treatment performance in aquaculture or wastewater systems. These findings provide a foundation for understanding the potential role of *U. crassus* in integrated aquaponic setups.

Building upon these insights, this study aims to evaluate the filtration capacity and practical integration of *Unio crassus* in two commonly used aquaponic configurations: Media Bed and NFT. By comparing water quality parameters and plant growth metrics across these systems, this research provides insight into the role of mussels in enhancing organic waste management and the overall sustainability of aquaponic production. The findings aim to contribute to both environmental conservation efforts and the development of innovative aquaculture practices.

Table 1. Previous Studies on Freshwater Mussels in Filtration and Aquaponic Systems.

Study (Year)	Mussel Species	System Type	Key Findings and Results
Demircan et al. (2022)	*Unio crassus*	Laboratory (aquaculture effluent, bacteria)	Reductions in *Staphylococcus* and *Aeromonas* loads within 48 h; depuration/antibiotic treatments improved outcomes.
Campos et al. (2022)	*Unio mancus*	Laboratory (*E. coli* challenge; clearance assay)	Suspended *E. coli* was rapidly cleared within the first 24 h; retention in soft tissues was observed for up to 4 days.
Tang et al. (2015)	*Hyriopsis cumingii*	Fish–mussel integrated culture (pond/IMTA-vari)	Fish–mussel integration (with feed supplementation) increased fish and pearl yields and improved nitrogen utilisation efficiency.
Ranjbar et al. (2021)	*Anodonta cygnea*	Closed-loop wastewater treatment reactor	Biological removal of pollutants in a closed-loop reactor; results indicated decreases in suspended solids and microbial load.
Geng et al. (2022)	*Mixed (mussel–microalgae–bacteria)*	Pilot-scale aquaculture wastewater treatment	Significant reductions in NH_3–N, TN, TP, COD and suspended solids using a mussel–microalgae–bacteria complex; improved water quality in pilot and field (river) applications.

Materials and Methods

Experimental Design

The experiment was conducted at the Aquaponics Research Unit of Istanbul University, Faculty of Aquatic Sciences. Two types of recirculating aquaponic systems were established: the Media Bed System and the NFT System. Both systems were designed to operate under similar environmental conditions and were run concurrently over 30 days.

Each system was replicated three times, with identical tank volumes (~150 L) and biological loads to allow for direct performance comparison (Figure 1). The systems shared a standard design in which water was continuously circulated between the fish tank and plant-growing units. In both systems, *Unio crassus* mussels were incorporated as a biological filtration component.

Media Bed System: Constructed using 130 × 40 × 33 cm plastic containers filled with ~100 L of expanded clay media (hydroton). Each container was fitted with a custom-made bell siphon (Ø50 mm outer shell, Ø20 mm inner air break pipe) to enable periodic flood-and-drain cycles. Water from the sump tank was pumped into the media bed and drained by gravity after reaching a set height.

NFT System: Comprised two 1-meter-long polyvinyl chloride (PVC) pipes (Ø110 mm) per unit. Each pipe featured five equally spaced openings (20 cm apart) to accommodate net pots. Submersible pumps delivered water from the sump tank to the top of each pipe. The water passed over the plant roots and returned to the tank by gravity, flowing past mussels located in mesh baskets at the return point to optimise contact with suspended solids.

Both systems utilised full-spectrum LED grow lights (100 W) to maintain consistent photoperiods of 16 hours of light and 8 hours of darkness. The ambient room temperature ranged from 22 °C to 25°C.

Biological Material

Two biological components were actively utilised in both aquaponic system types: plants and freshwater mussels. Nile tilapia (*Oreochromis niloticus*) were not directly involved in the experiment but served as the source of nutrient-rich effluent water.

Fish Effluent Source**:** Nile tilapia (*Oreochromis niloticus*) culture tanks supplied the daily effluent. Stocking density was 10 kg m^{-3} with a mean individual mass of 200 g. Fish were fed with a commercial trout feed, consisting of 45% crude protein and 12% crude fat at 2% BW day^{-1}, 2 times per day. On each experimental day, 15 L of clarified effluent was taken from the tilapia tanks and dosed to each replicate (≈10% of the ~150 L working volume). This standardised organic loading across replicates without manipulating the fish, allowing for a consistent comparison of design-level effects between systems.

Plants: Two leafy vegetable species—lettuce (*Lactuca sativa*) and collard greens (*Brassica oleracea* var. *acephala*)—were selected for their compatibility with aquaponic systems and rapid growth. Each replicate consisted of five plants of each species, arranged in an alternating order to minimise competition effects.

Plant performance was evaluated as fresh weight (FW) at harvest after 5 min surface-drying, and as relative growth rate (RGR):

$$RGR = (\ln W_2 - \ln W_1) / t \ (day^{-1}),$$

Where W_1 and W_2 are initial and final FW, and t is the cultivation period (days). Procedures followed standard small-scale aquaponic practice for leafy crops.

Mussels: Each replicate received 15 *U. crassus* (shell length 5.8 ± 0.4 cm; total biomass ~250 g), corresponding to ~1.7 g L^{-1} and 0.10 ind L^{-1}. The target density was selected to ensure measurable contact between suspended solids and suspension feeders while remaining within a conservative biomass-to-volume range for non-lethal husbandry. Individuals were quarantined for 14 days and housed in perforated containers placed near the return line to maximise exposure to suspended solids and maintain high oxygenation.

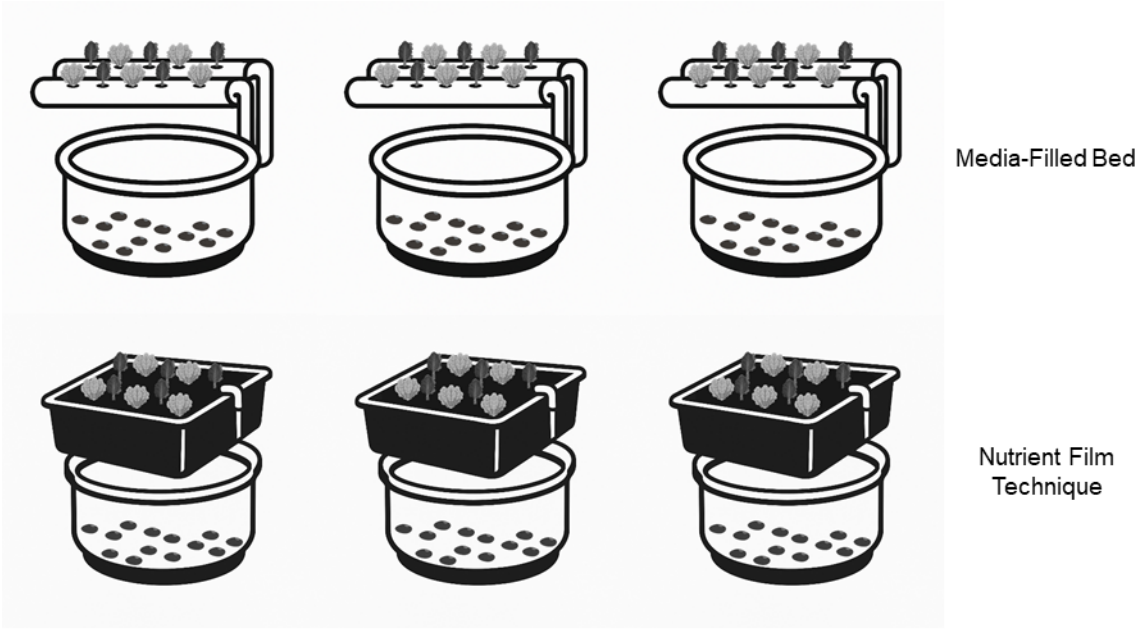

Figure 1. Experimental aquaponics system design

Figure 2. Lettuce and collard greens (left) and freshwater mussels (*Unio crassus*) (right).

Water Quality Analysis

Water samples were collected over 30 days. TSS, pH, and DO were measured using gravimetric and probe-based methods. The total suspended solids were calculated using:

$$TSS\ (mg\ L^{-1}) = (A - B) \times 1000 / V$$

Where:

A = final mass of crucible + residue,

B = mass of empty crucible,

V = volume of water sample (mL)

Statistical Analysis

Data were analysed using Student's t-test; significance was set at $p < 0.05$. Normality and homogeneity were checked by Shapiro–Wilk and Levene's tests, respectively.

Ethical Statement

This study did not involve any direct experimentation on live animals. Fish were not subjected to handling or invasive procedures, and only wastewater from existing aquaculture systems was utilised. Therefore, no ethical approval was required for the mussels, as per institutional and national guidelines. Mussel handling was non-lethal; individuals were returned to their source habitat.

Results and Discussion

Water Quality

Differences in water quality were observed between the two system types over the 30 days. Total Suspended Solids (TSS), dissolved oxygen (DO), pH, and ammonia (NH_3) were the primary indicators used to assess system performance (Table 1).

Localised visual clarity was noted around mussel clusters; however, no mussel-free control was included. Therefore, mussel-specific effects cannot be isolated from design-level effects (e.g., media trapping vs. NFT hydraulics). Visual comparisons are qualitative only and are not interpreted as quantitative filtration outcomes.

The media bed showed lower TSS (14.2 ± 2.1 mg L^{-1}) than NFT (22.7 ± 3.4 mg L^{-1}; $p < 0.01$). Dissolved oxygen was higher in NFT (5.8 ± 0.6 mg L^{-1}) than in the media bed (4.2 ± 0.9 mg L^{-1}). pH ranged between 6.8–7.4 in NFT and 6.7–7.3 in media beds. Ammonia concentrations were 0.18 ± 0.03 mg L^{-1} in NFT and 0.26 ± 0.04 mg L^{-1} in media beds.

Figure 3 illustrates the temporal profiles of TSS for both systems over 30 days.

Plant Growth Performance

Final plant fresh weight was higher in NFT than in media beds (by ~20–25%; Figure 4). Figure 4 presents the final plant fresh weight for both systems.

Table 1. Summary of water quality parameters in NFT and media bed systems over the 30-day trial.

Parameter	NFT System	Media Bed System
TSS (mg L⁻¹)	22.7 ± 3.4[a]	14.2 ± 2.1[b]
DO (mg L⁻¹)	5.8 ± 0.6[a]	4.2 ± 0.9[b]
pH	7.2 ± 1.3[a]	7.3 ± 1.2[a]
NH_3 (mg L⁻¹)	0.18 ± 0.03[a]	0.26 ± 0.04[b]

Values are mean ± SD. Different superscript letters within a row indicate significant differences between systems ($p < 0.05$; statistical test specified in Methods)

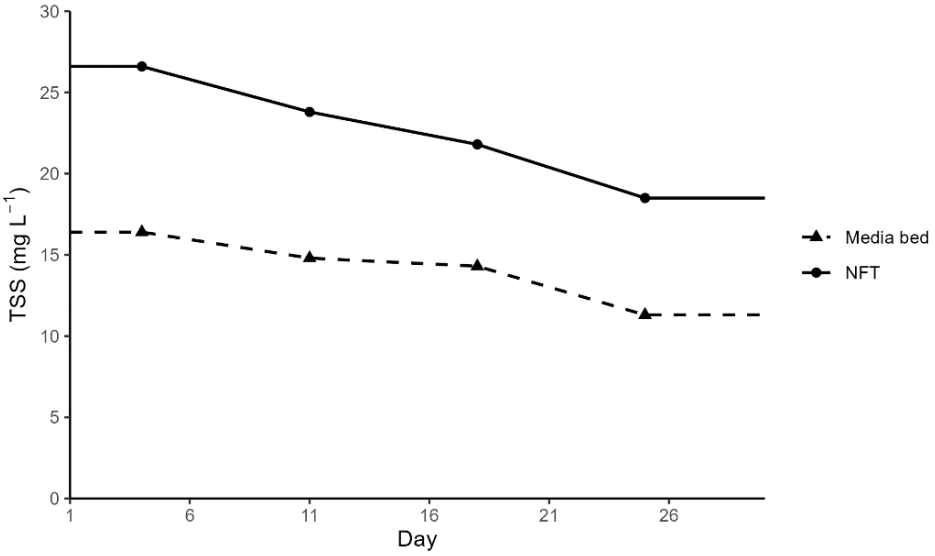

Figure 3. Temporal profiles of TSS in NFT and media bed systems over 30 days

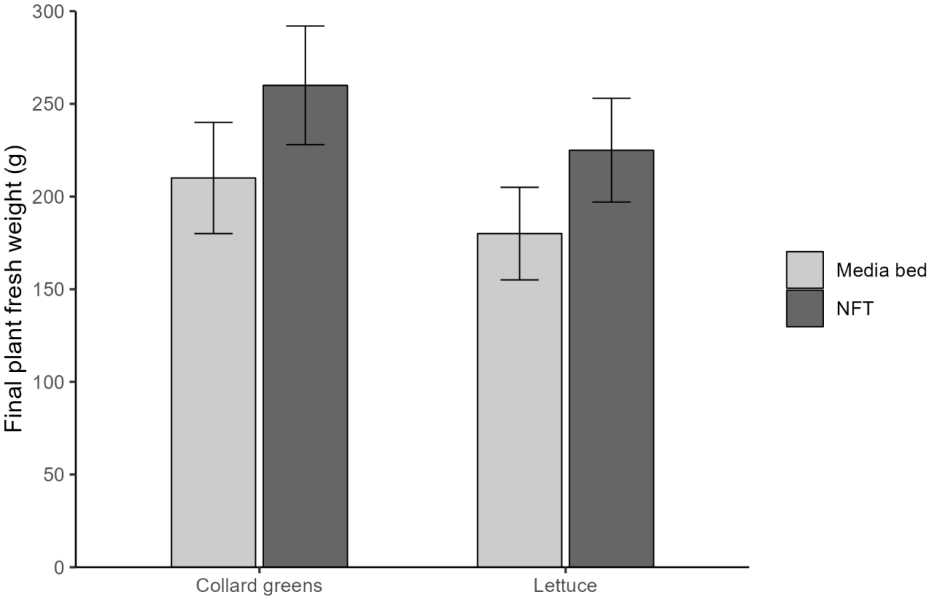

Figure 4. Final plant fresh weight in NFT and media bed systems (mean ± SD)

Mussel Filtration Activity

Localised zones of reduced turbidity were observed around mussel clusters, especially near water return areas. Quantitative filtration metrics were not collected; therefore, mussel-specific effects were not estimated.

The two designs differed in terms of suspended solids and dissolved oxygen. Potential mussel contributions require confirmation with mussel-free controls and quantitative turbidity/clearance measurements.

The present study compared two commonly used aquaponic configurations—media bed and nutrient film technique (NFT)—and documented apparent design-level differences in suspended solids, dissolved oxygen, and plant performance over a 30-day trial period. The media bed configuration exhibited lower total suspended solids (TSS; 14.2 ± 2.1 mg L^{-1}) than NFT (22.7 ± 3.4 mg L^{-1}; $p < 0.01$), which is consistent with the physical interception and settling that occur in porous substrates with longer hydraulic retention. Conversely, the NFT system maintained higher dissolved oxygen (DO; 5.8 ± 0.6 vs. 4.2 ± 0.9 mg L^{-1}), aligning with uninterrupted flow and intensive gas exchange along the film. Both systems held pH within operational ranges (NFT: 6.8–7.4; media bed: 6.7–7.3). The slightly higher ammonia levels in media beds (0.26 ± 0.04 vs. 0.18 ± 0.03 mg L^{-1}) likely reflect transient accumulation within the substrate before nitrification and capture, a known trade-off when solids retention is emphasised.

Regarding plants, the final fresh weight was ~20–25% higher in NFT than in media beds. This outcome is compatible with the well-established advantage of NFT for fast-growing leafy crops under adequate aeration and continuous nutrient delivery (e.g., Somerville et al., 2014; Goddek et al., 2019). Variation among media-bed units was also higher, which is plausible given the potential for micro-heterogeneity in flow paths (channelling) and moisture during flood–drain cycles. Collectively, these patterns underscore a practical compromise: media beds favour solids capture and clarification, whereas NFT favours oxygenation and crop growth. For applications prioritising water polishing and solids removal, a media component (or pre-filter) is advantageous; for maximising leafy biomass, NFT provides a performance edge, provided that upstream solids are effectively managed. Taken together, the media bed achieved lower TSS, whereas NFT maintained higher DO and supported greater plant biomass; these differences are attributable to system architecture rather than mussel effects, which were not quantified and require mussel-free controls.

A qualitative observation in both configurations was localised visual clarity around *Unio crassus* clusters, especially near water return points where suspended loads concentrate. Because the design lacked mussel-free controls and did not include measurements of turbidity, chlorophyll a, particle size distributions, or clearance rate assays, solids reduction cannot be attributed solely to mussels. The observation is therefore hypothesis-generating but consistent with the literature, which reports that suspension-feeding bivalves can polish water in recirculating and IMTA contexts through filtration and biodeposition (Ranjbar et al., 2021; Somerville et al., 2014; Goddek et al., 2019). Whether the net effect is beneficial depends on the hydraulic residence time, the availability of capture surfaces downstream, and maintenance that prevents resuspension.

Independent laboratory studies have shown that unionid mussels can rapidly reduce bacterial loads and suspended material under controlled conditions: in aquaculture effluent, *U. crassus* decreased *Staphylococcus* and *Aeromonas* within 48 h (Demircan et al., 2022), while *Unio mancus* cleared suspended *E. coli* in challenge assays with marked declines in the first 24 h (Campos et al., 2022). Likewise, a closed-loop reactor using *Anodonta cygnea* demonstrated biological removal of pollutants consistent with consumption of suspended solids and pathogen reduction (Ranjbar et al., 2021).

These results reflect a trade-off between particulate removal and oxygen/nutrient delivery, dictated by system design. Media beds outperform in solid filtration due to their high surface area and porous structure, while NFT systems favour faster plant growth through enhanced oxygenation and nutrient mobility (Tyson et al., 2011; Goddek et al., 2019). The integration of *U. crassus* provided additional ecological value in both systems, highlighting its role as a complementary filtration agent that does not impair plant productivity.

At a broader system scale, pairing filter-feeding bivalves with photosynthetic and microbial partners can enhance nutrient capture and water polishing. A pilot mussel–microalgae–bacteria "complex ecosystem" effectively reduced dissolved nutrients and suspended solids in aquaculture effluent (Geng et al., 2022). Similarly, pond-based fish–mussel integrations with *Hyriopsis cumingii* increased both yields and nitrogen-utilisation efficiency, underscoring how biotic assemblages and hydraulics jointly shape solids and nutrient dynamics (Tang et al., 2015).

Beyond system performance, the integration of *U. crassus* also offers ecological significance. As an endangered species (Lopes-Lima et al., 2024), its ex-situ inclusion in controlled aquaponic environments may support conservation efforts,

particularly in regions where natural habitats are compromised by pollution, habitat fragmentation, or declining host fish populations (Tomović et al., 2023). With appropriate water parameters and habitat design, aquaponic systems may even sustain the survival and potentially the reproduction of *U. crassus*.

While *Unio crassus* acts as a natural filter, it also produces waste and converts organic matter into biomass. These dual roles should be considered when evaluating their overall impact on nutrient dynamics. However, challenges remain. Like other unionid mussels, *U. crassus* produces glochidia larvae that require attachment to host fish for metamorphosis. In recirculating systems, unintentional interactions between glochidia and fish could stress cultured species or impair water quality if larval development fails. Future implementations may benefit from separating reproductive individuals or utilising sterile mussels. Moreover, the long-term viability of mussels under variable aquaponic conditions—such as fluctuating temperatures and nutrient loads—warrants further investigation.

Although previous literature highlights the bacterial filtration capacity of unionid mussels, this study did not conduct microbial analyses. Therefore, no direct conclusions can be drawn regarding bacterial removal by *Unio crassus* under the tested conditions. The role of nitrifying and heterotrophic bacteria, which are fundamental to nutrient conversion in aquaponics, was not monitored in this study. This omission limits a comprehensive understanding of biotic interactions within the system. Nevertheless, previous studies in aquaponic systems using koi carp and parsley have demonstrated that microbial compositions vary significantly between system compartments, with beneficial genera such as *Bacillus*, *Flavobacterium*, and *Pseudomonas* supporting system stability and inhibiting the growth of pathogenic strains. The integration of mussels could interact synergistically with such microbial communities, enhancing overall water quality.

Methodologically, the design-level contrasts observed here suggest tangible engineering refinements. First, pairing NFT with a dedicated solids-management stage (e.g., swirl separator, radial-flow settler, or a small media-polishing bed) could retain NFT's growth advantage while lowering TSS entering the plant channels. Second, distributing inflow across media beds (e.g., perforated manifolds) and verifying even flood–drain timing can reduce within-bed heterogeneity. Third, routine monitoring of DO not only in bulk water but also within root zones (NFT channels and media pores) would better resolve oxygen dynamics relevant to both nitrifiers and plant roots. Finally, adding quantitative optical metrics (NTU) and chlorophyll a alongside TSS will resolve "clarity" into size classes and trophic components (fine particulates vs. phytoplankton).

Limitations & Future Work

The main limitation is the absence of a mussel-free control, which prevents causal attribution of any observed clarity to *U. crassus*. We also did not measure turbidity (NTU), chlorophyll a, particle-size distributions, or mussel clearance rates, nor did we assess microbial load (indicator taxa), oxygen demand (BOD_5/COD), or root-zone DO. Future trials will therefore (i) implement parallel mussel-free loops; (ii) quantify optical and gravimetric metrics (NTU, TSS), phytoplankton proxies (chlorophyll-a), and particle spectra; (iii) measure mussel performance (clearance rate under controlled flows, biodeposit production); (iv) profile microbial communities and indicator bacteria across compartments; (v) track DO within root zones and media pores; and (vi) include a priori power analysis to size the study for detecting mussel effects against design-level variance. These steps will enable rigorous partitioning of contributions from system architecture versus mussel filtration, clarifying when mussel integration yields net benefits.

For stakeholders, two actionable messages emerge: (1) when solids reduction is the priority, incorporate a media or dedicated solids unit upstream of plants; (2) when maximising leafy biomass, NFT remains preferred but should be paired with effective solids control to avoid chronic channel fouling. Mussels may complement either pathway, but their deployment should be coupled to quantitative monitoring and clear maintenance protocols.

Conclusion

Within the scope of our measurements, the media bed design reduced suspended solids more effectively, whereas NFT maintained higher dissolved oxygen and supported greater plant biomass. The presence of *U. crassus* coincided with localised visual clarity; however, mussel-specific contributions cannot be inferred without mussel-free controls and quantitative turbidity/clearance data. Overall, these differences reflect system architecture rather than mussel effects, which were not quantified and require mussel-free controls. These results highlight design-dependent trade-offs and motivate future controlled evaluations of mussel integration in aquaponic loops.

Compliance with Ethical Standards

Conflict of interest: The author declares no actual, potential, or perceived conflict of interest for this article.

Ethics committee approval: Ethical committee approval was not required for this study as it utilised only aquaculture wastewater and invertebrate species (*Unio crassus*), with no direct experimentation on vertebrate animals.

Data availability: The data will be made available upon request from the author.

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