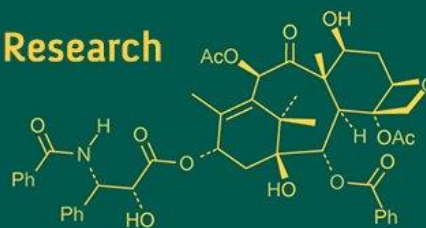


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## UV-C integrated bio-mechanical filtration for water quality management in koi (*Cyprinus rubrofasciatus*) culture tank

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### Abstract

The ornamental fish industry relies heavily on stable aquatic environments, yet small-scale systems frequently struggle with organic waste accumulation and algal blooms without affordable filtration solutions. This study aimed to design, construct and evaluate a cost-effective bio-mechanical filtration system integrated with ultraviolet (UV-C, 253.7 nm) light to enhance overall water quality. The 30-day investigation evaluated four distinct filtration configurations, comprising laterite gravel (T<sub>1</sub>), laterite gravel with UV (T<sub>2</sub>), biofoam sponge (T<sub>3</sub>) and biofoam sponge with UV (T<sub>4</sub>), alongside an unfiltered control (C) across five 110 L tanks stocked with Koi (*Cyprinus rubrofasciatus*). The UV-C integrated systems (T<sub>2</sub> and T<sub>4</sub>) effectively suppressed green water microalgal blooms (0.04 and 0.08 million of cells/ml, respectively) compared to the control (2.70 million of cells/ml). Furthermore, the biofoam system integrated with UV-C (T<sub>4</sub>) demonstrated superior efficiency in regulating total dissolved solids to 165.47 ppm and mitigating toxic ammonia accumulation to 0.22 mg/L. The integration of UV with accessible physical media offers a highly adaptable, practical and economical method to maintain optimal water clarity and fish welfare in ornamental aquaculture.

**Keywords:** Filtration, *Cyprinus rubrofasciatus*, laterite gravel, biofoam sponge, UV-C, green water estimation

### Introduction

The ornamental fish industry is rapidly recognized as one of the most prominent and fastest-growing sectors within global aquaculture, contributing substantially to international trade, rural employment and recreational activities. Currently, over 125 countries are actively engaged in the production and global distribution of ornamental fishes, with freshwater species dominating nearly 90% of the entire market. The widespread popularity of aquarium keeping is largely driven by its aesthetic appeal and documented therapeutic benefits, which include reducing stress and lowering blood pressure for hobbyists (Oertli *et al.*, 2023) [17]. Water quality remains the most critical determining factor in ornamental fish culture because these aquatic organisms spend their entire life cycle in constant, direct contact with their surrounding environment (Hemal *et al.*, 2024) [8]. Consequently, any sudden deterioration in water chemistry can rapidly compromise fish physiology, suppress immune responses and severely impact survival rates (Abdel-Tawwab *et al.*, 2019) [1].

A primary challenge inherent to intensive ornamental fish culture is the continuous accumulation of organic wastes, which originate from fish excretion, unconsumed feed residues, decaying plant materials and microbial decomposition (Elmitwalli *et al.*, 2006) [5]. As these organic wastes undergo biochemical transformations, they release highly toxic nitrogenous compounds directly into the water column. Ammonia serves as the principal toxic metabolite in these closed systems, capable of causing severe gill damage, disrupting osmoregulation and inducing mass mortality (Bhatnagar & Devi, 2013; Hussain *et al.*, 2014) [4, 9]. Because ammonia toxicity is strictly exacerbated by elevated pH and temperature levels which dictate the concentration of the highly lethal unionized ammonia (NH<sub>3</sub>) fraction, controlling its accumulation remains a central objective in aquarium management (Salisu *et al.*, 2023) [19]. The nitrogen cycle serves as the fundamental biological mechanism

responsible for mitigating this toxicity (Endut *et al.*, 2010)<sup>[6]</sup>. Beneficial nitrifying bacteria actively convert toxic ammonia into nitrite and subsequently into less harmful nitrate, through a sequential aerobic process known as nitrification (Endut *et al.*, 2010; Jafari *et al.*, 2024)<sup>[6, 10]</sup>. Establishing and sustaining these stable microbial communities requires highly efficient biological filtration systems that provide adequate surface area for bacterial colonization (Jafari *et al.*, 2024)<sup>[10]</sup>.

Modern recirculating aquaculture operations rely heavily on comprehensive filtration systems that seamlessly combine mechanical, biological and occasionally chemical processes to achieve superior water treatment (Maucieri *et al.*, 2018)<sup>[14]</sup>. Mechanical filtration plays a vital preliminary role by physically extracting suspended solids, feed residues and environmental debris that would otherwise decompose and elevate the biological oxygen demand (Liltved & Cripps, 1999)<sup>[13]</sup>. Simultaneously, these systems frequently battle challenges related to severe microbial contamination and nutrient-driven microalgal blooms. The excessive proliferation of phytoplankton results in green water conditions, which drastically reduce visibility, compromise the tank's aesthetic value and interfere with routine fish management practices (Alam *et al.*, 2001; Zhu *et al.*, 2024)<sup>[2, 22]</sup>. Traditional water exchanges provide only temporary relief and are not economically viable for large-scale operations (Shnel *et al.*, 2002)<sup>[20]</sup>. Therefore, the industry is increasingly shifting its focus toward alternative, advanced management practices, such as ultraviolet (UV-C) sterilization (Summerfelt *et al.*, 2003)<sup>[21]</sup>. UV-C radiation effectively damages the nucleic acids of suspended microorganisms, preventing their cellular replication and safely inactivating pathogens without introducing toxic chemical residues into the aquatic environment (Kamel *et al.*, 2022; Zhu *et al.*, 2024)<sup>[12, 22]</sup>.

Among freshwater ornamental species, Koi carp (*Cyprinus rubrofasciatus*) stand out as one of the most economically valuable and highly prized fishes globally, renowned for their vibrant color patterns and cultural significance (Jha & Barat, 2005; Hussain *et al.*, 2014)<sup>[9, 11]</sup>. However, because Koi are exceptionally sensitive to sudden environmental fluctuations, inadequate filtration and overcrowding frequently lead to elevated concentrations of toxic ammonia and suspended solids (Jha & Barat, 2005; Fan *et al.*, 2022)<sup>[7, 11]</sup>. This environmental stress suppresses their immunity and adversely affects pigmentation (Abdel-Tawwab *et al.*, 2019; Fan *et al.*, 2022)<sup>[1, 7]</sup>. Furthermore, maintaining optimal dissolved oxygen (DO) is a fundamental requirement for the aerobic metabolism of both the Koi and the beneficial nitrifying bacteria residing in the biofilters (Abdel-Tawwab *et al.*, 2019; Jafari *et al.*, 2024)<sup>[1, 10]</sup>. Despite the significant advancements in Recirculating Aquaculture System (RAS) technology, many small-scale ornamental fish keepers and commercial breeders still face challenges related to the high costs and maintenance complexities of commercial filters.

Based on the current literature, there is a distinct necessity to develop affordable, highly efficient filtration systems that utilize locally available natural materials, such as laterite gravel (Nguyen *et al.*, 2021)<sup>[15]</sup> or cost-effective synthetic options, such as biofoam sponges, integrated with modern UV-C technology. Sufficient scientific evidence evaluating the exact comparative efficacy of these specific media combinations under controlled high-density Koi rearing conditions remains limited. Therefore, the primary aim of

the present study is to design and construct a multi-stage filtration system utilizing these accessible media, both with and without UV-C integration, to evaluate their efficacy in maintaining optimal water quality.

The findings of this research will contribute a practical, scalable and environmentally sustainable framework for managing physical and biological contaminants in closed aquatic systems. By optimizing these combined bio-mechanical and UV-C filtration setups, this study provides actionable insights to improve aquarium husbandry, enhance Koi survival and promote the responsible utilization of accessible materials within the broader ornamental aquaculture industry.

## Materials and Methods

### Experimental design

The filtration system was designed with locally available HDPE plastic buckets measuring 40 cm × 30 cm, capable of holding 20 liters of water. The experiment utilized five circular HDPE water tanks, each with a 110 L capacity, located at the College of Fisheries, Shirgaon, Ratnagiri. Plumbing consisted of 1/2-inch flexible PVC tubing, ball valves and PVC threaded adaptors to regulate the incoming water flow. A 40 W (180-240 V) mini submersible pump was installed to circulate water from the experimental tanks to the filters. The experimental setups were defined as: (C) (Control with no filtration), T<sub>1</sub> (Laterite gravel filter), T<sub>2</sub> (Laterite gravel + UV light), T<sub>3</sub> (Biofoam sponge filter) and T<sub>4</sub> (Biofoam sponge + UV light). Submersible UV-C lights (9W) were integrated into the T<sub>2</sub> and T<sub>4</sub> setups for sterilization.

### Experimental fish

Koi carp (*Cyprinus rubrofasciatus*) with an average initial length of approximately 3 cm were selected for the experiment. Prior to stocking, the fish were acclimatized to minimize thermal stress. Subsequently, 30 fish were stocked in each treatment tank, maintaining a stocking density of 30 fish/tank (100L tank). The fish were fed floating commercial pellets containing 32% protein twice daily, in the morning and evening, at 5% of their body weight. The experimental trial was conducted over a 30-day period.



Fig 1: Filter design

### Filter efficacy parameters

#### Water flow test

The water flow rate per minute was calculated by timing with a stopwatch, measuring the volume of water returning to the ornamental fish tank from the filtration unit. Maintaining an adequate flow rate was closely monitored to

evaluate the physical operation of each filter design (Othman *et al.*, 2017) <sup>[24]</sup>.

### Green water estimation

The green water algal density, specifically for unicellular algae, was estimated using a spectrophotometric method (Rodrigues *et al.*, 2011). Absorbance readings of the water samples were taken at 650 nm using a spectrophotometer, as this represents the wavelength of maximum sensitivity for quantifying these samples. For obtaining the cell density of the water samples, the absorbance value was applied to a calibrated mathematical model. The formula according to maximum wavelength absorbance by the sample was used as given below:

$$\text{Cell Density} = \frac{e^{\ln A + 16.726}}{1.0219}$$

- Cell Density = Algal concentration (millions of cells/ml)
- A = Absorbance at 650 nm

### Total dissolved solids and total suspended solids

Total Dissolved Solids were measured by using a TDS meter to monitor water quality (Budianto *et al.*, 2023) <sup>[23]</sup>. Total Suspended Solids (TSS) were determined by passing a 100 ml water sample through a pre-weighed glass fiber filter, which was subsequently dried at 103-105 °C for a minimum of one hour, after which its final weight was recorded (APHA, 2005) <sup>[3]</sup>.

### Temperature (°C)

Water temperature was recorded daily by immersing a calibrated digital thermometer (MEXTECH DT-9) directly into the water tank until a completely stable reading was visually obtained (Nuwansi *et al.*, 2016) <sup>[16]</sup>.

### pH

The pH was measured daily using a calibrated digital pH meter, where a water sample was collected in a beaker and the electrode was submerged until the reading stabilized (Nuwansi *et al.*, 2016) <sup>[16]</sup>.

### Dissolved Oxygen (DO) (mg/L)

DO was determined daily via the Winkler titrimetric method (APHA, 2005) <sup>[3]</sup>. Water was carefully collected in DO bottles to avoid air bubbles. The oxygen was fixed utilizing 1 ml of Winkler A (manganese sulphate) and 1 ml of Winkler B (alkaline potassium iodide). After a 5-minute floc settling period, the floc was dissolved with 1 ml of H<sub>2</sub>SO<sub>4</sub> and a 20 ml aliquot was titrated against an N/40 standard sodium thiosulphate solution using a starch indicator.

### Alkalinity (mg/L)

Alkalinity was estimated weekly via the titrimetric method (APHA, 2005) <sup>[3]</sup>. A 100 ml sample received 0.5 ml of phenolphthalein and was titrated against N/50 H<sub>2</sub>SO<sub>4</sub> until the pink color vanished. Subsequently, two drops of methyl orange were added and titration continued until the solution transitioned from yellow to orange.

### Hardness (mg/L)

Hardness was measured weekly using the titrimetric method

(APHA, 2005) <sup>[3]</sup>. A 100 ml sample was mixed with 1 ml of ammonia buffer and 3 drops of Eriochrome Black-T indicator. The resulting wine-red solution was titrated against a standard EDTA solution until the color shifted to blue.

### Ammonia

Ammonia concentration was determined using the phenate method (APHA, 2005) <sup>[3]</sup>. In 25 ml of the water sample, 1 ml of phenol solution, 1 ml of sodium nitroprusside solution and 2.5 ml of oxidizing solution (alkaline citrate and sodium hypochlorite) were added and mixed thoroughly. The mixture was covered, kept in the dark for 1 hour and absorbance was measured at 640 nm on a spectrophotometer. Sample concentrations were derived by comparison with a constructed standard curve.

### Nitrite (mg/L)

Nitrite concentration was determined weekly utilizing the colorimetric method (APHA, 2005) <sup>[3]</sup>. A 2 ml portion of a coloring reagent (containing phosphoric acid, sulfanilamide and N-(1-naphthyl)-ethylenediamine dihydrochloride) was added to a 50 ml water sample. Absorbance was then measured at 543 nm using a Shimadzu UV-1780 spectrophotometer and concentrations were calculated via a standard calibration curve.

### Nitrate (mg/L)

Nitrate was analyzed weekly using the ultraviolet spectrophotometric screening method (APHA, 2005) <sup>[3]</sup>. In a 50 ml sample, 1 ml of 1M HCl was added and absorbance was read at 220 nm and 275 nm using the spectrophotometer. The final absorbance attributable to nitrate was calculated by subtracting twice the 275 nm reading from the 220 nm reading.

### Growth parameters of the fish

Fish growth parameters were monitored and recorded weekly throughout the study.

### Absolute length gain (cm)

Total length (from mouth tip to caudal fin) was measured using a standard scale. Gain (cm) was calculated by subtracting the initial average length from the final average length (Jha and Barat, 2005) <sup>[11]</sup>.

### Absolute weight gain (g)

Individual fish mass was recorded using a digital analytical balance (iScale DM-3). Gain (g) was calculated by subtracting the initial average weight from the final average weight (Jha and Barat, 2005) <sup>[11]</sup>.

### Survival rate (%)

The percentage of surviving fish was determined by dividing the final number of fish by the initial number stocked, then multiplying by 100 (Jha and Barat, 2005) <sup>[11]</sup>.

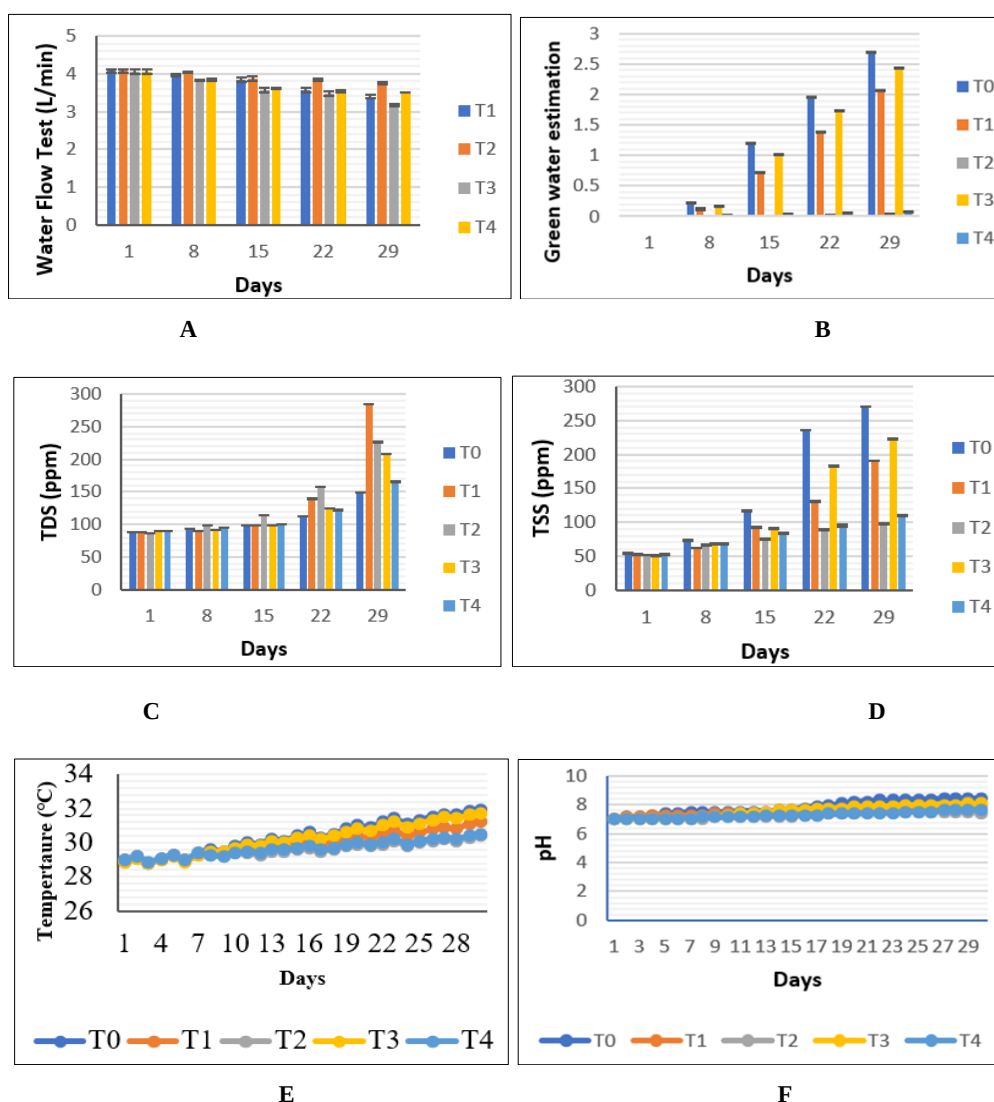
### Statistical analysis

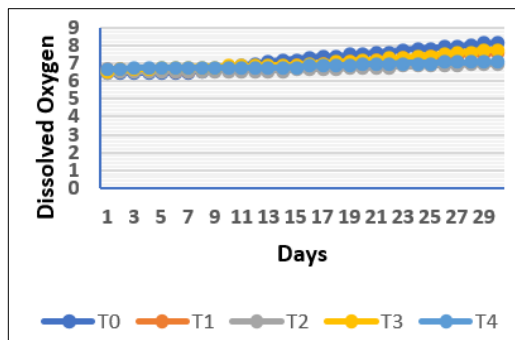
All collected data were statistically analyzed using One-way ANOVA to determine whether significant differences existed among the independent treatment groups. Data analysis was carried out using SPSS-16 software. Significance of differences was defined at ( $p < 0.05$ ).

## Results

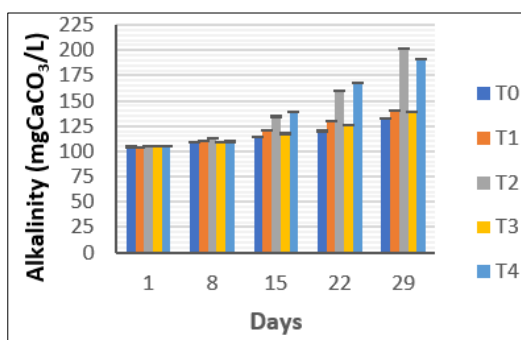
The bio-mechanical filtration systems demonstrated varying degrees of efficacy in maintaining comprehensive water parameters over the 30-day period. UV-integrated systems were remarkably successful at maintaining water clarity by suppressing algal blooms. Water flow test results showed the UV-integrated laterite gravel filter (T<sub>2</sub>) sustained the highest flow rate at  $3.75 \pm 0.03$  L/min, whereas the biofoam filter (T<sub>3</sub>) exhibited the lowest flow at  $3.17 \pm 0.02$  L/min. Green water estimation in the control (C) spiked to  $2.70 \pm 0.01$  millions of cells/ml, whereas the UV-integrated systems remained exceptionally clear, with T<sub>2</sub> at  $0.04 \pm 0.01$  and T<sub>4</sub> at  $0.08 \pm 0.01$  millions of cells/ml. Furthermore, T<sub>4</sub> showed the lowest accumulation of Total Dissolved Solids ( $165.47 \pm 0.46$  ppm) and T<sub>2</sub> demonstrated the lowest Total Suspended Solids ( $98 \pm 1.00$  ppm) among the filtered tanks. Regarding physicochemical parameters, water temperature remained highly stable across all setups, fluctuating safely between a minimum of  $28.84 \pm 0.12$  °C in T<sub>1</sub> and a maximum of  $31.97 \pm 0.16$  °C in (C). The pH exhibited a continuous rise across all setups; however, the unfiltered (C) reached a highly alkaline  $8.46 \pm 0.06$ , while the UV-integrated T<sub>2</sub> and T<sub>4</sub> maintained more stable final values of  $7.45 \pm 0.09$  and  $7.67 \pm 0.06$ , respectively. Dissolved oxygen (DO) increased across all tanks, peaking at  $8.17 \pm 0.06$  mg/L in C and  $7.77 \pm 0.06$  mg/L in T<sub>3</sub> due to higher photosynthetic algal activity, whereas T<sub>2</sub> and T<sub>4</sub> ended at a healthy  $6.97 \pm 0.06$  mg/L and  $7.08 \pm 0.06$  mg/L. Total

alkalinity and hardness also showed gradual upward trends over the trial, with alkalinity reaching  $201.24 \pm 0.06$  mg CaCO<sub>3</sub>/L in T<sub>2</sub> and hardness peaking at  $161 \pm 1.00$  mg CaCO<sub>3</sub>/L in T<sub>3</sub> by day 29. Nitrogenous compounds were effectively managed by the active filtration systems. Ammonia levels surged in the non-filtered control, reaching  $1.84 \pm 0.02$  mg/L. While standalone physical filters (T<sub>1</sub> and T<sub>3</sub>) experienced mid-trial ammonia spikes (peaking at  $1.60 \pm 0.01$  mg/L and  $1.53 \pm 0.01$  mg/L, respectively) before stabilizing, the UV-integrated biofoam filter (T<sub>4</sub>) maintained the most stable and lowest ammonia profile throughout the study, peaking at only  $0.22 \pm 0.01$  mg/L. Similarly, nitrite peaked on day 8 in the T<sub>1</sub> and T<sub>3</sub> setups ( $0.45 \pm 0.01$  mg/L and  $0.55 \pm 0.01$  mg/L) but was successfully reduced and maintained at a safe baseline of  $0.02 \pm 0.01$  mg/L across all filtered treatments by the end of the experiment. Nitrate concentrations progressively decreased in all tanks, with the UV-integrated T<sub>2</sub> and T<sub>4</sub> systems achieving the lowest final levels of  $0.48 \pm 0.01$  mg/L and  $0.55 \pm 0.01$  mg/L. Absolute growth parameters, including length and weight gain, displayed positive trajectories across all tanks. Final absolute lengths ranged from  $4.07 \pm 0.20$  cm to  $4.40 \pm 0.35$  cm and final weights reached between  $1.05 \pm 0.13$  g and  $1.40 \pm 0.16$  g, indicating that the filtration conditions supported normal physiological development. Furthermore, the survival rate remained at a perfect 100% for all treatments during the entire 30-day period.

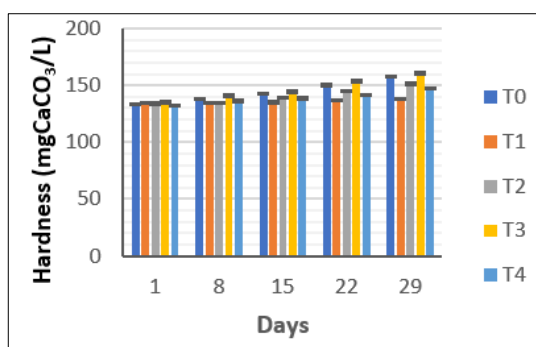




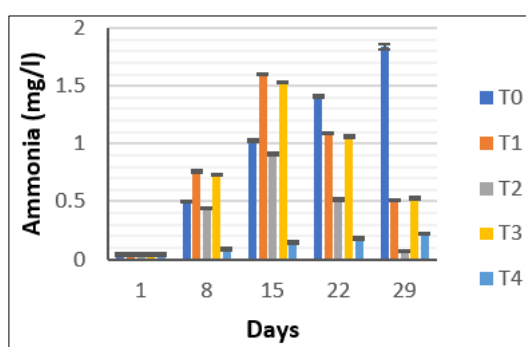
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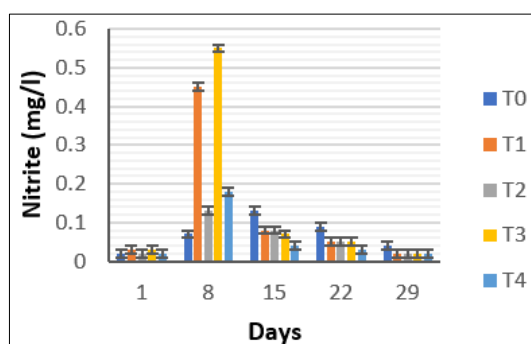
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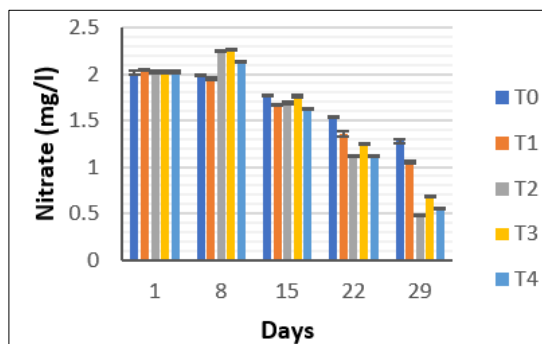
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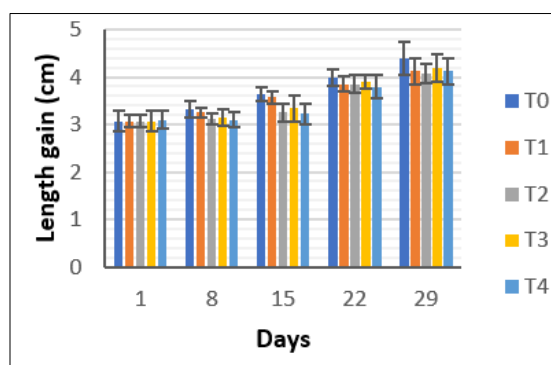
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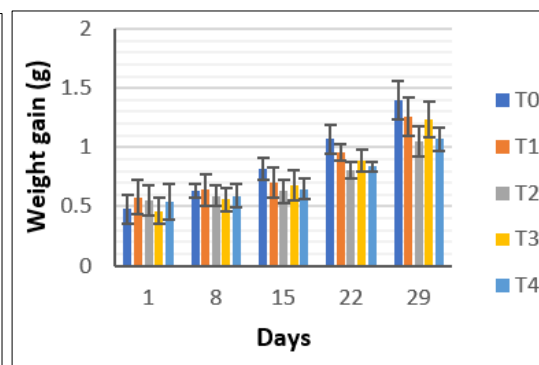
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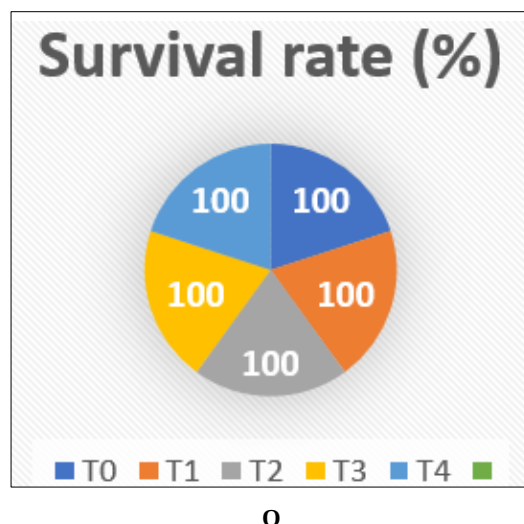


**Fig 2:** Filter efficacy parameters: (a) water flow rate, (b) green water estimation, (c) total dissolved solids, (d) total suspended solids, (e) temperature, (f) pH, (g) dissolved oxygen, (h) alkalinity, (i) hardness, (j) ammonia, (k) nitrite, (l) nitrate, (m) absolute length gain, (n) absolute weight gain and (o) survival rate, respectively

## Discussion

The 30-day experiment showed that UV-integrated filtration systems (T<sub>2</sub> and T<sub>4</sub>) significantly outperformed standalone physical media. Initial flow rates of approximately 4 L/min decreased by day 30; however, the gravel systems (T<sub>1</sub> and T<sub>2</sub>) sustained higher flows (3.39 and 3.75 L/min) than the biofoam setups due to reduced clogging, supporting Maucieri *et al.* (2018) [14], who noted that 0.8-8.0 L/min optimizes system performance. T<sub>4</sub> (Biofoam + UV) maintained the lowest Total Dissolved Solids (165.47 ppm), effectively preventing the mineral leaching observed in T<sub>1</sub> (285.1 ppm) and supporting Echiegu *et al.* (2018) on the importance of limiting dissolved solid accumulation. For Total Suspended Solids (TSS), the UV systems (T<sub>2</sub> and T<sub>4</sub>) ensured high water clarity (98 and 109 ppm), whereas the unfiltered control (C) experienced massive particulate accumulation (270.34 ppm), aligning with Ezhilmathi *et al.* (2022) [25].

Notably, UV-C integration in T<sub>2</sub> and T<sub>4</sub> nearly eliminated microalgae (0.04 and 0.08 million cells/mL), while (C) suffered severe blooms (2.70 million cells/mL) that standalone mechanical filters (T<sub>1</sub>, T<sub>3</sub>) could not arrest. This validates findings by Shnel *et al.* (2002) [20] and Summerfelt (2003) [21], regarding UV's efficacy in disrupting microalgal reproductive cycles.

Physicochemical parameters remained favorable: temperatures were stable (28.8 °C-31.9 °C) and dissolved oxygen stayed safely above 6.5 mg/L across all setups. Unchecked algal photosynthesis drove alkaline pH spikes in (C) and T<sub>3</sub> (8.46 and 8.07), whereas the UV systems maintained optimal pH levels. While (C) ammonia reached toxic concentrations (1.84 mg/L) and standalone filters exhibited mid-cycle spikes, T<sub>4</sub> maintained exceptional stability, with ammonia peaking at 0.22 mg/L and nitrite stabilizing at a safe 0.02 mg/L baseline. This confirms that optimized biofiltration securely manages nitrogenous wastes within strict limits, as demonstrated by Hussain *et al.* (2014) [9] and Endut *et al.* (2010) [6].

Ultimately, the Koi exhibited 100% survival, absolute length gains of 1.0-1.33 cm and weight gains of 0.50-0.92 g. Statistical uniformity in these growth parameters indicates that the integrated filtration setups provided stable, stress-

free environments highly conducive to normal physiological development.

## Conclusion

The present study successfully designed and evaluated a cost-effective, multi-stage filtration system for ornamental aquaculture. Based on the comprehensive water quality and efficacy assessments: Filtration setups integrating ultraviolet (UV) irradiation (T<sub>2</sub> and T<sub>4</sub>) exhibited unparalleled efficiency in mitigating hazardous parameters, specifically Total Suspended Solids (TSS), ammonia and microalgal green water blooms. The synergistic combination of highly porous biofoam sponge with continuous UV sterilization (T<sub>4</sub>) proved to be the most optimal configuration for stabilizing Total Dissolved Solids (TDS) while preventing toxic nitrogenous spikes. Standalone mechanical filtration is insufficient for managing high-density phytoplankton. UV sterilization is absolutely essential for disrupting algal reproductive cycles and preventing the severe pH fluctuations associated with green water outbreaks. These findings hold significant practical implications for the aquaculture industry. Utilizing affordable, locally sourced materials in tandem with UV technology offers a scalable, sustainable and highly effective water management strategy. This model encourages future entrepreneurial innovation in the design of efficient bio-mechanical filters for intensive ornamental fish cultivation.

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