

## Effect of feeding frequency and seasonal variation on water quality and growth performance of Nile tilapia (*Oreochromis niloticus*)

### Abstract

The principal challenge in intensive tilapia growing is achieving an appropriate combination between environmental sustainability and nutritional input. The study was a 120-day experiment that compared feeding frequency, once per day (T<sub>1</sub>), twice per day (T<sub>2</sub>) and thrice per day (T<sub>3</sub>) in combination with seasonal fluctuation (monsoon vs post-monsoon) on ecological stability and growth performance of *Oreochromis niloticus*. Though higher feeding rates are often linked with greater biomass, the thrice-a-day regime (T<sub>3</sub>) caused a metabolic bottleneck which led to the highest ammonia levels (0.0567mg/L) and nitrite levels that were accompanied with significantly lower dissolved oxygen. On the other hand, T<sub>2</sub> was seen as the most biologically favored, and it had better final body weights (220.93 gm), survival rates (91.00%), and total production (40.67 kg/dec) compared to both T<sub>1</sub> and T<sub>3</sub> with statistical significance ( $p < 0.05$ ). Statistical results obtained showed that over feeding enhances organic breakdown and respiration of microbes, thus exceeding pond carrying capacity regardless of seasonal buffering. These results show that T<sub>2</sub> improves the rate of nutrient absorption without reducing water quality. To improve the economic effectiveness and environmental sustainability of tilapia culture in tropical ponds, a twice-daily feeding regimen is recommended.

**Keyword:** Intensive aquaculture, Pond ecosystem stability, Ammonia and nitrite dynamics, Dissolved oxygen fluctuation, Survival rate

### Introduction

The global aquaculture industry has witnessed a significant shift toward the intensification of Nile tilapia (*Oreochromis niloticus*) culture, driven by the species' remarkable growth rates, environmental plasticity, and high consumer demand (Emam et al., 2025; Rodriguez-Barreto et al., 2019). In some areas like in Bangladesh where livelihood and property of rural people heavily depend on aquaculture industry, the shift towards large scale to the high-input intensive animal protein production is central to the transformation of the industry (Dompheh et al., 2024). Nevertheless, this exacerbation creates essential issues related to environmental sustainability

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and optimization of resources. Feed management is the best factor during intensive pond systems; it is the most significant cost of operation and the source of metabolic waste (Tabrett et al., 2024). The best frequency of feeding is therefore very important as it determines the effectiveness of the nutrient assimilation process and avoids the excessive buildup of organic matter which cause unsafe water quality conditions (Salger et al., 2020).

The feeding regimes (metabolic load induced on the environment through feeding) along with seasonal climatic changes significantly affect the physicochemical stability of a pond ecosystem (Mramba & Kahindi, 2023). The feeding rate affects main characteristics like the concentration of dissolved oxygen (DO), pH, water transparency and toxic metabolites such as ammonia and nitrite. These dynamics become more nuanced in tropical climatic regions with defined seasonality, like monsoon and post-monsoon seasons (Sipaúba-Tavares et al., 2013). Monsoon season in Bangladesh induces large-scale hydrologic changes through the process of rainfall mediated aeration and surface mixing, changes that may amplify or reduce respiratory distress induced by high-frequency feeding. In contrast, post-monsoon they would permit the retention of higher nutrient concentrations coupled with changed microbial dynamics due to stability (Islam et al., 2015). Although the demand for tilapia as per their physiology has been widely reported, the specific association between feeding management and individual species' seasonal environmental factors needs to be scientifically studied to define sustainable managerial practices.

The primary objectives of this study were to comprehensively evaluate the synergistic impact of varying feeding frequencies and seasonal transitions on the dynamic fluctuations of critical water quality parameters in earthen pond systems and to identify the optimal feeding regime that maximizes the growth performance, survival rates, and total production yield of *Oreochromis niloticus* over a 120-day culture period. By synchronizing management practices with seasonal environmental carrying capacities, the purpose of this study is providing a scientific basis for improving tilapia aquaculture's biological efficiency and environmental resilience.

## **Method and materials**

### **Study Area and Period**

The study was conducted at Bhabokhali Union, Sadar Upazila under Mymensingh District, Bangladesh). The experiment spanned a duration of 120 days, from July to November 2025.

### **Experimental Design and Pond Management**

The experiment was conducted using a completely randomized design (CRD) consisting of three distinct feeding frequency treatments, with each treatment replicated thrice ( $n=3$ ). These treatments were defined as once-daily feeding ( $T_1$ ), twice-daily feeding ( $T_2$ ), and thrice-daily feeding ( $T_3$ ). The study utilized six rectangular earthen ponds, each covering an area of 20 decimals with an average depth of 1.2 m. To ensure experimental consistency, all ponds were standardized for basin configuration and bottom type. Water levels were strictly maintained at a minimum of 1 m throughout the study period, supplemented by both groundwater and natural rainfall. Before the commencement of the trial, each pond underwent manual cleaning, and all unwanted species were eradicated through thorough netting.

### **Stocking and Feeding Regime**

Nile tilapia (*Oreochromis niloticus*) fry was sourced from the Sotota Motso Khamar in Sadar, Mymensingh, and underwent a period of acclimatization prior to stocking. Following this, fingerlings with a mean length of 6.5 cm and a mean weight of 6 g were stocked in the experimental ponds at a density of 200 fish per decimal. To support optimal growth and minimize waste, the feeding rate was systematically adjusted monthly according to the percentage of body weight (BW). The feeding schedule was initiated at 20% BW during the first month, followed by reductions to 15% BW in the second month, 10% BW in the third month, and finally 5% BW during the fourth month of the culture period.

### **Water Quality Monitoring**

Physicochemical parameters were monitored every seven days in the morning. Temperature, Dissolved Oxygen (DO), and pH were measured using a Portable Multiparameter (HANNA, HI 98194 pH/EC/DO multiparameter). Transparency of pond water was measured by Secchi Disc. Nutrient concentrations, including Ammonia-nitrogen ( $\text{NH}_3\text{N}$ ), Nitrite-nitrogen ( $\text{NO}_2\text{N}$ ), were analyzed using a HACH spectrophotometer DR-1900 with appropriate reagents (NitraVer-6, NitriVer-3, and Nessler reagent) at Water Quality Laboratory of Bangladesh Fisheries Research Institute (BFRI), Mymensingh.

### **Growth Performance and Yield Parameters**

To monitor growth performance throughout the 120-day culture period, monthly sampling was performed by collecting 10% of the fish population from each pond using a seine net. The collected data were used to evaluate growth and yield efficiency based on several standard parameters. Weight gain was determined by subtracting the mean initial weight from the mean final weight of the harvested tilapia. The survival rate (%) was calculated as the ratio of the total number of fish harvested to the total number of fish originally stocked, expressed as a percentage. Finally, total production per unit area (kg/dec) was calculated by multiplying the total number of fish caught at harvest by their average final body weight.

### **Statistical Analysis**

For the statistical analysis of the research data, R software was utilized to perform all computational tasks and data visualizations (Posit team, 2024). This open-source environment was specifically employed to execute the two-way Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference (HSD) tests to determine the impact of feeding frequencies and seasonal variations. Additionally, the software was used to generate the Pearson correlation matrix, which mapped the interrelationships between the physical and chemical water quality parameters.

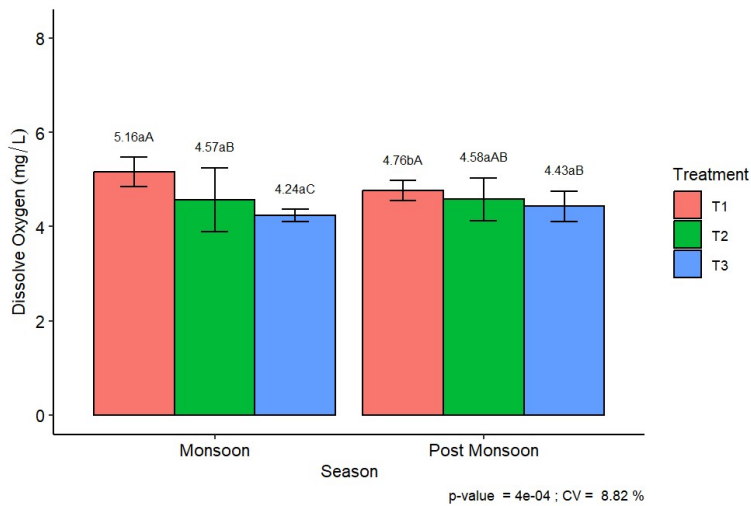
### **Result and Discussion**

The evaluation of growth indices and water quality indicators provides essential details on the biological efficiency and environmental stability of Nile tilapia (*Oreochromis niloticus*) culture under various management systems. This part describes how the seasons and feeding frequency interact to change the physicochemical dynamics of the pond ecosystem, which in fact influences fish productivity.

#### **Dissolve Oxygen**

Dissolved oxygen (DO) concentrations in the Nile tilapia culture system exhibited significant fluctuations influenced by both feeding frequency and seasonal transitions. During the monsoon, the highest DO was recorded in T<sub>1</sub> ( $5.16 \pm 0.32$  mg/L), which significantly decreased to  $4.57 \pm 0.68$  mg/L in T<sub>2</sub> and reached a minimum of  $4.24 \pm 0.13$  mg/L in T<sub>3</sub> (Figure 1). Post-monsoon values followed a similar declining trend from T<sub>1</sub> ( $4.76 \pm 0.22$  mg/L) to T<sub>3</sub> ( $4.43 \pm 0.33$  mg/L), although the disparity between T<sub>2</sub> and T<sub>3</sub> was less pronounced ( $p < 0.05$ ). The observed reduction in DO with increased feeding frequency is likely due to elevated biological oxygen

demand (BOD) resulting from the microbial decomposition of uneaten feed and increased metabolic waste (He et al., 2015). Additionally, higher monsoon DO levels may be attributed to enhanced atmospheric aeration and surface mixing during rainfall, which partially offset the respiratory demands of the intensified feeding regimes (Wan et al., 2022). Similar findings were also reported by Ayisi et al. (2021) and Wan et al. (2022), who conducted comparable studies and observed the same trend.



**Figure 1** Effects of seasonal variation (monsoon and post-monsoon) and feeding frequency (T<sub>1</sub>: once daily, T<sub>2</sub>: twice daily, T<sub>3</sub>: thrice daily) on dissolved oxygen (DO) concentrations (mg/L) in a Nile tilapia (*Oreochromis niloticus*) culture pond. Values are expressed as mean ± SD ( $p < 0.05$ ; CV = 8.82%).

### Air and water temperature

Environmental thermal profiles in the tilapia culture system were primarily governed by seasonal transitions rather than feeding interventions. Air temperatures were significantly higher during the monsoon (31.60°C) compared to the post-monsoon (28.04°C), a trend mirrored by water temperatures which reached 29.91°C and 26.50°C, respectively ( $p < 0.05$ ) (Table 1). While feeding frequencies (T<sub>1</sub>–T<sub>3</sub>) showed negligible impact on thermal stability, a significant interaction was noted for transparency, where higher feeding intensity reduced water clarity. The observed thermal patterns are fundamentally driven by seasonal solar radiation and atmospheric conditions characteristic of the monsoon cycle (Giddings et al., 2021). Unlike dissolved oxygen,

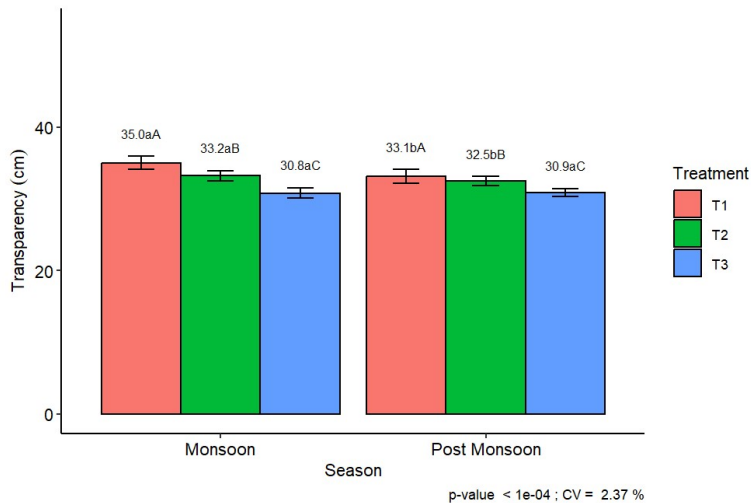
temperature remained independent of feeding-induced organic loading or microbial respiration, suggesting that the pond's thermal capacity was sufficient to buffer any localized metabolic heat generated by fish or decomposition processes across the different treatment groups.

**Table 1** Variations in air and water temperature (°C) under different feeding frequencies (T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub>) during monsoon and post-monsoon seasons in a Nile tilapia (*Oreochromis niloticus*) culture system.

		Air Temperature (°C)	Water Temperature (°C)
Environment	Monsoon	31.60a	29.91a
	Post Monsoon	28.04b	26.50b
Treatment	T1	30.24	28.61
	T2	30.33	28.61
	T3	30.15	28.61

### Water Transparency

Water transparency serves as a critical indicator of the physical and biological turbidity within the tilapia culture environment. During the monsoon, transparency was highest in T<sub>1</sub> ( $35.0 \pm 0.9$  cm) and significantly decreased as feeding frequency increased, reaching  $33.2 \pm 0.5$  cm in T<sub>2</sub> and a minimum of  $30.8 \pm 0.6$  cm in T<sub>3</sub> (Figure 2). Post-monsoon observations mirrored this trend, with values declining from  $33.1 \pm 0.8$  cm (T<sub>1</sub>) to  $30.9 \pm 0.4$  cm (T<sub>3</sub>), indicating that increased feeding intensity consistently reduced water clarity across both seasons. The significant reduction in transparency in T<sub>3</sub> is likely attributable to the accumulation of uneaten feed and metabolic wastes, which promote phytoplankton blooms and increase total suspended solids through organic matter decomposition (Song et al., 2026). Furthermore, the slightly higher transparency noted during the monsoon, particularly in T<sub>1</sub>, may result from the dilution effect of rainwater and lower initial nutrient concentrations compared to the post-monsoon period, where reduced water volume and stable temperatures often favor higher microbial and algal densities (Uddin et al., 2007).

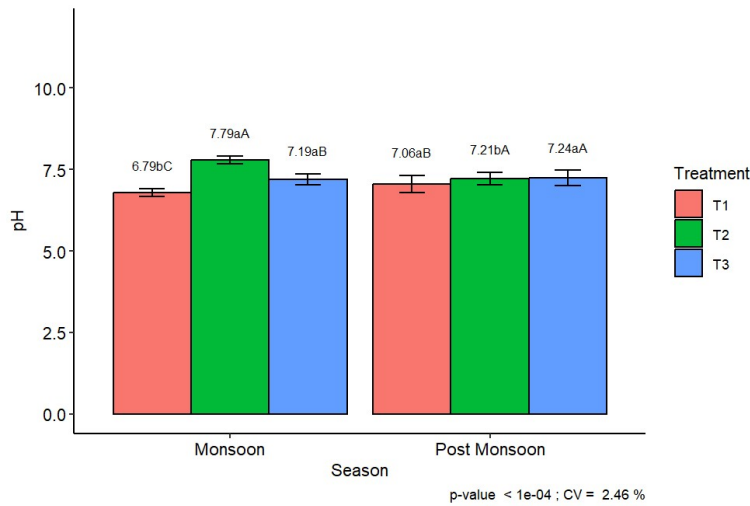


**Figure 2** Variations in water transparency (cm) influenced by seasonal conditions (monsoon and post-monsoon) and feeding frequencies (T<sub>1</sub>: once daily, T<sub>2</sub>: twice daily, T<sub>3</sub>: thrice daily) in a Nile tilapia (*Oreochromis niloticus*) culture pond. ( $p < 0.05$ ; CV = 2.37%)

### Pond Water pH

Water pH remains a critical chemical parameter that dictates the chemical speciation of nutrients and the physiological homeostasis of cultured Nile tilapia. During the monsoon, pH values exhibited significant fluctuations among treatments, with the lowest concentration recorded in T<sub>1</sub> ( $6.79 \pm 0.13$ ) and a peak observed in T<sub>2</sub> ( $7.79 \pm 0.1$ ), followed by  $7.19 \pm 0.17$  in T<sub>3</sub> (Figure 3). Conversely, the post-monsoon period demonstrated a more consistent and slightly alkaline trend across all groups, with values ranging from  $7.06 \pm 0.25$  in T<sub>1</sub> to  $7.24 \pm 0.22$  in T<sub>3</sub>. Notably, the T<sub>2</sub> treatment during the monsoon season represented the highest alkalinity observed in the study, while T<sub>1</sub> in the same season was significantly more acidic than its post-monsoon counterpart ( $p < 0.05$ ). These observed trends are primarily driven by the dynamics of the carbonate-bicarbonate buffering system and the metabolic balance between photosynthesis and respiration (Wurts & Durborow, 1992). The pH in monsoon T<sub>1</sub> is lower due to generation of high amount of carbon dioxide (CO<sub>2</sub>) by the decomposition of organic matter and microbial respiration which causes decrease in the pH value of water (Boyd, 1990). Thus, while the more alkaline trend in monsoon T<sub>2</sub> inputs points to increased productivity owing to the drawdown of CO<sub>2</sub> during photosynthesis driving up pH, in addition, monsoon seasonal rains can impact the buffering

capacity of the pond bath, probably leading to more pronounced pH fluctuations than we see in these data for post-monsoon stable conditions (Tucker & D'Abramo, 2008).

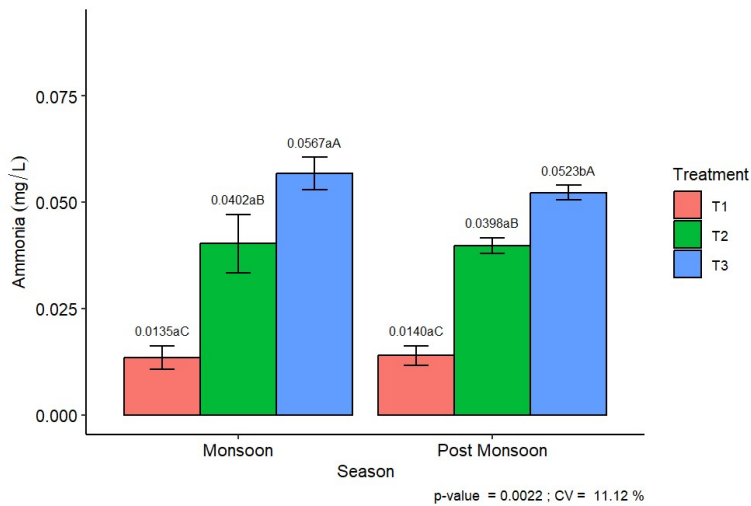


**Figure 3** Effects of seasonal variation and feeding frequency (T<sub>1</sub>: once daily, T<sub>2</sub>: twice daily, T<sub>3</sub>: thrice daily) on pH levels in a Nile tilapia (*Oreochromis niloticus*) culture pond ( $p < 1e-04$ ; CV = 2.46%).

### Ammonia

Ammonia concentration serves as a primary indicator of nitrogenous waste accumulation and toxicological stress within the intensive aquaculture environment (Jin et al., 2025; Sun et al., 2024). During the monsoon, ammonia levels increased significantly with feeding frequency, starting from a minimum in T<sub>1</sub> ( $0.0135 \pm 0.002$  mg/L), rising to  $0.0402 \pm 0.007$  mg/L in T<sub>2</sub>, and reaching a study-wide peak in T<sub>3</sub> ( $0.0567 \pm 0.004$  mg/L) (Figure 4). A remarkably similar trend was maintained during the post-monsoon period, with values recorded at  $0.0140 \pm 0.003$  mg/L,  $0.0398 \pm 0.002$  mg/L, and  $0.0523 \pm 0.002$  mg/L for T<sub>1</sub>, T<sub>2</sub>, and T<sub>3</sub> respectively. Statistically, T<sub>3</sub> exhibited significantly higher ammonia loads compared to T<sub>1</sub> and T<sub>2</sub> across both seasons ( $p < 0.05$ ), although the seasonal influence on ammonia within each specific treatment remained relatively marginal. The consistent increase in ammonia with feeding frequency is primarily driven by metabolic deamination of dietary proteins and subsequent excretion of unionized ammonia by tilapia (Lu et al., 2023). In parallel, higher feeding intensities in T<sub>2</sub> and T<sub>3</sub> generate greater quantities of uneaten feed and faeces, which undergo microbial decomposition and

release additional nitrogenous compounds into the water column (Torres-Beristain et al., 2006). The slightly higher peak observed during the monsoon in T3 may be linked to runoff-driven organic loading, as documented in seasonally dynamic warm-water systems (Alkhadher et al., 2025), although the overall stability of treatment-wise patterns suggests that feeding management remains the dominant driver of ammonia spikes in this culture system.

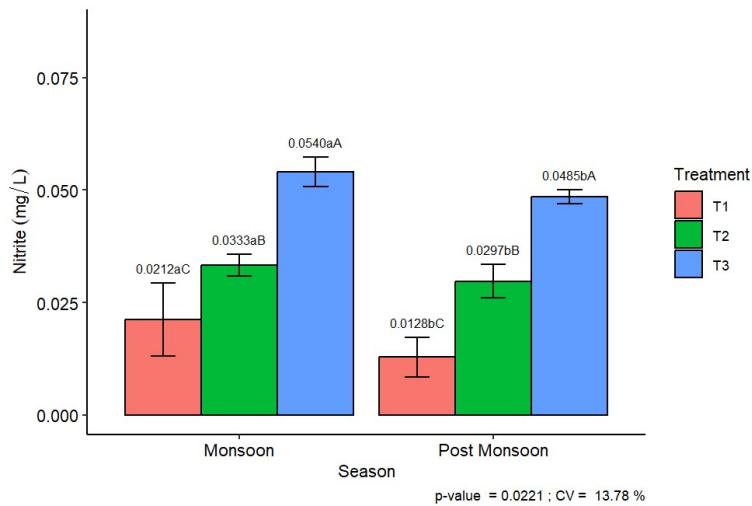


**Figure 4** Influence of seasonal variations and feeding frequencies (T<sub>1</sub>: once daily, T<sub>2</sub>: twice daily, T<sub>3</sub>: thrice daily) on ammonia concentrations in a Nile tilapia (*Oreochromis niloticus*) culture pond ( $p = 0.0022$ ; CV = 11.12%).

#### Nitrite-Nitrogen (NO<sub>2</sub><sup>-</sup>) Concentration

Nitrite concentrations in the aquaculture system serve as a vital indicator of the efficiency of the nitrification process and the overall nitrogenous load within the pond environment (Zhou et al., 2022). During the monsoon, nitrite levels increased progressively with feeding frequency, recorded at  $0.0212 \pm 0.008$  mg/L in T<sub>1</sub>,  $0.0333 \pm 0.002$  mg/L in T<sub>2</sub>, and peaking at  $0.0540 \pm 0.003$  mg/L in T<sub>3</sub> (Figure 5). A similar significant upward trend was observed during the post-monsoon period, with values rising from  $0.0128 \pm 0.004$  mg/L (T<sub>1</sub>) to  $0.0485 \pm 0.001$  mg/L (T<sub>3</sub>). Notably, T<sub>3</sub> maintained the highest nitrite levels across both seasons, while the monsoon period generally exhibited higher concentrations compared to the post-monsoon within each treatment ( $p < 0.05$ ), consistent with reports of elevated reactive nitrogen under warmer, high-loading conditions.

This marked increase in nitrite with feeding intensity is plausibly linked to the incomplete oxidation of ammonia originating from the decomposition of uneaten feed and fish metabolic waste, particularly when organic and ammonia inputs approach or exceed the functional capacity of nitrifying consortia (Effendi et al., 2020). Under such conditions, higher feed inputs in T<sub>2</sub> and T<sub>3</sub> can transiently overwhelm nitrite-oxidizing bacteria, leading to the accumulation of nitrite as an intermediate product. Furthermore, elevated monsoon levels may reflect increased organic runoff and higher temperatures, which accelerate early mineralization and ammonium oxidation, whereas the more hydrologically stable post-monsoon period favours slightly more efficient completion of nitrification to nitrate (Zhou et al., 2022).

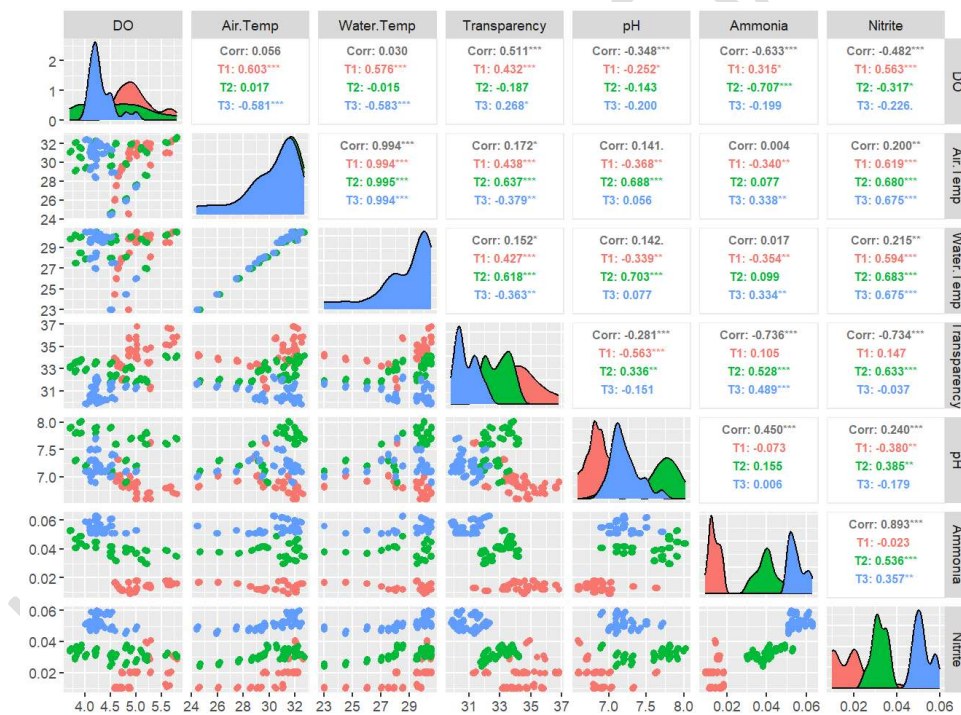


**Figure 5** Seasonal and feeding frequency-dependent variations in nitrite (NO<sub>2</sub><sup>-</sup>) concentrations in a Nile tilapia (*Oreochromis niloticus*) aquaculture pond (p = 0.0221; CV = 13.78%).

### Inter-parameter Correlation Analysis

The complex interactions between physicochemical variables in the aquaculture pond reveal how feeding management and seasonal shifts co-regulate the culture environment (Jiang et al., 2021). Statistical analysis showed that dissolved oxygen (DO) was negatively correlated with ammonia ( $r = -0.633$ ) and nitrite ( $r = -0.482$ ), while showing a strong positive relationship with transparency ( $r = 0.511$ ) (Figure 6) (Maurya et al., 2025). Specifically, in T<sub>3</sub>, DO exhibited a significant negative correlation with air and water temperatures ( $r = -0.581$  and  $-0.583$ , respectively), a trend not observed in T<sub>1</sub> (Jiang et al., 2021). Furthermore, ammonia and nitrite

displayed a very high positive correlation ( $r = 0.893$ ), especially under the intensive feeding of  $T_2$  and  $T_3$ . Transparency was inversely related to both nitrogenous wastes ( $r = -0.736$  for ammonia) and pH ( $r = -0.281$ ), highlighting the systemic impact of organic loading (Maurya et al., 2025). These patterns suggest that high feeding intensities drive a biological cascade where excess nutrients stimulate microbial respiration and phytoplankton growth, simultaneously reducing transparency and DO while elevating toxic nitrogenous metabolites. The stronger negative correlations between temperature and DO in high-frequency treatments indicate that thermal increases exacerbate the oxygen demand of both fish and decomposers when organic matter is abundant. This synergy between temperature and nutrient load highlights the precariousness of water quality stability during the monsoon, where high temperatures and intensive feeding jointly accelerate the depletion of vital oxygen reserves (Jiang et al., 2021).



**Figure 6** Pearson correlation matrix illustrating the interrelationships between physical and chemical water quality parameters in a Nile tilapia (*Oreochromis niloticus*) pond under varying feeding frequencies and seasonal conditions.

## Growth Performance and Production Metrics

Growth trajectories and total yield of Nile tilapia were significantly influenced by the optimization of daily feeding schedules within the pond environment, consistent with previous reports on the importance of feeding frequency for this species (Mabroke et al., 2021; Thongprajukaew et al., 2017). While initial weights remained uniform at 6 g across all groups, the T<sub>2</sub> treatment (twice-daily feeding) demonstrated superior performance, yielding a significantly higher final weight of 220 g and weight gain of 21 g compared to T<sub>1</sub> (200 g; 194 g) and T<sub>3</sub> (209 g; 203 g) (Table 2). Survival rates peaked at 91.00% in T<sub>2</sub>, whereas T<sub>1</sub> and T<sub>3</sub> exhibited significantly lower values of 84.33% and 82.67%, respectively ( $p < 0.05$ ). Consequently, total production in T<sub>2</sub> reached 40.67 kg/dec, outperforming both T<sub>1</sub> (32.67 kg/dec) and T<sub>3</sub> (34.67 kg/dec), indicating that twice-daily feeding provided the most effective balance for maximizing biomass, in line with findings that two daily meals are often sufficient for optimal growth of Nile tilapia juveniles (Cadorin et al., 2022; Mabroke et al., 2021). The enhanced productivity observed in T<sub>2</sub> is likely a result of efficient nutrient assimilation and minimized metabolic and environmental stress, whereas the performance decline in T<sub>3</sub> can be attributed to the deterioration in water quality, particularly the accumulation of ammonia and reduction in dissolved oxygen that commonly accompany high feeding intensities (Abd El-Hack et al., 2022). High-frequency feeding in T<sub>3</sub> likely promoted excessive organic matter decomposition and microbial respiration, creating a physiological bottleneck that impaired growth and survival. Conversely, the lower yield in T<sub>1</sub> suggests that once-daily feeding provides insufficient energy to support maximum growth potential, highlighting T<sub>2</sub> as an optimal compromise between nutrient supply and water-quality stability (Cadorin et al., 2022; Thongprajukaew et al., 2017).

**Table 2** Growth performance, survival rates, and total production yield of Nile tilapia (*Oreochromis niloticus*) under varying feeding frequencies over a 120-day culture period.

Treatment	Initial weight (gm)	Final weight (gm)	Weight gain (gm)	Survival (%)	Production (Kg/dec./120 days)
T1	6a	200b	194b	84.33b	32.67b
T2	6a	220a	214a	91.00a	40.67a
T3	6a	209b	203b	82.67b	34.67b
CV	3.46	2.12	2.11	2.68	3.92

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LSD	0.47	10.09	9.74	5.23	3.2
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## Conclusion

Feeding frequency is a primary driver of environmental stability and production efficiency in Nile tilapia culture. While intensification often favors frequent feeding, the thrice-daily regime (T<sub>3</sub>) exceeded the pond's carrying capacity, resulting in degraded water quality and diminished survival. Conversely, the twice-daily treatment (T<sub>2</sub>) emerged as the biological optimum, maximizing growth performance and total yield. Seasonal variations, particularly monsoon-driven aeration, further modulated these metabolic stressors. Consequently, a twice-daily feeding protocol is recommended to balance nutrient assimilation with ecosystem resilience. This approach optimizes the trade-off between fish growth and water quality maintenance, providing a scientifically grounded management strategy for sustainable intensive tilapia farming in tropical regions.

## Disclaimer (Artificial Intelligence)

The authors hereby declare that no generative AI technologies, such as Large Language Models (e.g., ChatGPT, Copilot) or text-to-image generators, have been used during the writing or editing of this manuscript.

## Competing Interests

The authors have declared that no competing interests exist.

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