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Research Article

Assessing Growth, Survival, and Physiological Responses of Gangetic Mystus (*Mystus cavasius*) to Incremental Salinity Levels: Implications for Aquaculture Management in a Changing Climate

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Climate change is causing saline intrusion, negatively affecting aquaculture productivity on a global scale. It is necessary to explore suitable species for coastal aquaculture in water with low to moderate salinity. Thus, the objective of the present study was to assess the impact of salinity on the growth performance, muscle composition, and blood parameters of a farmed fish, Gangetic mystus (*Mystus cavasius*). For this experiment, the fingerlings were raised in the aquarium for 60 days. Three distinct salinities, specifically 3, 6, and 9 parts per thousand (ppt), were employed for treatment 2 (T2), treatment 3 (T3), and treatment 4 (T4), whereas treatment 1 (T1) was referred to as the control with a salinity of 0 ppt. Increasing salinity did not have any influence on the water quality parameters. The survival rates were $97.5 \pm 0\%$, $96.25 \pm 1.25\%$, $92.5 \pm 2.5\%$, and $90 \pm 5\%$ for T1, T2, T3, and T4, respectively. The highest specific growth rate (SGR) and the percentage of weight gain (PWG) and the lowest food conversion ratio (FCR) were recorded at T1. T2 and T3 showed descending values for SGR and PWG and ascending values for FCR. Moreover, the body protein percentage reduced by about 2%, and lipids increased by 13% in T3 compared to T1. RBC and Hb exhibited an inverse relation with increasing salinity, whereas WBC and glucose displayed an opposite trend due to stressed conditions. Thus, the study implies that while salinity does hinder growth performance and compromise the immune system to some degree, *M. cavasius* is capable of enduring salinity levels of up to 6 ppt while maintaining a satisfactory survival rate.

Keywords: catfish; climate change; coastal zone; hematology; proximate composition

1. Introduction

Climate change is modifying the conditions of the aquatic environment for many aquatic species by altering the physico-chemical characteristics of water. Sea level rise and the intrusion of saltwater into coastal areas, which can also occur in freshwater regions, are significant consequences of climate change in tropical countries and deltas. The combination of salinity intrusion and waterlogging, along with frequent natural calamities, has profoundly affected the livelihoods of the residents in that specific region. This has had an extensive impact on food production, agricultural land use, and fish farming [1]. It is essential to adapt aquaculture practices to accommodate these changes in order to increase productivity and ensure sustainability in the context of ongoing climate change. The impacts could be effectively mitigated through the implementation of alternative aquaculture management strategies and the diversification of cultured species. In order to do so, it is necessary to identify appropriate freshwater species that can tolerate high levels of salinity by evaluating their ability to survive, their growth rate, and the physiological changes they undergo when exposed to different levels of salinity. Environmental changes pose a challenge to organisms in maintaining homeostasis. Salinity is a critical factor that could fluctuate significantly in coastal regions and affect the biology of aquatic species [2]. Some freshwater fish are known to have an inherent ability to withstand salinity up to a specific threshold. However, it is reasonable to expect that their physiological response may differ depending on the salinity levels. Furthermore, these factors may also have an impact on the proximate composition and blood parameters of the fish [3, 4].

Mystus cavasius (local name: 'gulsha tengra') is a member of the Bagridae family, and it is known for its ability to survive in challenging environments, including low oxygen levels, broad temperature variations, and poor water quality [5]. This species is frequently encountered in natural waterbodies of south Asian countries [6]. Studies have demonstrated that Silurid catfishes are capable of tolerating different salinity levels during different stages of growth [7, 8]. The Gangetic mystus (*M. cavasius*) is a type of Silurid catfish that is highly sought after by consumers due to its delicious taste and nutritional value [9]. Additionally, it has the potential to be used as an ornamental fish [10]. The average salinity values for most coastal surface waters in Bangladesh are below 6 ppt [11, 12]. Additionally, research has been conducted on the other species of the genus *Mystus* Viz. *Mystus vittatus* [13, 14], *Mystus gulio* [15–17], and *Mystus Tenggara* [18], with salinity ranging from 0 to 10 ppt. Furthermore, other potential siluriformes species for aquaculture, such as *Ompok bimaculatus* [19], *Heteropneustes fossilis* [1], *Clarias batrachus* [20], and *Pangasionodon hypopththalmas* [16] thrive in salinity ranging from 0 to 10 ppt. However, to date, no experiments have been conducted to investigate the impact of salinity on *Mystus cavasius*. In addition, two additional species of *Mystus*, namely, *M. gulio* and *M. vittatus*, are found in various parts of the Indian subcontinent, particularly in estuarine and tidal waters [21, 22].

M. cavasius, a freshwater variety, is a facultative air-breathing fish [23], which is widely believed to have the innate ability to thrive and grow in saline conditions. Therefore, this experiment has been postulated to investigate the culture potentiality of *M. cavasius* in saline water conditions by determining the survival, growth performance, proximate composition, and hematological parameters of *M. cavasius* at varying salinities. The outcomes of this study will establish a baseline for further studies and may facilitate the culture of potential salt-tolerant freshwater fish species in saline environments.

2. Materials and Methods

2.1. Experimental Site and Water Sample Collection. From July 2022 to June 2023, a study was conducted at the Department of Aquatic Environment and Resource Management, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh. The concentrated seawater was collected from the salt beds located at Moheshkhali in Cox's Bazar, Bangladesh. Subsequently, the solution was filtered through a 1-μm filter cartridge to remove the impurities and diluted with tap water to achieve the desired concentrations.

2.2. Fish Rearing and Feeding. A randomized design was followed in this experiment. The experiment utilized four treatments, consisting of a control (0 ppt) group and three different levels of salinity (3, 6, and 9 ppt) groups, with three replications each. For this experiment, 12 glass aquaria having dimensions of $75 \times 45 \times 45$ cm and a water-holding capacity of 40 L were used. The fries of *M. cavasius* were sourced from Sharnalata Agro-Fisheries Ltd., a commercial hatchery located in Mymensingh, Bangladesh. Acclimatization was performed for a week, and then 20 fish with an average weight ranging from 1.17 to 1.24 g were carefully weighed, chosen, and distributed in each aquarium to ensure uniform biomass across all tanks. This experiment utilized commercial feed, which comprised 36% protein, 7% fat, 25% carbohydrates, 2.5% crude fiber, 12% ash, 11% moisture, 2% calcium, and 1% phosphorus. This 0.8-mm floating pellet feed is nutritionally balanced, offering high protein levels along with a combination of fats, carbohydrates, and vital minerals, rendering it appropriate for aquatic species. The meal was provided to them at a frequency of 5% of their body weight (BW) two times daily, specifically in the morning (9:00 a.m.) and afternoon (5:00 p.m.). The quantity of feed requisite for fish was modified on a quarterly basis.

2.3. Water Quality Analysis. Different parameters of water quality were monitored every 15 days in all the aquaria. We used a portable pH meter from HANNA Instruments (model 'HI 98107′) to measure pH and temperature. For measuring dissolved oxygen (DO), we used the 'Lutron 5509 Portable Dissolved Oxygen Meter.' The ammonia level (in mg/L) was determined using a kit from HANNA Instruments (model 'HI3826' and 'HI3824') for saline water and freshwater, respectively. Salinity was checked daily using a portable digital refractometer from HANNA Instruments (model 'H196811').

2.4. Fish Sampling. Following the experiment, fish were anaesthetized using MS-222. BW was assessed using a digital balance (AND Ek-600i 0.01×600 g, Korea). A blood sample was taken from 5 fish from every individual treatment with the help of a syringe and an EDTA-containing tube (BD Microtainer, UK). The sample was stored for hematological examination. After obtaining blood samples from fish, the internal organs were taken out, and their carcasses were cleaned by using distilled water and subsequently kept at −20°C.

2.5. Growth Performance, Feed Efficiency, and Biological Indices. Fish weights were monitored quarterly till the completion of the experiment. During the sampling process, 5 randomly selected fish were measured from each tank. The weight gain (WG), percentage of weight gain (PWG), specific growth rate (SGR), food conversion ratio (FCR), and survival rate (SR) were determined using the formula mentioned below.

$$\begin{aligned}
\text{WG (g)} &= \text{Average final weight} - \text{average initial weight},\\
\text{PWG (\%)} &= \frac{\text{Average final weight} - \text{average initial weight}}{\text{Average initial weight}} \times 100,\\
\text{SGR (\% per day)} &= \frac{\ln \text{final weight} - \ln \text{initial weight}}{\text{No. of days}} \times 100,\\
\text{FCR} &= \frac{\text{Total feed consumption}}{\text{Weight gain of fish}},\\
\text{SR (\%)} &= \frac{\text{Number of total live fish}}{\text{Number of total fish stocked}} \times 100.
\end{aligned} \tag{1}$$

2.6. Analysis of Proximate Composition. Pooled samples of five fish were analyzed for carcass composition. The standard operating protocols of the Association of Official Analytical Chemists [24] were followed in order to ascertain the moisture, crude protein, crude lipid, and ash content. Every test was run through three times. After acid digestion, the nitrogen content was determined using the Kjeldahl method using an automated Kjeldahl System (UDK 152, VELP) to estimate the amount of crude protein. Using a solvent extractor (SER 148, VELP), the ether extraction method was used to quantify the crude lipid content. Following combustion, the amount of inorganic residue (ash) was measured at 550°C, and the amount of water present was determined by oven-drying of samples at 105°C for a full day.

2.7. Hematological and Biochemical Parameters. The Neubauer hemocytometer counting method [25] was used to determine the total count of red blood cells (RBCs) and white blood cells (WBCs) in this investigation. The levels of hemoglobin (Hb; g/dL) and glucose (Glu; mg/dL) were immediately examined using a digital meter equipped with separate glucose and hemoglobin strips. The particular meter used was the EasyMate Glu/Hb double monitoring system, model ET232, manufactured by Biotic in Taiwan [26].

2.8. Statistical Analysis. The data collected for this experiment were recorded and stored in a spreadsheet program on a computer. The Shapiro–Wilk test was used to check the normality of the data, and Mauchly's test of sphericity was conducted to check the assumption of sphericity. Where the assumption of sphericity was violated, the Greenhouse–Geisser or Huynh–Feldt correction was applied to adjust the degrees of freedom. A repeated measure analysis of variance (ANOVA) was used to identify any significant differences between the treatments. After that, the post hoc pairwise comparisons were performed using the Bonferroni correction to control ($p < 0.05$). The data were processed, analyzed, and visualized using SPSS statistics 10.0, R, and RStudio.

3. Results

3.1. Water Quality Parameters. The measured water quality metrics stayed within acceptable ranges (Figure 1) during the entire duration of the experiment. Detailed observations are presented in Supporting Table S1. The water pH level was in the range of 7.15–7.75, with no statistically significant differences observed across treatments ($p > 0.05$) (Figure 1). The highest pH was found in T4 during the third fortnight (7.75 ± 0.05), and the lowest pH was found in treatment T1 during the fourth fortnight (7.15 ± 0.35). Water temperature was within a very narrow range of 24.45°C–25.65°C; among all the treatments, the fluctuations were same ($p > 0.05$) (Figure 1). The maximum temperature was recorded in treatment T3 during the second fortnight (25.65 ± 0.45°C), while the lowest temperature was recorded in treatments T1 and T4 during the first and third fortnights (24.45 ± 0.05°C), respectively. DO levels ranged from 4.9 to 5.65 mgl^{-1}, with some slight decreases in treatments T3 and T4 that did not vary significantly ($p > 0.05$) (Figure 1). The highest DO level was observed in treatment T1 during the first fortnight (5.65 ± 0.05 mgl^{-1}). Water ammonia concentrations ranged from 0.0085 to 0.0175 mgl^{-1}, similar across the treatments ($p > 0.05$) (Figure 1). The highest ammonia level was found in treatment T4 during the fourth fortnight (0.0175 ± 0.002 mgl^{-1}), and the lowest was recorded in treatment T1 during the first fortnight (0.0085 ± 0.001 mgl^{-1}), respectively.

3.2. Growth Performance and Survivability of M. cavasius at Different Salinities. During the final sample, the final weight, weight gain, average daily gain, and SGR appeared to be the highest in the T1 treatment compared to the other

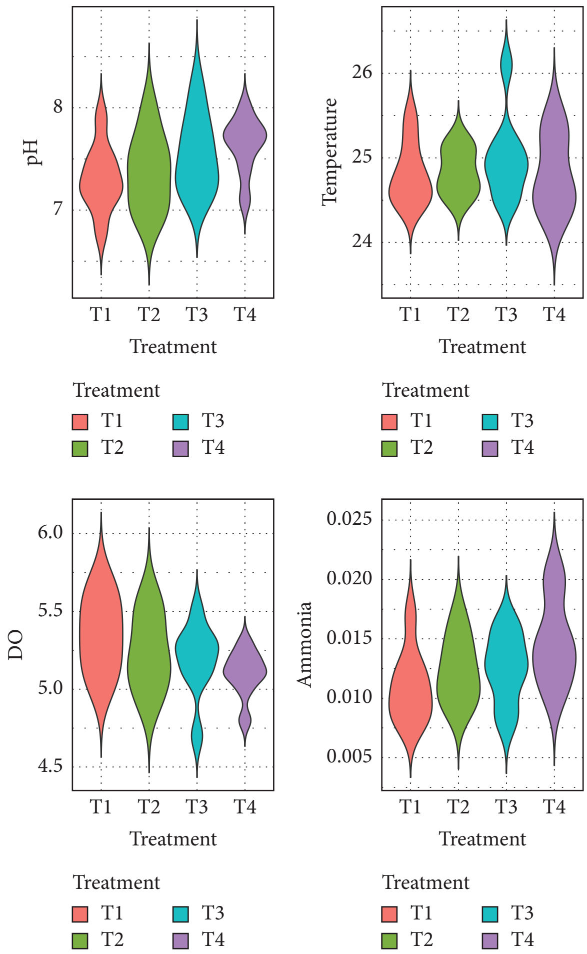

Figure 1: Violin plots demonstrating the range and density distribution of each water quality parameter.

treatments (Supporting Table S2). In this study, the average final weight gain of *M. cavasius* ranged from 3.03 ± 0.03 g to 3.30 ± 0.03 g (Supporting Table S2). The highest result was recorded in T1 (3.30 ± 0.03) and the lowest in T4 (3.03 ± 0.03), which differed significantly ($p < 0.05$). The SGR (% per day) of *M. cavasius* was higher in T1 (2.19 ± 0.01) followed by T2 and T3, which differed significantly ($p < 0.05$). Relative percent increment of weight gain was highest in T1 (273.08 ± 3.25%) and the lowest in T4 (251.40 ± 2.88%). Figure 2 demonstrated that the FCR value was in an increasing trend and significantly differed among T1, T2, T3, and T4, which were 1.94 ± 0.13, 2.09 ± 0.13, 2.29 ± 0.14, and 2.52 ± 0.19, respectively. The highest SR was found in T1 (97.5 ± 0%) followed by T2 (96.25 ± 1.25%), T3 (92.5 ± 2.5%), and T4 (90 ± 5%) (Supporting Table S2).

3.3. Proximate Composition. The table shows the average water, ash, fat, and crude protein values for *M. cavasius* raised at different salinities. Fish raised at 0 parts per thousand (ppt) salinity (T1) had a moisture content of 78.05 ± 0.02%, decreasing this value as salinity increased. Treatment 4 (T4) exhibited the lowest moisture content, measuring 77.22 ± 0.02%. The fish in T4 exhibited the lowest levels of crude protein and the highest levels of fat and ash compared to the fish in the other treatments (Table 1). The escalating stress caused by salinity resulted in a decline of approximately 2% in protein content and a rise of 13% in fat content in T3. In contrast, fish in T1 exhibited the highest protein content and the lowest lipid levels (Table 1).

3.4. Hematological and Stress Parameters. The blood parameters analyzed for *M. cavasius* included erythrocyte/RBC count, hemoglobin concentration (Hb), WBC (leukocyte/WBC), and glucose level as a stress indicator. The highest hemoglobin and RBC were observed in T1 (0 ppt), followed by T2, T3, and T4 (Figure 3). The hematological parameters showed a negative correlation for RBC ($r = -0.96$, $p < 0.01$) and hemoglobin ($r = -0.97$, $p < 0.01$) with salinity (Figure 4). The salinity stress led to an increase in both the WBC count and glucose level in T4 (Figure 3). The Pearson plot demonstrated a positive correlation for WBC ($r = 0.84$, $p < 0.01$) and glucose ($r = 0.91$, $p < 0.01$) with salinity (Figure 4).

4. Discussion

Extensive research to study salinity impacts in aquaculture is necessary due to its significant impact on the growth and survival of fish [27, 28]. Salinity stressors can cause hematological modifications and changes in muscle composition, which can affect the immune system physiologically [29, 30].

4.1. Water Quality Parameters. The assessment of water quality characteristics is crucial in fish farming as they are the primary elements that directly impact fish production. The water temperature is an important variable that has a direct impact on the growth of fish and other biological processes [31, 32]. In tropical fish culture, water temperatures outside the optimal range (25°C–32°C) reduce feed intake and growth [33, 34]. Reduced temperatures lead to a decline in the metabolic rate, resulting in a reduction in growth [35]. The suitable range of temperature for *Mystus* sp. is 25°C–28°C [36, 37]. The temperature, DO, and pH recorded in the present investigation fell within the ideal range for promoting fish growth. A recommended minimum DO concentration of 5 parts per million (ppm) is necessary to support fish production [38]. The catfish need a pH level between 6.0 and 8.0 for maximum growth and development [37, 39]. Ammonia's acceptable concentration for aquatic species is 0.01–0.02 mgl^{-1} [38, 40]. Increased salinities may affect water quality [41]. However, the various salinities considered in this study did not significantly change the water quality parameters. Only a lower DO and higher ammonia were observed in T4 and T3 than in T1 and T2. Saline water contains comparatively less DO than freshwater [42], and higher ammonia is correlated with a higher FCR value [43]. Based on the given data, it is evident that the water quality parameters in the present study were appropriate for the production of Gangetic mystus catfish (*M. cavasius*).

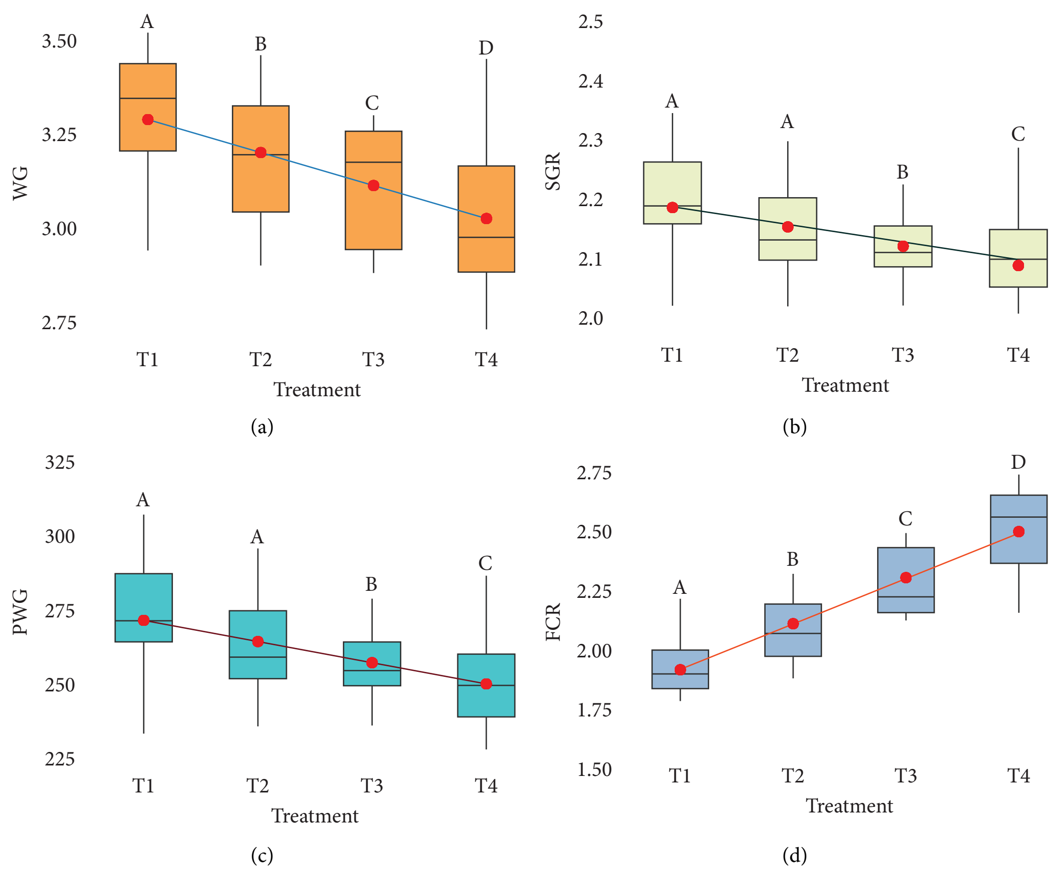

Figure 2: Box plots displaying growth parameters along with a linear regression line among treatments. The box represents the interquartile range (IQR: 25th to 75th percentile), with the median indicated by the horizontal line inside the box. Whiskers (error bars) extend to the 90th percentile above and the 10th percentile below. Different uppercase letters denote significant differences in mean values ($p < 0.05$) as determined by Tukey's multiple range test. (a) Box plot of WG by treatment, regression: WG = 3.3 + −0.12 *treatment. (b) Box plot of SGR by treatment, regression: SGR = 2.19 + −0.05 *treatment. (c) Box plot of PWG by treatment, regression: PWG = 273.09 + −10.95 *treatment. (d) Box plot of FCR by treatment, regression: FCR = 1.94 + 0.15 *treatment.

Table 1: Proximate composition of *M. cavasius* under different salinity conditions.

Proximate composition (%)	T1	T2	T3	T4
Moisture	78.05 ± 0.02^{a}	77.94 ± 0.03^{a}	77.71 ± 0.04^{b}	77.22 ± 0.02^{c}
Protein	15.84 ± 0.02^{a}	15.63 ± 0.02^{b}	15.53 ± 0.02^{c}	15.47 ± 0.02^{c}
Fat	2.17 ± 0.01^{a}	2.34 ± 0.02^{b}	2.45 ± 0.02^{c}	2.62 ± 0.02^{d}
Ash	3.14 ± 0.01^{a}	3.32 ± 0.01^{b}	3.59 ± 0.02^{c}	3.72 ± 0.03^{d}

^{a,b,c,d}Values in the same row having different superscripts are significantly different ($p < 0.05$).

4.2. Growth Performance. Fish growth involves material cycles and energy conversions that increase their size [44]. A conducive living environment minimizes the energy expended for ion and osmotic pressure regulation, promoting enhanced growth [45]. The current investigation has demonstrated that the salinity level has an impact on the growth of *M. cavasius*. This discovery aligns with previous studies conducted on *Clarias batrachus* [20], *Trichogaster fasciata* [46], *Pangasius hypophthalmus* [47], *Oreochromis niloticus* [48], *Cyprinus carpio* [49], and *Tilapia rendalli* [50]. The weight gain of *C. batrachus* at 0%, 4%, and 8% salinities was assessed to be 62.7%, 57.8%, and 54.5%, respectively, throughout a 90-day period [20]. Similarly, Arunachalam and Reddy [13] found that fish (*Mystus vittatus*) growth decreased as salinity levels increased. The minimum growth rate of 1.13 mg/fish × day was reported at a salinity level of 10 ppt. Fish raised in freshwater had greater SGRs than those raised in higher salinities (6 and 10 ppt). Asaduzzaman et al. [19] observed a negative relation of higher average weight gain, PWG, and SGR for *Ompok bimaculatus* with increasing salinity. Additionally, higher SGR and daily weight gain were observed in lower salinities, and it was stated that freshwater to lower salinities resulted in better conditions for the growth of *P. hypophthalmus* than higher salinities [47, 51]. Likewise, the weight gain rate of common carp (*C. carpio*) was highest in freshwater, which decreased and became negative at 10.5 ppt [49]. Xu et al. [52] found that the slope of the BW regression equation reached its maximum value at

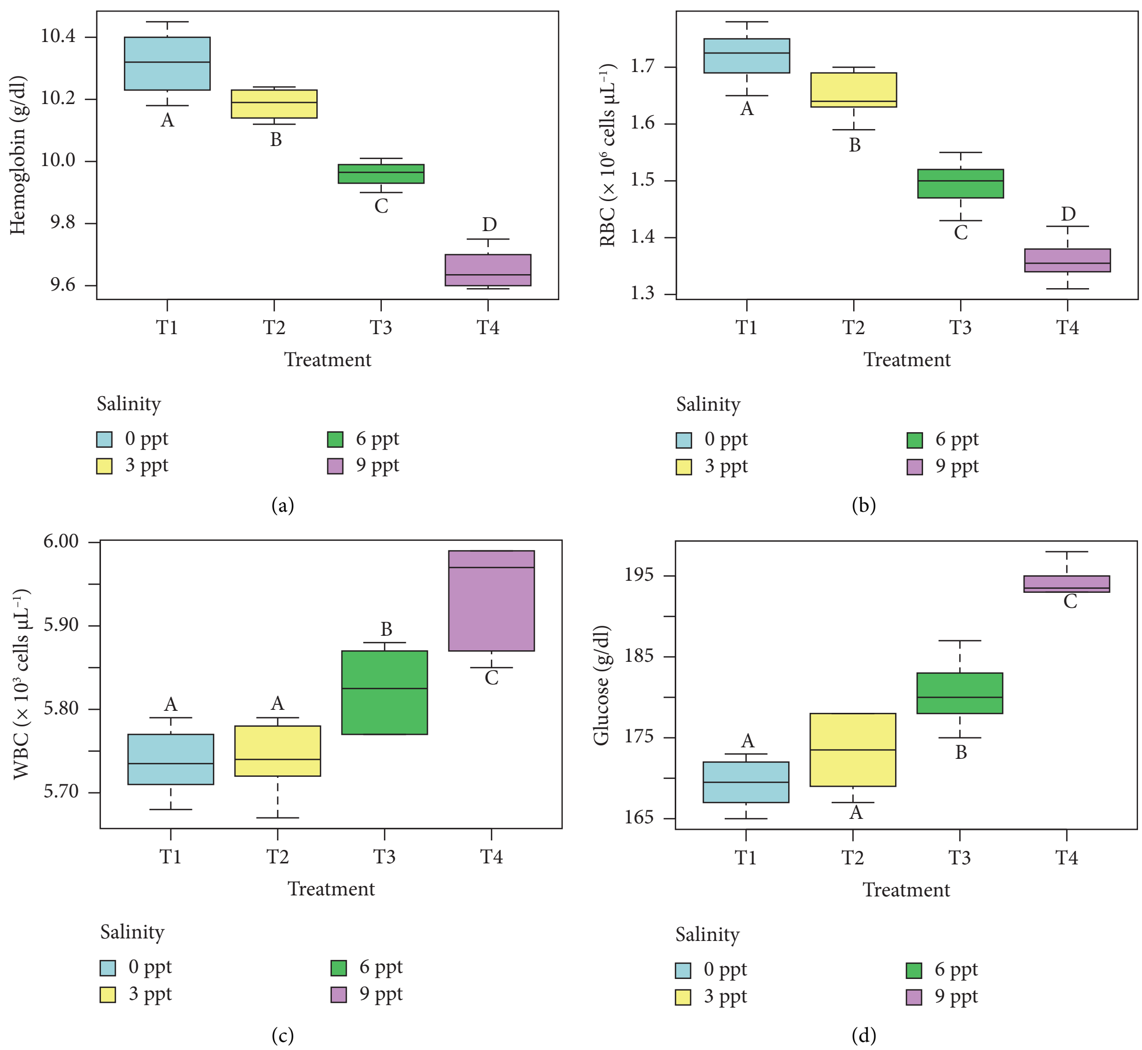

Figure 3: Box plots illustrating the hematological parameters of *M. cavasius* are presented for (a) hemoglobin, (b) red blood cells (RBC), (c) white blood cells (WBC), and (d) glucose across different treatments. In each box plot, the box represents the interquartile range (IQR: 25th to 75th percentile), the horizontal line within the box denotes the median, and the whiskers (error bars) extend to the 90th percentile above and the 10th percentile below. Significant differences in mean values ($p < 0.05$) are indicated by different uppercase letters, as determined by Tukey's multiple range test.

a salinity level of 5 ppt and then dropped as salinity levels exceeded 10. These findings indicate that the rate of BW gain was higher at lower salinity levels than higher salinity levels. Similar findings of better growth in lower salinity were also reported for *Lutjanus guttatus* [53], *O. niloticus* [30], *C. carpio* [54], *Rutilus frisii kutum* [55], and other freshwater species [56]. As salinity increases, the metabolic rate of freshwater fish decreases, leading to slower growth [22, 57] because more energy is needed for osmoregulation [58]. A significant rise in salinity can be fatal for fish [59]. Better growth of *M. cavasius* was observed in freshwater and up to 3 ppt. This could be because the salinity level of 3 ppt is near the isotonic threshold of *M. cavasius*. The fish allocate less energy towards osmotic pressure regulation, enabling a greater amount of energy to be allocated towards growth [60, 61].

The low SRs of *M. cavasius* at higher salinity levels are comparable to those reported in other studies such as *O. bimaculatus* [19], *Trichogaster fasciata* [46], *C. batrachus* [20], *P. hypophthalmus* [51, 62], *C. carpio* [54], and *H. fossilis* [1]. For instance, the authors in [20] found SRs of 96.7%, 93.3%, and 83.3% at 0, 4, and 8 ppt salinity, respectively. The SRs after 90 days were 100% for salinities of 0 and 3 ppt, 97% for a salinity of 6 ppt, and 70% for a salinity of 9 ppt [1]. In contrast, the low SR at any salinity is more likely due to fish perceiving osmotic stress [62].

Better FCRs were observed in freshwater to lower salinities for *M. vittatus* [13], *O. niloticus* [30], *T. fasciata* [46], *P. hypophthalmus* [51], and *Scatophagus argus* [52], which aligns with the finding of the present study. The FCR was lowest at 2.5 ppt salinity (1.11–1.38), followed by freshwater (1.48–1.53), and increased with higher salinity for *C. carpio*

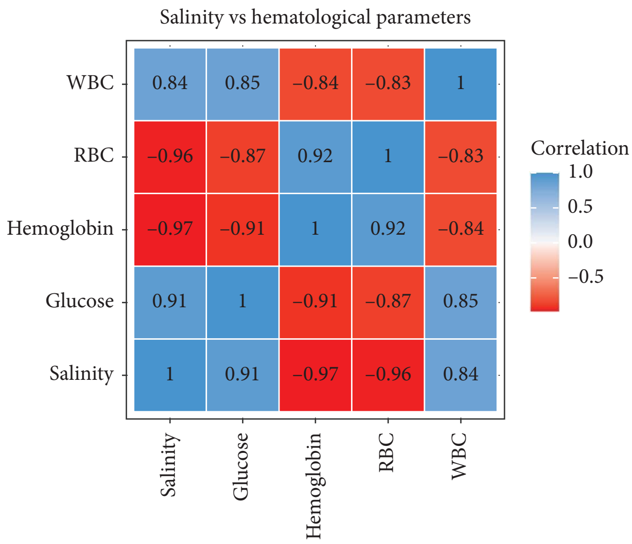

Figure 4: The correlation matrices between salinity and hematological parameters for *M. cavasius* are displayed, with R^2 values indicating the proportion of variance explained by the relationships between the variables. In the graph's upper right section, increasing shades of blue denote moderate ($p \le 0.05$) to strong correlations ($p < 0.01$). Conversely, increasing shades of red illustrate minor ($p \ge 0.05$) to negligible shared variance ($p > 0.05$).

[49]. Food conversion efficiency was best at 15.10% in fresh water and decreased to 3.07% at 10 ppt salinity for *M. vittatus* [13]. The maximum FCR value in higher salinities was found in *O. niloticus* [30], with values of 1.54 in freshwater and 2.13, 2.85, and 2.56 at salinities of 8, 16, and 24 ppt, respectively. Reducing the salinity of freshwater enhances the efficiency of energy utilization from food, leading to improved growth of freshwater fish compared to higher salinity conditions. Consequently, this results in a lower FCR value [58, 60].

4.3. Proximate Composition. Salinity has a profound effect on the physiological and metabolic functions of fish, resulting in alterations in the nutrient makeup of their muscles [30]. There have been a few initiatives to examine the changes in body composition in response to salinity for freshwater catfish [13, 47] in comparison to various marine species. Arunachalam and Reddy [13] observed that the salinity levels had a significant impact on the body composition of *M. vittatus*, similar to the findings of the present study. When the salinity level was elevated, there was a concurrent rise in fat content and a reduction in water content.

The inverse correlation between moisture content and salinity in *M. vittatus* is due to the fish's tendency to release more water to maintain homeostasis. This adaptation allows them to thrive in surroundings with higher salinity, which is a result of the fish's regulation of osmotic pressure [63]. The findings were found to be similar in the studies with Soiuy Mullet (*Liza haematocheila*) [64], Striped Mullet (*Mugil cephalus*) [65], and Striped Dwarf Catfish (*M. vittatus*) [13]. Zhou et al. [44] reported that when salinity increased, both the moisture content and crude protein levels declined. Nevertheless, they noted insignificant changes in the levels of crude fat and ash. In contrast, similar to the current work, Wu et al. [66] discovered that ash content rose in correlation with rising salinity levels. However, they noted an opposing pattern in the levels of lipids in farmed Nile tilapia (*O. niloticus*) of the GIFT strain. In addition, Mubarik et al. [67] also reported a corresponding decrease in crude protein. The findings of Gan et al. [30] regarding crude protein and ash content of *O. niloticus* exhibited a similar trend to the current study; however, they varied for moisture and lipid. In their study, Mandal et al. [47] reported that the lipid, protein, and ash content of *P. hypophthalmus* did not alter significantly across the treatments under varied salinity conditions. The observed inconsistencies in the aforementioned study with the present research may be attributed to variations in species, the interplay of feed, and other factors influencing the culture environment.

Studies have focused on examining the influence of salinity on the body composition of certain fish species. While previous research has suggested a hypothesis that salinity affects growth and body composition [13, 52, 68, 69], few studies have explored this relationship. That said, the findings of this research validated the hypothesis, demonstrating that salinity undeniably impacts the growth and body composition of fish. The study revealed that salinity had a significant impact on the growth performance of *M. cavasius*, as well as on the moisture level, crude protein, and crude lipid content of the fish ($p < 0.05$). While the impact on body composition was minimal, notable disparities in growth performance were noted between freshwater and saline environments. The study suggests that *M. cavasius* can be cultured in low salinity, especially in coastal water with a salinity level of up to 6 ppt.

4.4. Hematological and Stress Parameters. Hematological and biochemical indices offer comprehensive insights into fish growth, immune function, and stress levels [70, 71]. These indices can be utilized to observe the well-being of fish in relation to fluctuations in water quality, nutrition, disease, and treatment [72]. Suppression of hemoglobin and RBC by the salinity level was shown for Butter Catfish, *O. bimaculatus* [19], freshwater Gourami *T. fasciata* [46], and *C. carpio* [67]. For striped catfish (*P. hypophthalmus*), the study observed a substantial decrease in Hb levels and RBC counts at 8 and 12 ppt compared to 0 and 4 ppt. Conversely, the WBC count and glucose level exhibited the reverse pattern [51]. Ali et al. [73] observed a decrease in the average number of RBC in *O. niloticus* at salinity levels of 5 and 10 ppt compared to a baseline salinity of 0 ppt. Hemoglobin levels were determined to be lower in samples with 5 and 10 ppt compared to samples with 0 ppt.

The discovery of the current study in terms of the levels of hemoglobin and RBCs at different salinity levels is reinforced by the research conducted by Elarabany [74] and De Azevedo et al. [75]. A markedly reduced hemoglobin concentration was seen at salinities of 8 and 12 ppt compared to the control group at 0 ppt. In a similar vein, Bosisio et al. [76] noted a decline in Hb levels as salinity increased. Rauf & Arain [77, 78] revealed a comparable inverse relationship between hemoglobin concentration and salinity in *O. mossambicus* and *Tilapia guineensis*, respectively. Our observed results could be attributed to osmoregulatory dysfunction caused by elevated salinity levels, as shown by previous studies [79, 80]. The decrease in the quantity of RBCs may be caused by changes in osmotic pressure due to the leaking of ions from the plasma when fish are exposed to a hyperosmotic environment [74, 76]. In their study, Jezierska and Witeska [81] found that the RBC count in fish can be influenced by many stressors. However, they observed that this change is inconsistent in a certain direction; it can either increase or decrease. In addition, Witeska [82] asserted that factors such as age, sex, reproductive status, and ploidy play a significant role in determining the level of erythrocytes in fish.

This study found a statistically significant ($p < 0.05$) relationship between the salinity level and the quantity of WBCs. The findings demonstrated a positive correlation between salinity levels and the increase in the WBC count, aligning with the studies conducted by Elarabany [74] and De Azevedo et al. [75] but contradicting the findings of Bosisio, Rezende, and Barbieri [76]. Elarabany [74] demonstrated that the leukocyte counts of *Oreochromus niloticus* increased in the treatment with the highest salinity (12 gl^{-1}). Rainbow trout, *Oncorhynchus mykiss*, had elevated leukocyte counts when exposed to high salinity compared to those placed in freshwater [83] and silver barb, *Barbonymus gonionotus*, when placed in brackish water [84]. Higher salinities were found to cause elevated WBC counts also in *Notopterus notopterus* [85] and *O. niloticus* [73]. The higher WBC count may be attributed to the nonspecific immune response by the interaction of prolactin and cortisol resulting from the adapting behavior of fish in the changing salinity condition of the water [80, 85].

Blood glucose is a reliable indicator of the impact of aquatic environmental stress on fish [86, 87]. Researchers have suggested that glucose levels vary significantly in response to different salinities. In their studies, Jahan et al. [51] and Bosisio et al. [76] discovered that glucose levels surged as salinity increased for *P. hypophthalmus* and *O. niloticus*, respectively. Ahmmed et al. [1] observed a notable rise in blood glucose levels when the fish was tested at salinity up to 9 ppt (17.4 ± 0.83 mgg^{-1}) compared to those at 0 ppt (10.6 ± 0.65 mgg^{-1}) for stinging catfish (*H. fossilis*). Moreover, Uddin et al. [46] found a positive relationship between elevated salinity levels and increased blood glucose levels in *T. fasciata*. A study conducted by Sarma et al. [20] revealed that when exposed to a salinity level of 4%, *C. batrachus* exhibited a higher blood glucose level than the control group (0%), suggesting the presence of a hyperglycemic state. Stress in fish can trigger an initial reaction that involves the stimulation of neuro-hormones, resulting in physiological alterations referred to as 'secondary effects' [88, 89]. High plasma glucose levels are indicative of secondary stress responses [90]. Fiess et al. [2] noticed that as salinity levels increased, there was a notable rise in plasma glucose levels in *O. mossambicus*. They attributed this to the stress response and the greater energy required to maintain hydromineral balance at higher salinity.

Changes in hematological and biochemical parameters can be influenced by various factors, including life history, environmental stress, genetic composition, nutritional condition, and age groups within a species. Variations in the duration of the culture period may also contribute to irregular outcomes [91]. In this study, it can be concluded that environmental stress and salinity, in particular, are responsible for the above-mentioned changes in hematological and biochemical parameters.

5. Conclusion

Due to the intrusion of saltwater, a significant number of individuals globally are at risk of losing their primary source of income and sustenance. To address the increasing protein needs of the growing population, it is imperative to identify fish species that can be farmed, are tolerant to and can adapt to different levels of salinity, and are widely accepted by consumers. Considering all the outcomes of this study, it is realistic to assume that *M. cavasius* has an excellent culture potential in saline water up to 6 ppt with a $92.5 \pm 2.5\%$ SR, and there was only around 2% reduction of protein percentage and a 13% increase of lipid in proximate composition. Although based on the growth performance and blood parameters, it can be inferred that a salinity level of freshwater to 3 ppt is optimal for the thriving of this species. This research will make it easy to propagate the culture of *M. cavasius* by knowing the salinity level or its fluctuations in a salinity-intruded area. Hence, this study will provide advantages to fish farmers in the coastal area by assisting them with cultivating *M. cavasius* in a saline habitat, thereby improving their quality of life.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics Statement

Ethical approval for this study was obtained from The Ethical Committee, Department of Aquatic Environment and Resource Management, Faculty of Fisheries, Aquaculture and Marine Science, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

Md. Foysul Hossain: conceptualization, funding acquisition, methodology, data curation, formal analysis, writing – original draft, and writing – review and editing; Koushik Chakroborty and Rabina Akther Lima: methodology, formal analysis, writing – original draft, and writing – review and editing; Nafees Bin Reza, Sumiya Bhuyain, and Alim Hossen: data curation; Bhaskar Chandra Majumdar: methodology and writing – review and editing.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. *(Supporting Information)*

Supporting Table S1: Water quality parameters of different treatments; Supporting Table S2: Growth and feed utilization in *M. cavasius* under different salinity conditions.

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