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Comparative analysis of hematological characteristics of some freshwater fish species from wild and cultured environments

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Abstract

Hematology serves as a valuable diagnostic tool in aquaculture for assessing fish health, monitoring environmental conditions, and evaluating responses to nutrition and management practices. Therefore, this study aimed to compare the hematological characteristics of three economically significant fish species such as Gangetic mystus (*Mystus cavasius*), stinging catfish (*Heteropneustes fossilis*), and walking catfish (*Clarias batrachus*) obtained from wild and cultured habitats. Wild and cultured fish specimens were collected from the Turag river and a commercial fish hatchery, respectively. Blood samples were extracted from the caudal peduncle and stored in heparinized tubes for hematological examination. The results demonstrated that the cultivated environment showed increased dissolved oxygen, pH, and temperature, along with elevated electrical conductivity, whereas the wild environment presented higher concentrations of nitrite and ammonia. Among the hematological parameters, no significant differences ($p > 0.05$) were observed in HCT and MCHC content between the wild and cultured fish. However, WBC and RBC varied significantly ($p < 0.05$) across all the species in both environments. Lym, Gra, Hb, and PLT counts in stinging catfish varied significantly between natural and cultured habitats. For Gangetic mystus, Lym, MCV, and MCH differed significantly ($p < 0.05$) while, walking catfish exhibited insignificant variations in terms of any hematological parameters except WBC and RBC. These findings underscore that hematological parameters are sensitive to environmental conditions and can serve as reliable indicators of fish health. The species-specific variations observed further suggest that different fish respond uniquely to wild and cultured environments, highlighting the importance of species-based assessments in environmental monitoring and aquaculture management.

Keywords: Cultured fish, hematology, immune response, water quality, wild fish

Introduction

Hematological parameters are essential markers of the fish's physiological, nutritional, and pathological condition, offering valuable information about their health and ability to adapt to environmental deviations. Evaluating these parameters is especially important in aquaculture, where maintaining optimal fish health and growth is critical to attaining sustainable production (Gabriel *et al*. 2004, Clauss *et al*. 2008). Variations in hematological profiles can reflect the impact of environmental factors, such as water quality, stocking density, and feeding regimes, as well as stressors associated with culture conditions. In the context of South Asian aquaculture, Gangetic mystus *(Mystus cavasius),* stinging catfish *(Heteropneustes fossilis)* and walking catfish *(Clarias batrachus)* hold substantial economic and ecological importance. These species are greatly valued due to their rich nutritional profile, ability to thrive in warm water conditions and substantial role in supporting the livelihoods of small-scale farmers. (Alam 2024). However, the physiological responses of these species, particularly hematological parameters, serve as effective tools for assessing fish health. Examining blood components like red blood cells, white blood cells, hematocrit, and hemoglobin levels offers valuable insights about the general health status of fish and serves as an effective tool for assessing their stress responses (Bristy *et al*. 2025). It is essential to recognize that hematological profiles are influenced by factors, including different environmental condition, feeding behavior, dietary composition, pollution, stress and management practices all of which should be taken into account for a precise assessment of fish health (Parrino *et al.* 2018 and Fazio 2019). The health and performance of cultured fish are affected by the management of key factors such as feeding practices, water quality, and stocking density (Aljehani *et al.* 2023), which critically influence their physiological and hematological parameters. Among these factors, nutrition, particularly the availability of

trace elements, significantly impacts on hematological parameters and growth (Lima *et al.* 2024). These effects highlight how aquaculture diets influence fish physiology differently from wild populations, underscoring the need of developing optimized feeding strategies and conducting comparative analyses to better understand physiological adaptations and responses to environmental stressors.

Comparing the hematological parameters of wild and cultured stocks is critical to understand the physiological and health impacts of different environments on fish. Wild fish inhabit environments with frequent and rapid fluctuations in conditions (Blewett *et al.* 2022), while cultured fish are reared in a well-managed system (Conte, 2004). Such comparisons aid in assessing stress levels, disease resistance, and overall health status between the two groups (Clauss *et al.* 2008). By identifying the physiological distinctions between wild and cultured stocks, researchers can contribute in conserving wild populations, enhancing aquaculture efficiency, and ensuring the long-term viability of economically important species (Hossain *et al.* 2012). These findings establish a foundation for monitoring fish health and formulating strategies to mitigate stress and improve resilience within aquaculture systems (Gabriel *et al.* 2004).

The present study aims to analyze and compare the hematological parameters of Gangetic mystus, stinging catfish and walking catfish from wild and cultured stocks. By investigating how environmental conditions affect these parameters, the research offers important insights into the species-specific physiological responses. The findings contribute to a broader understanding of fish health in varying environments and support the development of sustainable aquaculture practices. Additionally, the study establishes baseline hematological profiles for these species, providing reference data that can support future research in fish health monitoring and environmental impact assessments.

Materials and methods

Collection of fish sample: Wild fish samples were collected from the Turag river at Bhawal Mirzapur Point, Gazipur, Bangladesh on February 2024. Turag river (23°46′N, 90°20′E) is an upper tributary of the Buriganga river, that is one of Bangladesh's major waterways, originating from the Bangshi river. A variety of nets, including mesh and gill nets, were used to catch the fish. Data on species, length, and weight were recorded. Cultured fish samples were collected from Sharnalata Agro Fisheries Ltd., a commercial hatchery in Mymensingh, Bangladesh. Both wild and cultured fish were then transported with minimal handling to the Wet Laboratory of the Department of Aquaculture at Gazipur Agricultural University, Gazipur-1706, Bangladesh. Fish were disinfected with 0.1% $KMnO_4$ solution. The fish were handled carefully to lessen the stress. A digital electric balance (EK600i, Korea) weighed each specimen, and a centimeter scale was used to measure their overall length.

Blood sampling: Fishes were cold anesthetized using MS-222 (Tricaine methanesulfonate). For the hematological analysis, a total of 20 fish were randomly selected from each species, and blood samples were collected using heparinized syringes into EDTA (Ethylene Diamine Tetra Acetic Acid) tubes. The tubes were then carefully turned upside down and mixed gently.

Hematological analysis: A completely automatic hematology analyzer (Model DH36, Dymind Biotechnology, China) was used to examine the blood samples and determine hematological parameters like white blood cells (WBC), lymphocytes (Lym), granulocytes (Gra), red blood cells (RBC), hemoglobin (Hb), hematocrit (HCT), mean corpuscular volume (MCV), mean cell hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC), and platelet counts (PLT).

Statistical analysis: All data were carefully recorded and saved in a computer spreadsheet for analysis. Data for all parameters from both cultured and wild fish species were analyzed statistically using one-way analysis of variance (ANOVA) to compare the treatment means with Statistix 10 software (2013). Prior to statistical analysis, all data were tested for normality and homogeneity using Shapiro-Wilk test and Levene test, respectively. At $p < 0.05$, Tukey's post hoc test was performed to determine the significant differences among the treatments.

Results

Table 1 exhibits the weight and length of fishes used in this study. There were significant difference in length and weight of fishes from wild and culture for each species. Table 2 summarizes the water quality parameters recorded in both wild and cultured environments, highlighting the differences between the two environments. The cultured environment contained with higher dissolved oxygen (6.8 mg L^{-1}) and a more neutral pH (7.1). The wild environment had a slightly elevated nitrite (0.4 mg L^{-1}) and ammonia (0.6 mg L^{-1}) levels compared to the cultured system (0.1 mg L^{-1} for both parameters), while electrical conductivity was significantly higher in the cultured environment (1067 µS cm^{-1}). Temperature was slightly elevated in cultured environment (31.4 °C), and ammonia levels were similar in both environments.

Fig. 1 depicts the WBC count (×10^3µL^{-1}) of three fish comparing wild and cultured environments. WBC counts varied significantly ($p < 0.05$) between wild and cultured fish across all species. In walking catfish, the WBC count was higher in cultured individuals (113.56 × 10^3 µL^{-1}) than in wild counterpart (76.48 × 10^3 µL^{-1}). Conversely, stinging catfish exhibited a higher WBC count in wild specimens (61.14 × 10^3 µL^{-1}) compared to cultured ones (42.56 × 10^3 µL^{-1}). In Gangetic mystus, wild fish showed a significantly ($p < 0.05$) elevated WBC count (28.51 × 10^3 µL^{-1}) relative to cultured fish (5.39 × 10^3 µL^{-1}).

In terms of Fig. 2, it illustrates the red blood cell (RBC) counts (×10^6 µL^{-1}) for three fish under wild and cultured conditions. In walking catfish, the cultured group exhibited substantially higher RBC counts (2.96× 10^6µL^{-1}) than the wild group (2.51× 10^6 µL^{-1}). A similar pattern was observed in stinging catfish, where the cultured group showed significantly higher RBC counts (2.39 × 10^6 µL^{-1}) compared to the wild group (1.26 × 10^6 µL^{-1}). In contrast, for Gangetic mystus, no significant difference ($p > 0.05$) was observed between the wild and cultured groups. Among all the species, the cultured groups generally displayed higher or similar RBC counts compared to the wild groups, with noticeable variability observed in the cultured walking catfish and stinging catfish. In both walking catfish and stinging catfish, the cultured groups showed significantly higher RBC counts than their wild counterparts. However, for Gangetic mystus, no significant difference ($p > 0.05$) was observed.

Fig. 3 illustrates the hemoglobin (Hb) levels across the three fish species. Cultured species tended to have higher Hb levels than their wild counterparts. For walking catfish, the cultured group had a slightly higher hemoglobin concentration (17.23 g dL^{-1}) than the wild group (16.63 g dL^{-1}), though the difference was not statistically significant ($p > 0.05$). While for stinging catfish, the cultured group showed a significantly higher Hb concentration (14.67 g dL^{-1}) compared to the wild group (9.76 g dL^{-1}). Similarly,

Table 1. Standard length and body weight of wild and cultured fish species used in this study (Mean ± SD)

Species	Walking catfish		Stinging catfish		Gangetic mystus	
	Wild	Cultured	Wild	Cultured	Wild	Cultured
Average Standard Length (cm)	22.01 ± 0.20	19.55 ± 0.12	20.95 ± 0.12	18.58 ± 0.15	8.25± 0.10	8.89 ± 0.20
Average Weight (g)	44.02 ± 1.12	44.25 ± 1.09	43.12± 1.19	43.40 ± 1.16	8.0 ± 0.6	8.5 ± 0.50

Table 2. Comparative water quality parameters of wild and culture environment (Mean ± SD)

Water Quality Parameter	Wild	Culture
Dissolve oxygen (mg L^{-1})	4.02 ± 0.40	6.83 ± 0.03
pH	6.12 ± 0.74	7.11 ± 0.07
Nitrite (mg L^{-1})	0.41 ± 0.02	0.11 ± 0.01
Temperature (°C)	30.05 ± 0.03	31.41 ± 0.02
Electrical conductivity (EC, µS cm^{-1})	572.3 ± 11.7	1067.1 ± 14.4
Ammonia (mg L^{-1})	0.6 ± 0.03	0.1 ± 0.01

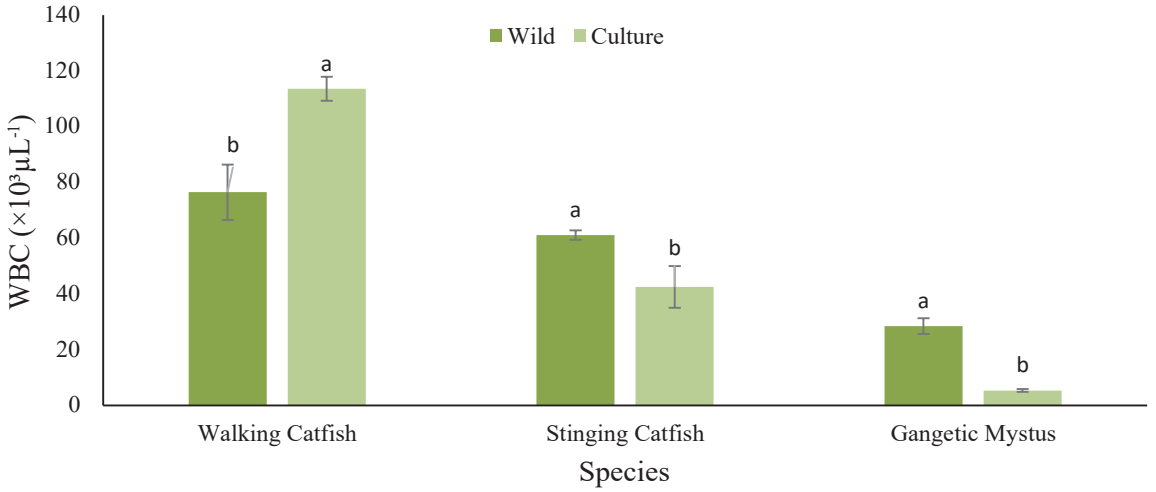


Figure 1. White blood cell count (×10³ µL⁻¹) of wild and cultured walking catfish, stinging catfish, and Gangetic mystus.

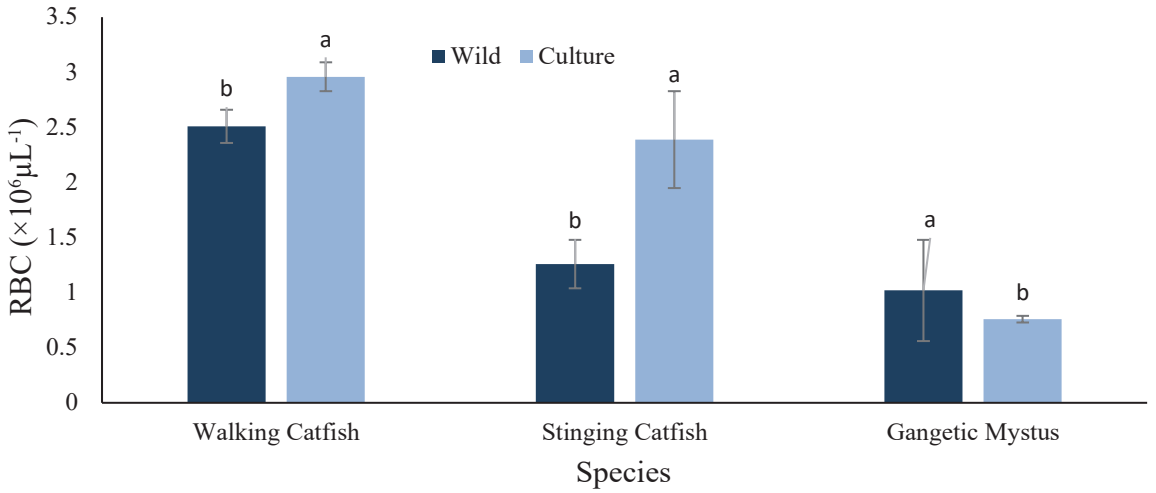


Figure 2. Red blood cell count (×10⁶ µL⁻¹) of wild and cultured walking catfish, stinging catfish and Gangetic mystus.

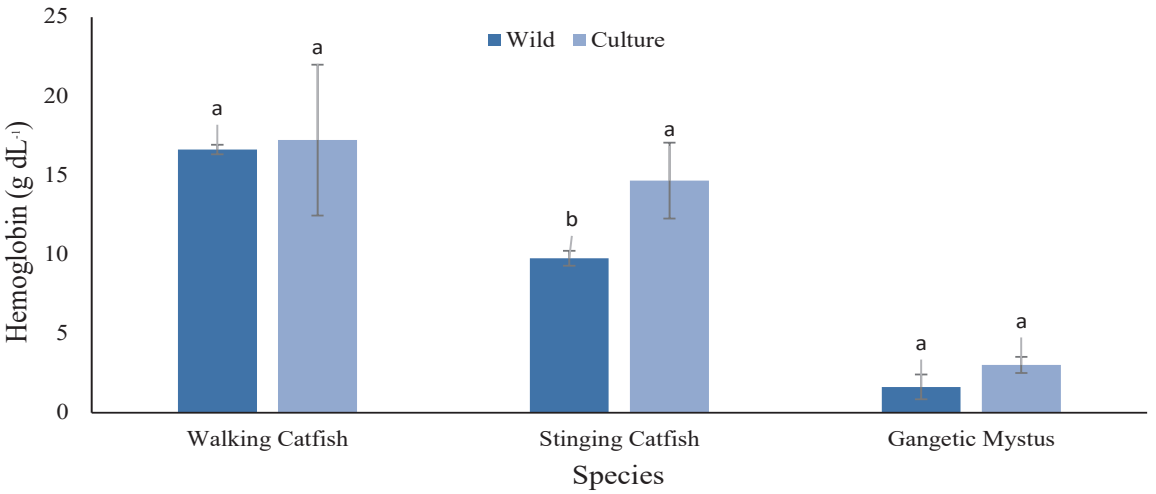


Figure 3. Hemoglobin (g dL⁻¹) of wild and cultured walking catfish, stinging catfish, and Gangetic mystus.

Table 3. Other hematological parameters of selected wild and cultured fish species (mean ± SD)

Parameters	Walking catfish		Stinging catfish		Gangetic mystus	
	Wild	Culture	Wild	Culture	Wild	Culture
Lym (%)	82.9 ± 1.85[a]	82.3 ± 5.11[a]	66.06 ± 0.72[b]	81.03 ± 4.33[a]	104.82 ±10.28[a]	85.33 ± 4.68[b]
Gra (%)	7.37 ± 1.90 [a]	5.33 ± 3.63 [a]	15.68 ± 0.61[a]	5.67 ± 4.15[b]	5.58 ± 7.10[a]	6.00 ± 0.51[a]
HCT (%)	46.87 ± 4.02[a]	44.5 ± 6.63[a]	39.89 ± 0.67[b]	51.63 ± 7.35[a]	9.39 ± 5.84[a]	8.73 ± 0.54[a]
MCV (fL)	179.53 ± 8.96[a]	150.13 ± 16.66[b]	223.86 ±3.56[a]	216.9 ± 10.24[a]	156.28 ± 7.25[a]	133.73 ± 3.95[b]
MCH (pg)	64.6 ± 1.15[a]	58.1 ± 13.79[a]	72.43 ± 2.44[a]	61.7 ± 7.09[a]	102.32 ± 25.29[a]	54.43 ± 2.44[b]
MCHC (g dL^{-1})	36.10 ± 2.46[a]	40.85 ± 6.52[a]	24.77 ± 0.47[a]	28.4 ± 2.25[a]	24.44 ± 16.54[b]	40.17 ± 1.72[a]
PLT ($\times 10^3$ µL-1)	3.43 ± 1.78[a]	3 ± 1.73[a]	4.92 ± 0.51[b]	9.67 ± 2.08[a]	17.76 ± 16.77[b]	32.67 ± 0.38[a]

*Lym, lymphocytes; Gra, granulocytes; HCT, hematocrit; MCV, mean corpuscular volume; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration; PLT, platelets. Values for cultured and wild fish of a species presented in a row that have different superscripts are significantly different from one another ($p < 0.05$= *significant).*

in Gangetic mystus cultured groups exhibited slightly higher Hb levels, but there was no statistically significant difference between cultured and wild groups. Gangetic mystus had the lowest hemoglobin levels among both wild and cultured groups.

In Table 3, rest of the hematological parameters including Lym, Gra, HCT, MCV, MCH, MCHC, and PLT counts of the three species are presented. The hematological profiles of Ganetic mystus*,* stinging catfish and walking catfish under wild and cultured conditions demonstrated significant differences ($p < 0.05$). Lymphocyte percentage (Lym %) was higher in wild Gangetic mystus (104.82 ± 10.28%) compared to cultured Gangetic mystus (85.33 ± 4.68%), whereas wild stinging catfish exhibited the lowest value (66.06 ± 0.72%) compared to cultured. Gra (%) was elevated in wild stinging catfish (15.68 ± 0.61%) compared to cultured stinging catfish (5.67 ± 4.15%). HCT (%) was higher in cultured stinging catfish (51.63 ± 7.35%) compared to in wild stinging catfish (39.89 ± 0.67%). Wild stinging catfish exhibited the highest MCV (223.86 ± 3.56 fL), and wild Gangetic mystus showed higher MCH (102.32 ± 25.29 pg) compared to their cultured counterparts. Wild Walking catfish resulted with the highest MCHC (36.1 ± 2.46 g dL^{-1}), while cultured Gangetic mystus had the highest PLT (32.67 ± 0.38×10^3 µL^{-1}), indicating notable species and condition-specific variations.

Discussion

According to Rehulka *et al.* (2004), hematological parameters can be affected by various factors, including water quality variables such as temperature, DO, EC, nitrite, and ammonia levels. one particular study revealed that the DO levels were notably lower in the wild compared to cultured environments, likely reflecting the higher oxygen concentrations maintained in cultured environments through effective aeration practices (Baker *et al.* 2018). A significant variation in pH levels was also observed, with cultured water tending to be more alkaline. Photosynthesis, respiration, and the organic matter decomposition influence pH values (Wetzel 2001).

Cultured systems had elevated RBC and Hb levels in walking catfish and stinging catfish. This was probably due to the presence of higher DO as hematological parameters might get significantly influenced by individual reactions to environmental changes (Puspaningsih *et al.* 2019).

EC was significantly higher in cultured water than in wild water, with this increase primarily attributed to higher concentrations of mineral salts and nutrients in cultured systems (Lindholm-Lehto 2023). Nitrite concentrations and ammonia levels were marginally elevated in the wild compared to cultured environments. This may have impaired erythropoiesis and immune function, as evidenced by lower RBC and WBC counts in stinging catfish (Esmaeili *et al*. 2017). However, Gangetic mystus

exhibited minimal hematological variation, suggesting species-specific resilience to environmental fluctuations (Kumar and Joy 2019).

According to Bahmani *et al.* (2001), examining blood indices is a highly effective method for assessing the health of animals, as they provide early and reliable indicators of metabolic disorders, nutrient deficiencies, and chronic stress before clinical symptoms appear. The comparative analysis of hematological parameters between wild and cultured populations of three fish species walking catfish, stinging catfish, and Gangetic mystus revealed significant physiological differences, highlighting the profound influence of environmental conditions on fish health.

The findings of this study indicated that environmental conditions significantly affect WBC counts among the three fish species studied. For walking catfish, the higher WBC count in cultured conditions could be attributed to high stocking density, confined environments, exposure to pathogens, and limited space which might stimulate the release of stress hormones like cortisol and immune-related chemicals such as cytokines and interleukins (Witeska *et al*. 2023). A higher white blood cell (WBC) count reflects a robust immune system, as WBCs play a central role in the body's innate immune defense (Ballarin *et al*. 2004). Conversely, stinging catfish exhibited a substantial decrease in WBC count in cultured environments compared to the wild, implying that prolonged exposure to suboptimal conditions in culture may lead to immune suppression (Barton 2002 and Urbinati *et al*. 2020). Gangetic mystus's low WBC counts in both wild and cultured populations reflected either an inherent species-specific trait or compromised health under cultured conditions (Kumar and Joy 2019). The significant differences in WBC counts between wild and cultured populations among the species underscore the importance of optimizing aquaculture practices to minimize stress and support immune health in cultured fish.

The observation of elevated RBC and Hb counts in cultured walking catfish and stinging catfish aligns with earlier findings by (Banu *et al.* 2020), where controlled diets and reduced environmental stressors in aquaculture systems promoted hematopoietic efficiency. (Habib *et al.* 2021) reported analogous results, where cultured silver carp, rohu, common carp, and grass carp exhibited higher RBC levels than their wild counterparts. This was attributed to enhanced oxygen transport to the tissues, which promoted improved growth and stimulated erythropoiesis under regulated aquaculture conditions (Esmaeili 2021). Consistent with these findings (Zahan *et al*. 2024) reported elevated RBC and Hb levels in cultured stinging catfish, linked to improved erythropoiesis and metabolic function resulting from optimized oxygenation and feed supplementation.

The reduced RBC and Hb levels in wild counterparts may be linked to elevated ammonia levels, lower temperatures, presence of microplastics and exposure to heavy metals (El-Bouhy *et al.* 2021).

The significant difference observed between wild and cultured fishes indicate how each species responds to changes in environmental conditions. It suggests that cultured environments, being more controlled, can influence fish physiology differently than wild habitats (Barton 2002 and Urbinati *et al*. 2020).

In contrast, Gangetic mystus showed higher RBC counts in the wild, which differs from the findings of Zhou *et al*. (2009), who reported higher RBC values in cultured pond loach (*Misgurnus anguillicaudatus)* compared to their wild counterparts. It suggested that this species either sustains comparable erythropoietic activity regardless of conditions or that environmental and dietary enhancements in aquaculture have a minimal effect on its RBC levels (Kumar and Joy 2019). Overall, these results highlighted the importance of environmental management in aquaculture for enhancing fish health and productivity, particularly for species such as walking catfish and stinging catfish. The variability in RBC counts, particularly observed in cultured walking catfish and stinging catfish, may reflect differences in individual physiological responses or variations in aquaculture practices. These findings emphasized the importance of species-specific management strategies to optimize health and promote productivity in aquaculture systems. The consistently lower Hb levels observed in Gangetic mystus, irrespective of the environment, may suggest a reduced oxygen requirement or an adaptation to habitats with low oxygen availability (Kumar and Joy 2019).

According to Sebastiao *et al.* (2011), the HCT percentage might serve as an effective indicator of a fish's ability to transport oxygen. This allowed the establishment of connections between the oxygen levels in their environment and the overall health of the fish. This study showed that the HCT values were consistently higher in wild part for walking catfish and Gangetic mystus, which might be crucial for their survival in natural habitats (Urbinati *et al*. 2020). The observed decline in HCT in cultured fish might indicate anemia (Barton 2002). In this study, the significant differences in MCV and MCH between wild and cultured fish further emphasized the physiological adaptations triggered by varying environmental conditions. The reduced MCV in cultured fish might reflect smaller erythrocytes which could impact their oxygen-carrying capacity (Pankhurst and Munday 2011) while increased MCV in the wild may suggest macrocytic anemia (Khoshbavar and Soltani 2016).

The Lym percentages in stinging catfish and Gangetic mystus species varied substantially between wild and cultured environments. The walking catfish maintained high Lym levels in both environments. In contrast, the stinging catfish showed elevated Lym levels in culture. This increase in lymphocytes is a common physiological response to infection and may also be influenced by the quality of the diet provided in captivity (Fagbenro *et al.* 2013 and Rashidian *et al.* 2020). A higher lymphocyte count enhances the immune system's capacity to clear pathogens from the bloodstream, which can be particularly beneficial during periods of stress or injury (Meuthen *et al.* 2020). The Gangetic mystus exhibited an anomalously high lymphocyte percentage in the wild, which could be an indication of a robust immune response, likely due to the natural habitat's diverse and stable conditions (Urbinati *et al*. 2020).

The increase in PLT counts in cultured fish, particularly in Gangetic mystus, suggested a physiological response to stress or potential micro-vascular damage, which could often be observed in fish subjected to stressful conditions (Kumar and Joy 2019). Elevated PLT levels might serve as an adaptive mechanism to mitigate potential injuries (Schreck 2010). Overall, these findings underscore the influence of environmental factors on fish immune responses, offering important insights for improving aquaculture management practices.

Conclusion

This study offers valuable insight into the hematological distinctions between wild and cultured populations of Gangetic mystus, stinging catfish, and walking catfish. The results demonstrate that environmental conditions significantly affect blood parameters, with notable, species-specific physiological responses. Cultured fish exhibited elevated RBC and Hb levels while, wild fish often displayed higher lymphocyte and granulocyte counts. The cultured environment showed better water quality, particularly in terms of higher dissolved oxygen, pH, and electrical conductivity, while the wild habitat had elevated nitrite and ammonia levels. These variations were reflected in the hematological profiles of the fish, with stinging catfish showing the most pronounced changes, indicating greater environmental sensitivity. In contrast, Gangetic mystus exhibited more stable hematological values across both environments, suggesting a degree of resilience. These findings highlight the influence of the wild and cultured origins on the health and physiological condition of the fish. Hence, recognizing these differences is essential for formulating effective aquaculture strategies that support fish health, improve growth performance, and promote sustainable aquaculture practices.

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