Research in

ISSN : P-2409-0603, E-2409-9325

AGRICULTURE, LIVESTOCK and FISHERIES

An Open Access Peer-Reviewed International Journal

Article Code: 533/2026/RALF
Article Type: Research Article

Res. Agric. Livest. Fish.
Vol. 13, No. 1, April 2026: 197-217.

Water quality, biometric indices and hematological investigation of farm-reared Thai silver barb, *Barbonymus gonionotus* in spring

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ARTICLE INFO

Received
10 February 2026

Revised
12 April 2026

Accepted
15 April 2026

Key words:

Water quality
Biometry
Hematology
Thai silver barb
Mymensingh

ABSTRACT

Studies were conducted to determine water quality, biometric indices, and hematological parameters of farm-reared Thai silver barb (*Barbonymus gonionotus*) in the pre-spring, spring, and post-spring seasons. A total of 90 fish (average: 73.16 ± 19.45 g) were randomly collected from Reliance Aqua Farm (Ukilbari, Boilor, Trishal) and M/s Char Bhai Hatchery and Fish Farm (Shomvuganj, Mymensingh sadar) located in Mymensingh district. Corresponding water samples were collected from the respective ponds, and water temperature, DO, pH, and NH_3 were determined immediately. The experiment was conducted in the Fish Disease Laboratory, Department of Aquaculture, Bangladesh Agricultural University. The bacterial loads of pond water (CFU/mL) were determined by ten-fold serial dilution in duplicates on Tryptone soya agar (TSA) after incubation at 37°C for 24 hrs. Hematological and hemato-biochemical analyses of blood samples *viz.,* total RBC, total WBC, hemoglobin, blood glucose level, ESR, PCV, MCH, MCV, MCHC, and DLC, were performed, and data were analyzed statistically. The length and weight of *B. gonionotus* were measured, and the following biometric indices were calculated and analyzed: LWR, condition factor (K), and VSI. Findings showed that DO and pH levels increased with increasing water temperature, but NH_3 remained constant throughout the study period. The highest average bacterial load was $10.58 \pm 0.1.42 \times 10^3$ CFU/mL in pre-spring, while the lowest average load was $6.7 \pm 0.65 \times 10^3$ CFU/mL in the post-spring season. ESR, MCV, glucose, total WBC, and granulocytes were found to be higher at low temperatures, and PCV, MCH, MCHC, Hb, RBC, and monocytes were recorded to be higher at high temperatures. The study showed negative allometric growth with lower VSI% in the pre-spring period, but positive allometric growth in the spring and post-spring periods. The findings revealed baseline hematobiochemical information on the farm-reared Thai silver barb in the spring season, which will be helpful for sustainable production and for reinforcing proper health management strategies at the farm level.

To cite this article: Tasnim S., M. H. Fahim, A. Rahman, R. Jannat, L. T. Mim, I. Ahmed, H. J. Hashi, N. Tabassum, K. T. Kubra, M. A. R. Faruk and T. Rahman, 2026. Water quality, biometric indices and hematological investigation of farm-reared Thai silver barb, *Barbonymus gonionotus* in spring. Res. Agric. Livest. Fish. 13(1): 197-217.

DOI: https://doi.org/10.3329/ralf.v13i1.89616

Published by: AgroAid Foundation

www.agroaid-bd.org/ralf, E-mail: editor.ralf@gmail.com

Introduction

Aquaculture has become a key pillar of global food security and is expected to remain the primary driver of growth in fisheries production, which is projected to reach 212 million tons by 2034 (FAO, 2025). Global fisheries and aquaculture production is expected to grow by 12% (+23 Mt) over the next decade, alongside a rise in per capita consumption of aquatic foods from 21.1 kg in 2022–2024 to 21.8 kg (FAO, 2025). This continued expansion underscores the growing reliance on aquaculture to meet global demand for animal protein. In Bangladesh, aquaculture plays a vital role in the economy, ranking as the fifth-largest producer globally and second in freshwater fish production, while contributing 2.53% to national GDP, 22.26% to agricultural GDP (DoF, 2024). Bangladesh possesses a rich diversity of freshwater fish, with approximately 260 indigenous and 12 exotic species (Chakraborty, 2021). The freshwater aquaculture sector of Bangladesh also plays a crucial role in meeting national protein demand and supporting rural livelihoods and it's dominated by Indian major carps alongside widely cultured exotic species such as tilapia, pangas, koi, and silver barb (DoF, 2023).

Among these, Thai silver barb (*Barbonymus gonionotus*), commonly known as Thai sarputi was introduced in 1977 and has become an important aquaculture species due to its fast growth, adaptability, and high market demand, making it particularly valuable in carp polyculture systems as a minor carp species (Hossen *et al.*, 2017; Rahman *et al.*, 2021). It is widely used as a minor carp in polyculture systems, where it efficiently utilizes underexploited ecological niches and enhances overall pond productivity (Hossain *et al.,* 2022). Its short culture period (3 to 4 months) and ability to thrive in seasonal ponds and rice fields further make it highly suitable for small- and medium-scale aquaculture (Jewel *et al.,* 2020; Saenphet *et al.,* 2025). The government of Bangladesh, together with Food and Agriculture Organization (FAO) and WorldFish, promotes minor carp farming through polyculture and raising them with major carps and tilapia to increase pond productivity (Belton and Little, 2011; FAO, 2022).

Given the sensitivity of cyprinid species to environmental fluctuations, water quality plays a critical role in regulating the growth, health, and overall performance of *B. gonionotus* (Ali and Mondol, 2022). Maintaining suitable levels of dissolved oxygen, temperature, pH, and nitrogenous wastes is essential for proper metabolism, immunity, and survival (Boyd and Tucker, 2012; Ebeling and Timmons, 2010). Biometric indices, particularly, the length-weight relationship (LWR) and condition factor (K) are also important tools for assessing growth, health, and productivity of minor carps such as *B. gonionotus*, *L. bata*, and *P. sophore* (Enawgaw *et al.,* 2024). The LWR provides insights into growth patterns and biomass estimation, while the condition factor reflects overall fish health and nutritional status (Sarkar *et al.,* 2013; Madhulika *et al.,* 2024). On the other hand, hematological parameters are reliable indicators of the physiological and health status of carps, including *L. rohita*, *C. catla*, *C. cirrhosus*, and *B. gonionotus*. Blood analysis helps assess oxygen transport, immune response, and stress conditions in aquaculture systems (Abdel-Tawwab *et al.*, 2019). Key parameters such as red blood cell (RBC), hemoglobin, and packed cell volume (PCV) reflect the oxygen-carrying capacity, while white blood cell (WBC) count indicates immune status and response to stress or infection (Ahmed *et al.*, 2020). Changes in indices such as mean corpuscular hemoglobin (MCH) and mean corpuscular hemoglobin concentration (MCHC) can signal anemia or physiological imbalance, and elevated glucose levels are commonly associated with stress (Satheeshkumar *et al.*, 2012). Overall, hematological profiling is an effective tool for monitoring fish health and ensuring better management practices (Docan *et al.*, 2018).

B. gonionotus is an important aquaculture species in Bangladesh, particularly in the Mymensingh region, due to its rapid growth and adaptability to diverse culture systems, including polyculture and semi-intensive practices (Ahammad *et al.*, 2009). However, during winter (December–February), low temperatures induce physiological stress, leading to reduced metabolic activity, suppressed immune function, and heightened disease susceptibility (Arifin *et al.*, 2017). Seasonal fluctuations in key water quality parameters, such as temperature, dissolved oxygen, and ammonia further influence fish health and growth performance (Zhang *et al.*, 2025). The present study assessed water quality, biometric growth, and hematological indices of farmed *B. gonionotus* during the spring season. Considering the economic significance of *B. gonionotus,* the findings will help to improve farm management practices during the winter–spring transition, enhance disease prevention strategies, and support the sustainable production under seasonal environmental challenges.

Materials and Methods

Sample Collection, Area and Duration

Farmed Thai silver barb, *B. gonionotus*, was selected as the experimental species to evaluate biometric indices, hematological parameters, and rearing water quality during the over-spring period. Fish samples were collected from two commercial aquaculture farms: Reliance Aqua Farm located at Ukilbari, Boilor, Trishal, Mymensingh (24.6368°N, 90.3681°E), and M/s Char Bhai Hatchery and Fish Farm at Shomvuganj, Mymensingh Sadar (24.6455°N, 90.4090°E) **(Table 1)**. Corresponding water samples were also collected from these sites. All the experimental analyses were conducted at the Fish Disease Laboratory, Department of Aquaculture, Bangladesh Agricultural University, Mymensingh (24.72291°N, 90.43077°E). The study duration was categorized into three distinct seasonal phases: pre-spring (February, 2025), spring (March, 2025), and post-spring (April, 2025).

Table 1. List of 2 farms according to the study period

Farm No.	Name of the farms	Season
F_1	M/s Char Bhai Hatchery and Fish Farm (Shomvuganj, Mymensingh)	Pre-spring
F_2	Reliance Aqua Farm (Ukilbari, Boilor, Trishal, Mymensingh).	(February)
F_1	M/s Char Bhai Hatchery and Fish Farm (Shomvuganj, Mymensingh)	Spring
F_2	Reliance Aqua Farm (Ukilbari, Boilor, Trishal, Mymensingh).	(March)
F_1	M/s Char Bhai Hatchery and Fish Farm (Shomvuganj, Mymensingh)	Post-spring
F_2	Reliance Aqua Farm (Ukilbari, Boilor, Trishal, Mymensingh).	(April)

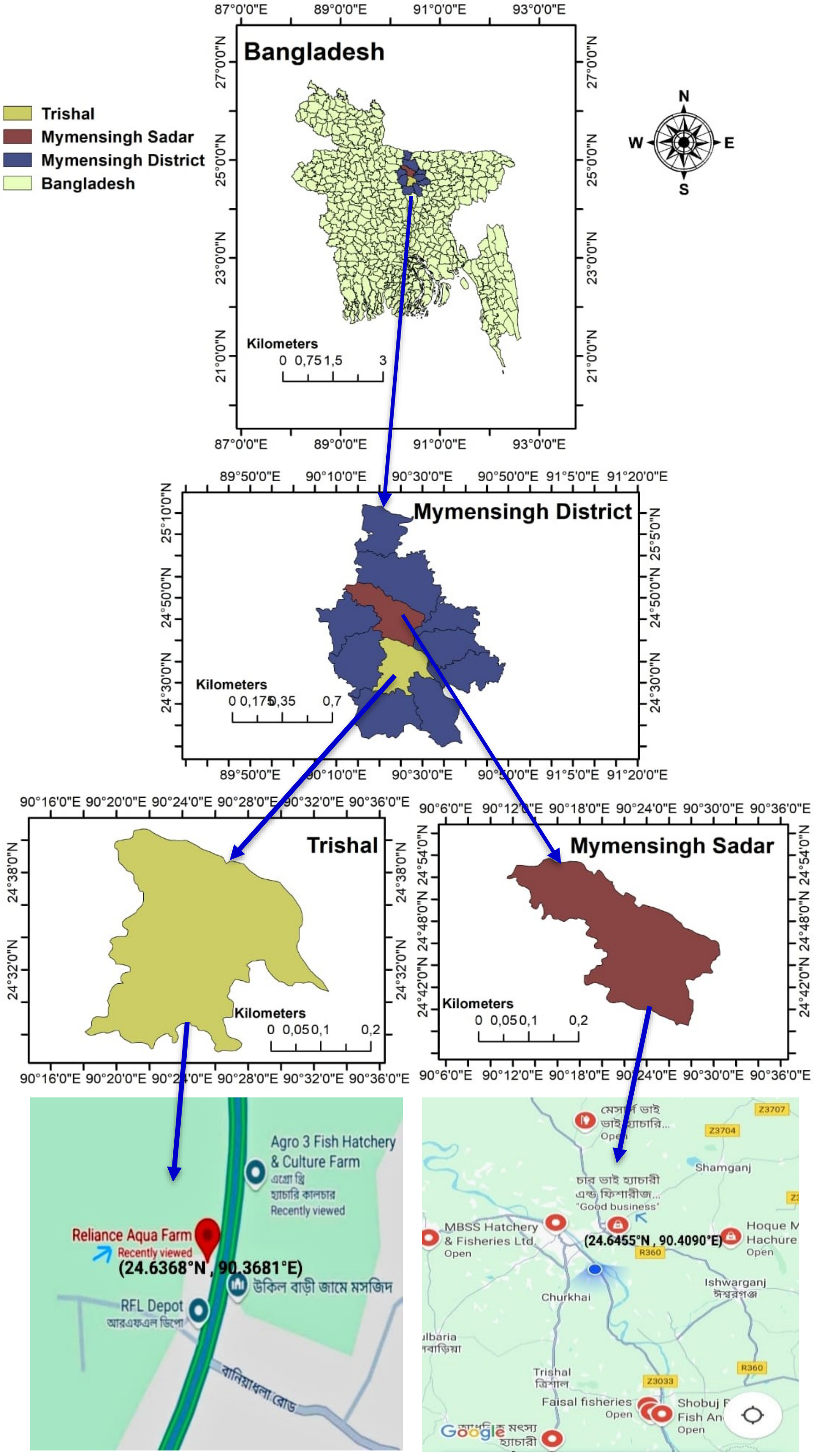

Figure 1. Map showing the location of the farms, from where fish samples were collected.

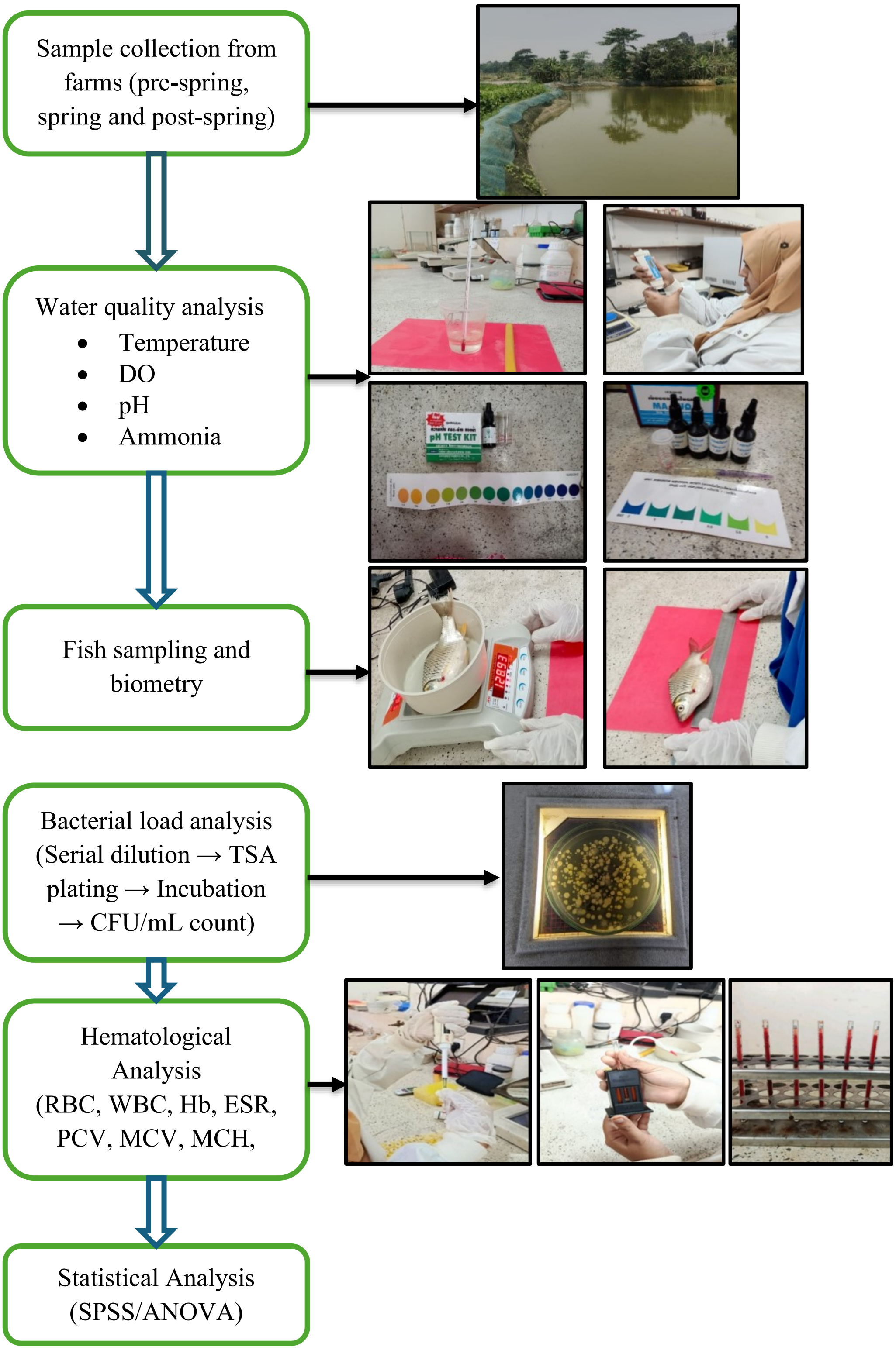

Figure 2. Schematic representation of the experimental design and methodological workflow.

Determination of Water Quality

Water samples were collected from the ponds at approximately 1 m depth for physicochemical analysis and analyzed promptly to prevent deterioration in quality. Water temperature was measured with a thermometer (Model CE 225908, Taiwan) and reported in °C. Dissolved oxygen (DO) was determined with a digital DO meter (Model: CE 225908, Taiwan) and recorded in mg/L. The pH of pond water was measured with a portable pH kit (Advance Pharma Co. Ltd., Thailand), and free ammonia (NH_3) levels were determined with commercially available test kits from the same manufacturer. All measurements were carried out following standard procedures to ensure accuracy and reliability.

Bacterial load analysis

Water samples for bacterial load analysis were collected from two fish farms using sterile plastic bottles (approximately 200 mL) from the mid-water column. The samples were transported to the Fish Disease Laboratory, Bangladesh Agricultural University, Mymensingh, and cultured on Tryptone Soya Agar (TSA) plates. The plates were incubated at 37°C for 24 hrs, after which colony-forming units (CFU/mL) were determined and expressed accordingly.

Hematological analysis

Blood samples were collected from the caudal vein of fish using sterile tips, following standard procedures, and the process was completed within a minute to minimize handling stress. The collected blood was gently mixed with appropriate diluting fluids for subsequent analyses (Dacie and Lewis, 2001). Total erythrocyte (RBC) and leukocyte (WBC) counts were determined using diluted blood samples and an improved Neubauer hemocytometer following standard formula (Clark *et al.,* 2019). Blood glucose levels were measured using a digital G1 Advance (Allmedicus Co., Ltd., Korea) glucometer. Hemoglobin concentration was estimated using the cyanmethemoglobin method (Blaxhall and Daisley, 1973). Erythrocyte sedimentation rate (ESR) was determined using the Wintrobe method after allowing the blood to stand vertically for one hour. Differential leukocyte counts (DLC) were performed from Giemsa-stained blood smears under a microscope, and different leukocyte types were expressed as percentages. PCV was measured by centrifugation using a hematocrit tube (Schalm, 1967). MCH was calculated and results were expressed in picograms (Dacie and Lewis, 2001). Mean corpuscular volume (MCV) and mean corpuscular hemoglobin concentration (MCHC) were calculated using standard formulae (Noga, 2010) based on hematocrit, and RBC values.

$$\text{RBC} = \frac{\text{Total no. of cells in 5 large squares} \times \text{df} \times \text{depth factor} \times 16}{\text{No. of small squares counted}}$$

$$\text{WBC} = \frac{\text{Total no. of cell in 1 large square} \times \text{df} \times \text{cf}}{\text{Volume factor (0.1)}}$$

Here, df = dilution factor and cf = counting factor.

MCH = Hb (in g/dL) ×10/RBC (in millions/μL)

MCV = Hct (%) ×10/RBC count (in millions/ μL)

MCHC = Hb (g/dL) ×100/Hct (%)

Investigation on the Biometric Indices

Following sampling, the body weight (g) and total length (cm) of each fish were measured using a digital weighing balance and measuring scale, respectively. These data were used to establish the length–weight relationship (LWR) following the equation $W = aL^b$, where W is body weight and L is total length, with constants *a* and *b* estimated through log-transformed linear regression. After blood collection, the fish were dissected to record visceral weight, and the viscero-somatic index (VSI) was calculated as, $VSI\% = Wv \times 100/W$, where W_v is visceral weight and W is total body weight. The condition factor (CF) was also determined using the formula $(W \times 100) / L^3$ to assess the overall growth and health status of the fish.

Data analysis

The relationship between biometric indices, particularly length and weight, was evaluated using linear regression analysis with Pearson's correlation coefficient. Water quality data were analyzed in Microsoft Excel (Version 10), while hematological parameters were analyzed in IBM SPSS Statistics (Version 25.0). All results are expressed as mean ± standard deviation (SD), and statistical significance was considered at $p < 0.05$.

Results

Water Quality Parameters

Seasonal variations in the water quality parameters *viz.*, temperature, DO, pH and NH_3 were observed throughout the study period. Water temperature exhibited a clear seasonal trend, with significant increases from 24.5 ± 0.71°C in the pre-spring period to 30.5 ± 0.71°C in post-spring **(Figure 3)**. This temperature increase is correlated with higher DO levels, which gradually improved from 4.9 ± 0.14 mg/L in pre-spring to 6.7 ± 0.14 mg/L in post-spring **(Figure 4)**. The pH of the water also showed a rising trend, increasing from 7.15 ± 0.21 in pre-spring to 7.85 ± 0.07 by post-spring **(Figure 5).** Interestingly, NH_3 remained constant across all three periods at 0.2 ± 0.00 ppm, indicating a stable level of nitrogenous waste in the system **(Figure 6)**. Despite fluctuating environmental parameters, the bacterial load in the water showed a noticeable seasonal difference, with the highest count observed in pre-spring ($10.58 \pm 1.42 \times 10^3$ CFU/mL) and the lowest in post-spring ($6.7 \pm 0.65 \times 10^3$ CFU/mL) **(Table 2)**. These changes in water quality parameters are important indicators of environmental stress on the farmed fish and could have significant implications for fish health and productivity.

Table 2. Average bacterial load estimated from silver barb, *B. gonionotus* fish ponds

Farms	Total heterotrophic bacteria count in TSA agar (CFU/mL)	Average bacterial load $\times 10^3$ (CFU/mL)	Study seasons
F_1	11.44×10^3	10.58±1.42	Pre-spring (February)
F_2	9.71×10^3		
F_1	9.47×10^3	8.61±1.17	Spring (March)
F_2	7.75×10^3		
F_1	7.15×10^3	6.7±0.65	Post-spring (April)
F_2	6.26×10^3		

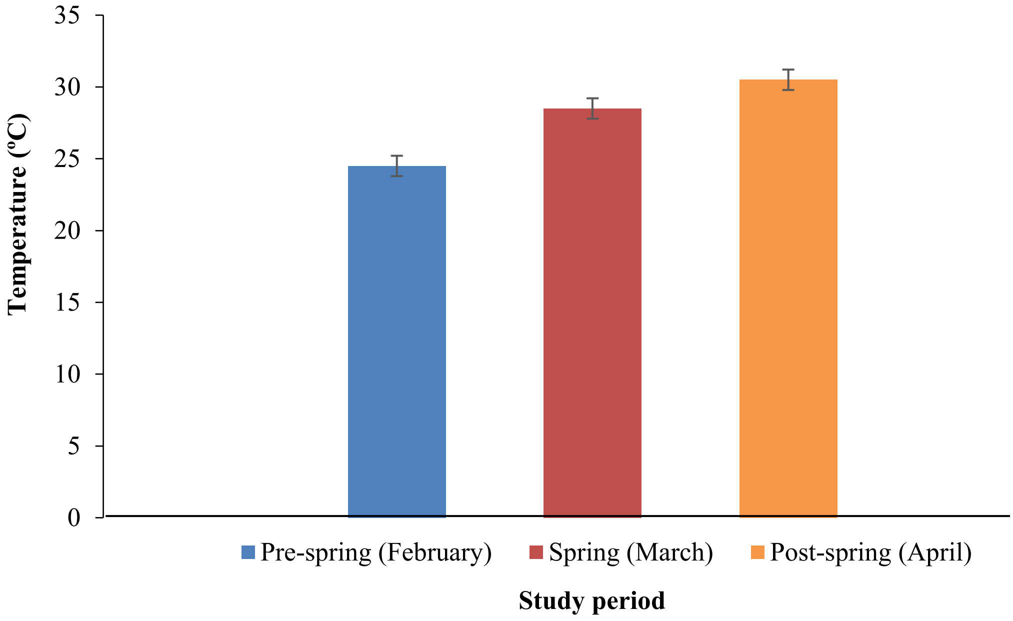

Figure 3. Variations of average temperature among silver barb ponds in the pre-spring (February), spring (March) and post-spring (April) season.

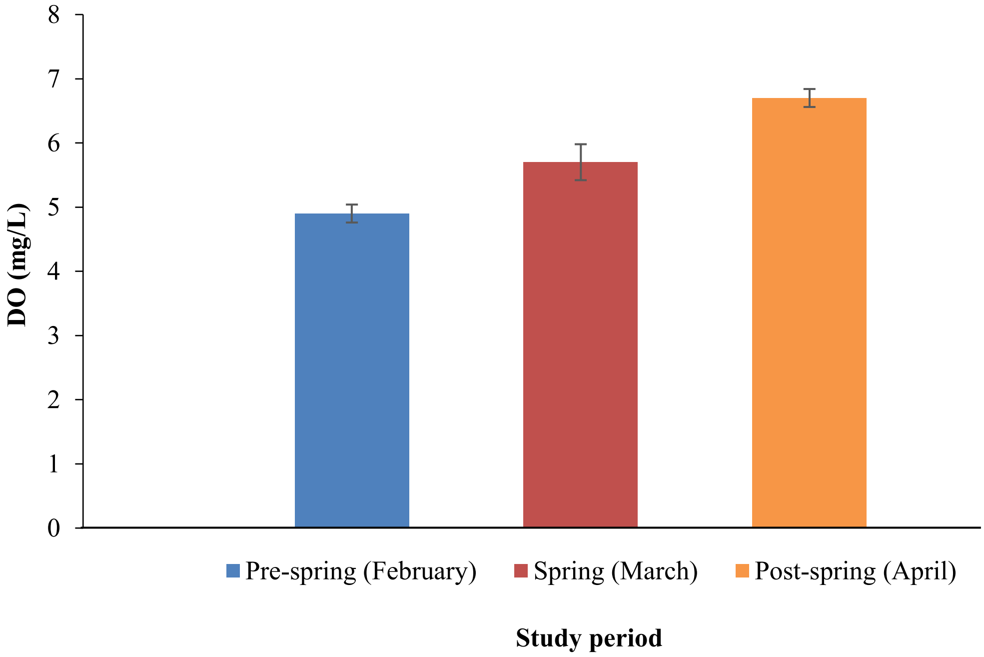

Figure 4. Variations of average DO among silver barb ponds in the pre-spring (February), spring (March) and post-spring (April) season.

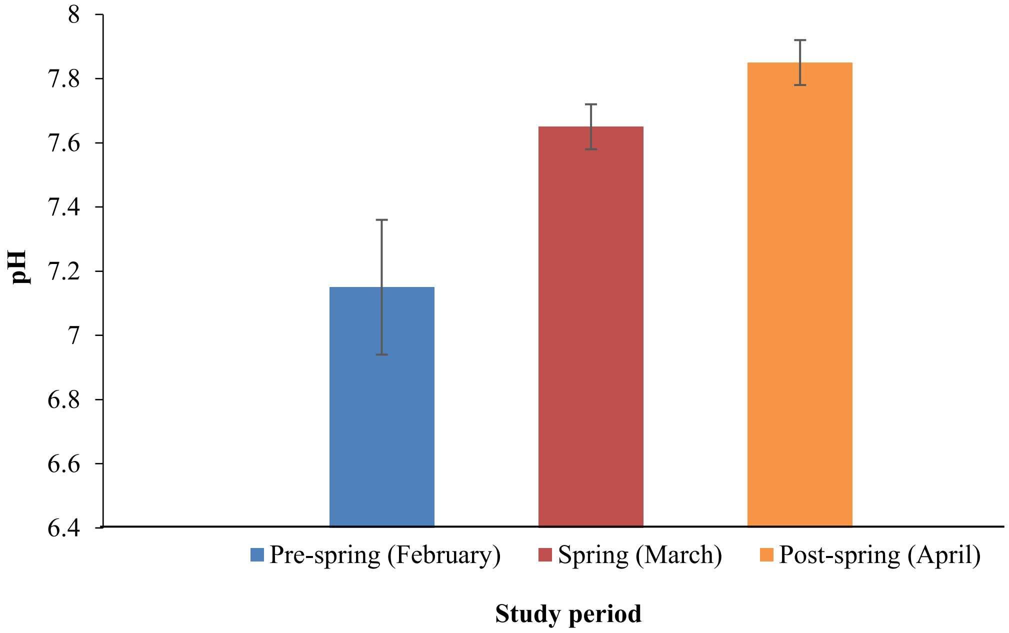

Figure 5. Variations of average pH among silver barb ponds in the pre-spring (February), spring (March) and post-spring (April) season.

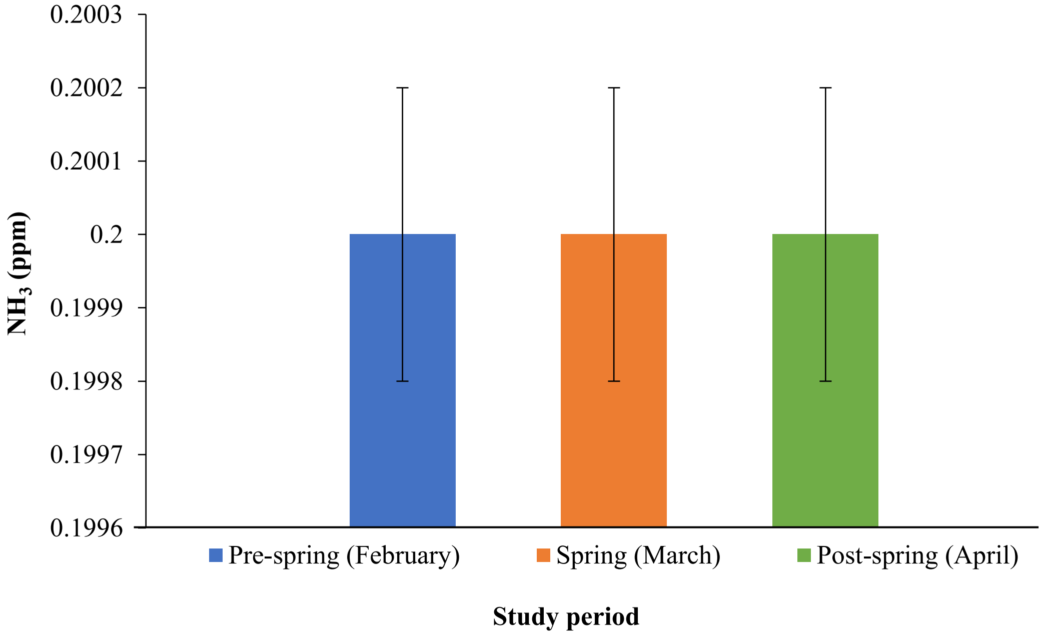

Figure 6. Variations of average NH_3 (ppm) among silver barb ponds in the pre-spring (February), spring (March) and post-spring (April) season.

Hematological Parameters

The hematological analyses (Table 3) revealed substantial seasonal changes in the fish's physiological condition, with clear differences between pre-spring, spring, and post-spring periods. During the post-spring period, the fish exhibited the highest hemoglobin (Hb) levels (9.73 ± 0.58 g/dL), PCV (30.00 ± 1.82%), and MCHC (32.47 ± 1.82%), suggesting improved oxygen-carrying capacity and overall health. Conversely, the pre-spring season was marked by elevated glucose levels (80.39 ± 17.04 mg/dL) and ESR (5.63 ± 1.01 mm/hr), indicating potential stress, possibly due to lower water temperatures and reduced feeding activity. This stress response was further reflected in the WBC count (Figure 7) (65.78 ± 5.42 × 10^3/mm^3) and a higher granulocyte (Figure 8) percentage (76.86 ± 2.86%), which are often associated with immune activation under adverse conditions (Table 3). The post-spring period also exhibited more favorable values in RBC count (Figure 7) (3.06 ± 0.14 × 10^6/mm^3) and MCH (26.01 ± 2.52 pg), both of which support the hypothesis that the fish experienced improved health and metabolism due to the warmer, more stable environmental conditions. Monocyte percentages (Figure 8) were highest during the post-spring season (37.23 ± 2.03%), suggesting the fish's adaptive immune responses to improved water quality and metabolic conditions.

Table 3. Average (mean ± SD) hematological parameters of Thai silver barb in three different study periods

Parameters	**Season**			**P value**	**Level of significance**
	Pre-spring (February)	**Spring (March)**	**Post-spring (April)**		
Hb (g/dl)	7.06 ± 0.98^a	8.32 ± 0.88^b	9.73 ± 0.58^c	0.00	*
Glucose (mg/dl)	80.39 ± 17.04^c	67.51 ± 14.29^b	61.44 ± 3.74^a	0.000	*
ESR (mm/hr)	5.63 ± 1.01^c	4.13 ± 1.22^b	2.97 ± 0.81^a	0.000	*
PCV (%)	24.1 ± 3.93^a	28.33 ± 2.31^b	30.00 ± 1.82^c	0.000	*
MCH (pg)	29.95 ± 6.44	29.61 ± 2.61	31.75 ± 0.56	0.089	NS
MCV (fL)	101.18 ± 14.9	101.03 ± 8.99	98.02 ± 5.04	0.413	NS
MCHC (%)	29.5 ± 4.4^a	29.38 ± 2.01^a	32.47 ± 1.82^b	0.000	*
WBC (cells×10^3/mm$^{3)}$	65.78 ± 5.42^c	55.5 ± 2.9^b	50.45 ± 4.26^a	0.000	*
RBC (cells×10^6/mm^3)	2.45 ± 0.68^a	2.84 ± 0.47^b	3.06 ± 0.14^c	0.000	*
Granulocyte (%)	76.86 ± 2.86^c	67.04 ± 2.21^b	62.77 ± 2.03^a	0.000	*
Monocyte (%)	23.14 ± 2.86^a	32.96 ± 2.21^b	37.23 ± 2.03^c	0.000	*

Data are presented as the mean ± SD of three replicates. In a row, superscript values with the same letter or without a letter do not differ significantly, whereas figures with dissimilar letters differ significantly (as per DMRT).

* = Significant at 5% level of probability

NS = Not Significant

Biometric Indices

The biometric indices demonstrated significant seasonal variations, with clear differences in the length-weight relationship (LWR) and condition factor (K). The LWR showed a negative allometric growth ($b = 2.69$) (Figure 9) during the pre-spring period, which indicates that the fish were growing in length more than in weight during this colder season. This trend shifted to positive allometric growth in the spring ($b = 3.01$) (Figure 10) and post-spring ($b = 3.09$) (Figure 11) periods, with the fish gaining weight more rapidly than length, which is typical for optimal growth conditions in aquaculture. The correlation coefficient (r^2) between length and weight was strong in all periods: 0.976 in pre-spring (Figure 9), 0.962 in spring (Figure 10), and 0.996 in post-spring (Figure 11), indicating that length and weight were strongly correlated across all seasons, with a slight decline in spring and a marked improvement in post-spring, where growth conditions were most favorable.

The condition factor (K), an indicator of overall fish health and nutritional status, was lowest in pre-spring (1.35 ± 0.09) and significantly higher in the post-spring period (1.57 ± 0.02), reflecting better growth conditions during the warmer months (Table 4). These higher K values in post-spring suggest improved feed conversion and body condition, likely due to higher water temperatures and dissolved oxygen levels. Similarly, VSI%, which measures the relative weight of internal organs to body weight, increased from 5.35 ± 1.66% in pre-spring to 8.00 ± 1.64% in post-spring, indicating improved internal organ condition and energy reserves during the warmer months (Table 4). The increased VSI during post-spring reflects the more favorable feeding conditions and metabolism, further supporting the growth and health outcomes observed in the biometric indices.

Table 4. Average conditional factor and Viscero-Somatic Index (VSI%) of experimental *B. gonionotus* in three different study periods

Parameter	**Season**			**P value**	**Level of significance**
	Pre-spring (February)	**Spring (March)**	**Post-spring (April)**		
Condition factor (K)	1.35 ± 0.09^{b}	1.41 ± 0.11^{b}	1.57 ± 0.02^{a}	0.001	*
VSI (%)	5.35±1.66^{b}	7.42 ± 2.56^{a}	8.00 ± 1.64^{a}	0.001	*

*At 5% level of significance

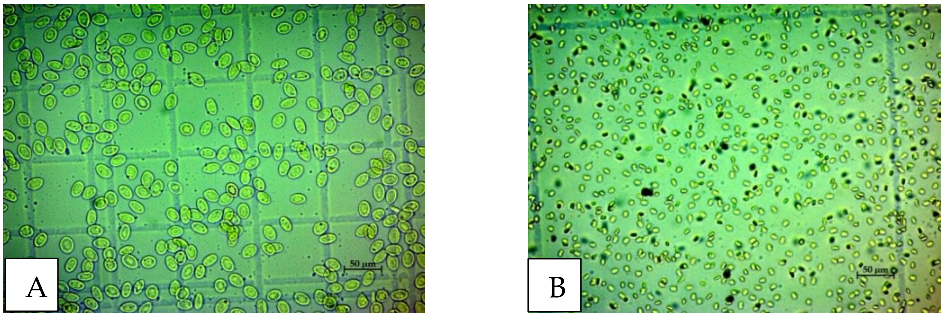

Figure 7. RBC content (A) and WBC content (B) in *B. gonionotus* load was observed under a light microscope (Carl Zeiss Microscopy GmbH, AxiocamERc 5s) (40x magnification)

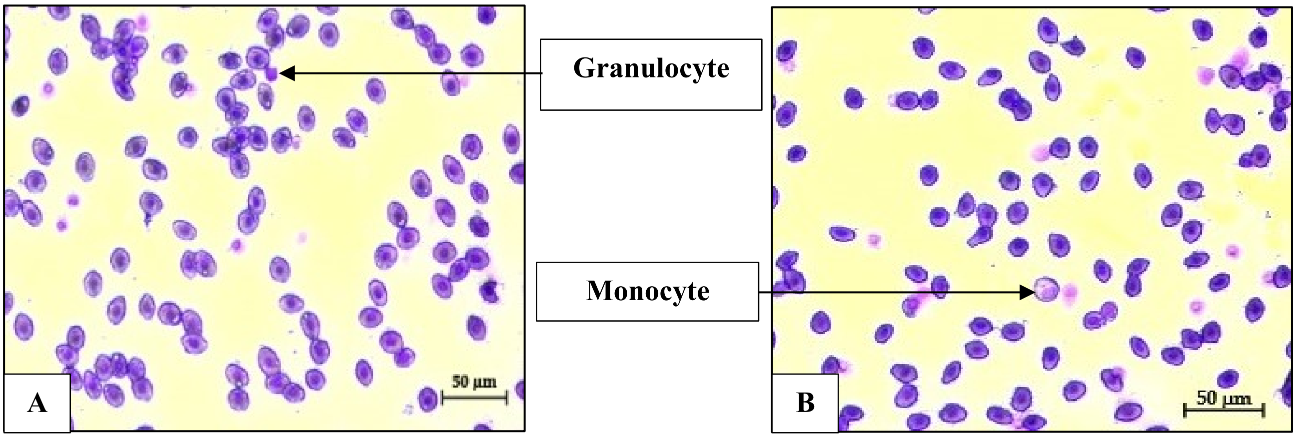

Figure 8. Differential WBC content (A. granulocyte and B. monocyte) in *B. gonionotus* blood observed under a light microscope (Carl Zeiss Microscopy GmbH, AxiocamERc 5s) (40x magnification)

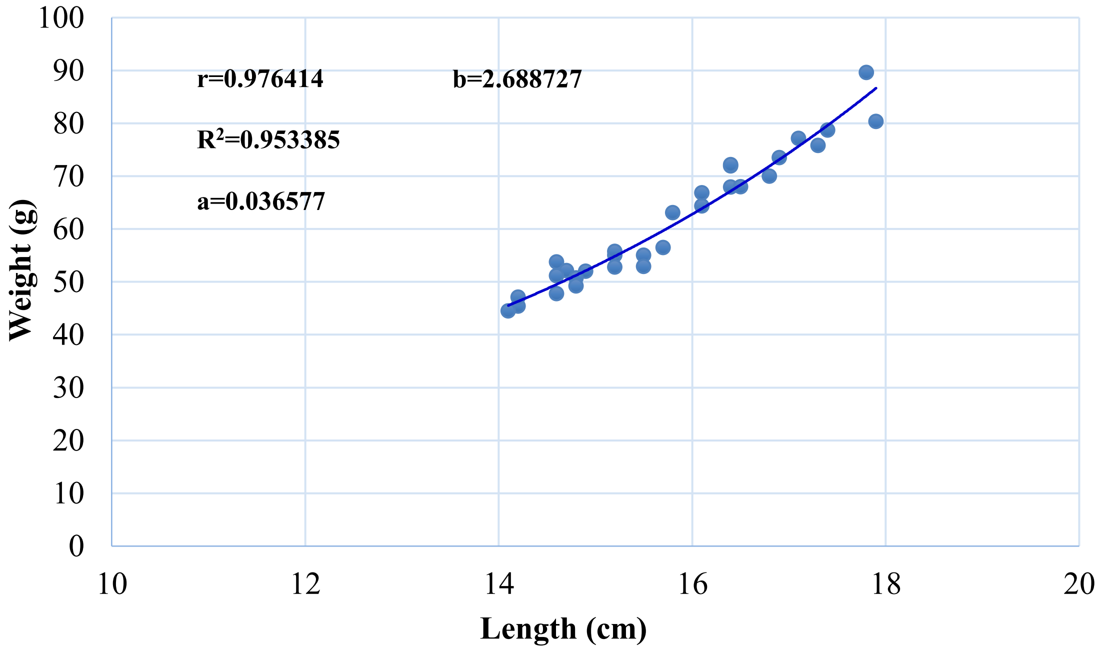

Figure 9. Length-weight relationships for the first two samplings in the pre-spring (February) period

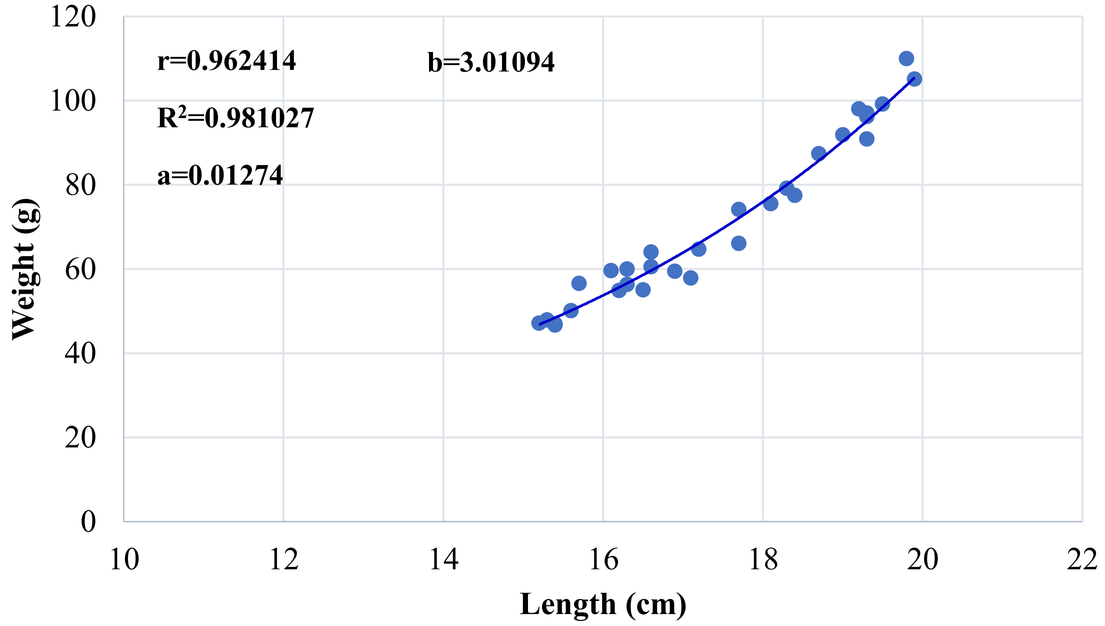

Figure 10. Length-weight relationships for the two samplings in the spring (March) period

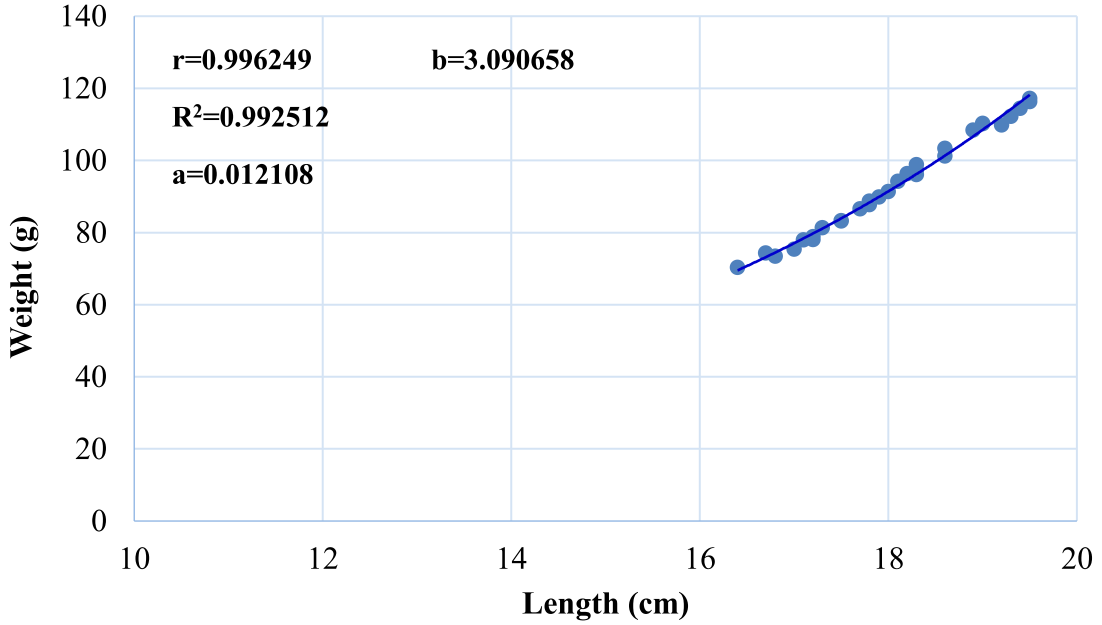

Figure 11. Length-weight relationships for the two samplings in the post-spring (April) period.

Discussion

Water Quality Parameters

The average water temperatures in the present study were recorded from 24.5 ± 0.71°C in pre-spring, to 28.5 ± 0.71°C in spring, and 30.5 ± 0.71°C in post-spring following expected climatic patterns in subtropical regions. The recorded range falls within the optimal range of 25°C to 32°C for B. gonionotus, supporting optimal growth and survival (Chakraborty et al., 2011) and optimal physiological and metabolic functions (Rahman *et al.,* 2015). Dissolved oxygen levels increased from 4.9 ± 0.14 mg/L in pre-spring to 6.7 ± 0.14 mg/L in post-spring, likely due to higher photosynthetic activity by phytoplankton and aquatic plants during warmer periods, resulting in more oxygen release during daylight hours (Boyd and Tucker, 1998). Furthermore, the observed values remained within acceptable limits (5-7 mg/L) for freshwater aquaculture (Bhatnagar and Devi, 2013) but DO values below 3 mg/L can induce stress and susceptibility to disease, especially in fast-growing species such as *B. gonionotus* (Ali *et al.,* 2018). pH increased 7.15 ± 0.21 in pre-spring to 7.85 ± 0.07 in post-spring, remained within the optimal range of 6.5 to 8.5 for freshwater fish culture, as outlined by the FAO (Tucker and Hargreaves, 2004) and likely influenced by photosynthetic activity algal productivity due to carbon dioxide uptake (Boyd, 2015). Such conditions with high DO can enhance feed conversion efficiency and reduce physiological stress in *B. gonionotus* (Hossain *et al.,* 2016). Ammonia level remained consistently low (0.2 ± 0.00 ppm) across all seasons, indicating efficient waste management and nitrification, as NH_3, even at 0.05 ppm, can be toxic to fish (Randall and Tsui, 2002) and also well-managed semi-intensive ponds with adequate aeration and phytoplankton activity maintain ammonia concentrations below critical thresholds (Roy *et al.*, 2021).

Bacterial loads in water were found decreased from 10.58×10^3 to 6.7×10^3 CFU/mL from pre-spring to post-spring, indicating reduced microbial stress and more stable environment. Higher loads during cooler periods may reflect increased susceptibility to bacterial proliferation (Austin and Austin, 2016), though the study's values remained within acceptable limits for semi-intensive aquaculture (Ahmed *et al.,* 2020).

Hematological Parameters of *B. gonionotus*

Hemoglobin is an iron-containing metalloprotein in red blood cells that transports oxygen from gills to tissues by removing carbon dioxide. Changes in hemoglobin levels indicate anemia, stress or improved oxygenation under favorable conditions (Witeska, 2013; Fazio, 2019). In the current study, the Hb concentration increased gradually from 7.06 ± 0.98 g/dL in pre-spring to 9.73 ± 0.58 g/dL in post-spring, which may be attributed to improved water quality and higher temperatures during the post-spring period, which enhance metabolic efficiency and oxygen uptake. Similar trends were reported by Adeyemo *et al.,* (2003), who found that warmer temperatures improve hemoglobin synthesis in fish due to increased metabolic demand with enhanced physiological performance. On the contrary, Tavares-Dias and Moraes (2007) observed lower Hb levels in stressed or immunocompromised fish populations at lower water temperatures. Glucose is a simple sugar circulating in the blood, the primary source of energy and is a key indicator of metabolic activity with acute stress. In this study, glucose levels decreased significantly from 80.39 ± 17.04 mg/dL in pre-spring to 61.44 ± 3.74 mg/dL in post-spring, suggesting reduced stress under improved environmental conditions that aligns with previous findings indicating improved feeding with better energy utilization and metabolic stability (Chatterjee *et al.,* 2006). Whereas elevated glucose levels in fish often occur due to handling, temperature changes, poor water quality, or pathogen exposure (Barton, 2002; Iqbal *et al.,* 2018) leads to hyperglycemia (Wendelaar Bonga, 1997).

Erythrocyte Sedimentation Rate (ESR, mm/hr) measures how quickly red blood cells settle at the bottom of a test tube over an hour and is a non-specific marker of inflammation and immune activity. A decrease in ESR from 5.63 ± 1.01 mm/hr in pre-spring to 2.97 ± 0.81 mm/hr in post-spring was observed in this study. Rehulka (2000) reported that lower ESR values are associated with healthy, non-stressed individuals, whereas elevated ESR values indicate stress-associated changes in plasma concentrations and red cell morphology. Similar ESR variations have been documented in tilapia (*O. niloticus*) and catfish (*Clarias batrachus*) (Gabriel *et al.,* 2011). Therefore, the declining ESR in *B. gonionotus* suggests improved environmental adaptation in the post-spring period. PCV (%), also known as hematocrit, reflects oxygen transport efficiency, blood viscosity, and general health status. In this study, PCV increased from 24.1±3.93% in pre-spring to 30.0 ± 1.82% in post-spring. Lower PCV values are often observed under stress or anemia, whereas higher values indicate better oxygen-carrying capacity and better health status (Satheeshkumar *et al.,* 2012). This upward trend parallels the observed increases in Hb and RBC count, and together they reflect enhanced hematopoietic and physiological adaptation.

RBC count refers to the total number of red blood cells per unit volume of blood, a primary indicator of oxygen transport. RBC counts increased significantly from 2.45 ± 0.68×10^6/mm^3 in pre-spring to 3.06 ± 0.14×10^6/mm^3 in post-spring. This indicates improved erythropoiesis and overall health, confirming post-spring as an optimal rearing period for the species. As a higher RBC count supports efficient oxygen transport and hematopoietic system, vital for coping with environmental stressors (Hrubec and Smith, 2010). Previous studies on seasonal variations in hematology of *B. gonionotus* and related cyprinid species have shown similar increases in RBCs with rising temperature and improved water quality (Das *et al.,* 2006). WBC representing leukocytes per volume of blood involved in fighting infections. WBC counts showed a decreasing trend from 65.78 ± 5.42×10^3/mm^3 in pre-spring to 50.45 ± 4.26×10^3/mm^3 in post-spring. Elevated levels suggest immune activation due to infection or stress, whereas low levels suggest immunosuppression (Roberts and Rodger, 2012). The observed decline in WBC count in post- spring with improving environmental conditions aligns with reports of seasonal normalization of WBC in cyprinids and catfish (Rehulka, 2000 and Gabriel *et al.,* 2011), indicating improved health status in *B. gonionotus.*

MCH, the oxygen-carrying potential of each erythrocyte, values fluctuated slightly across seasons, (highest 31.75 ± 0.56 pg in post-spring to lowest in spring 29.61±2.61 pg). without statistical significance ($p>0.05$), indicating stable hemoglobin count per erythrocyte and maintained hematopoietic balance (Witeska *et al.,* 2010). In contrast, MCHC (%), an important index of hemoglobin packing and saturation level of erythrocytes, increased from 29.5 ± 4.4% in pre-spring to 32.47 ± 1.82% in post-spring suggesting improved hemoglobin synthesis and oxygen carrying efficiency under favorable conditions (Roberts and Rodger, 2012 and Rani *et al.,* 2011). Again, MCV count remained relatively constant across seasons - 101.18 ± 14.9 fL in pre-spring, 101.03 ± 8.99 fL in spring, and 98.02 ± 5.04 fL in post-spring without statistical significance ($p>0.05$). Differential leukocyte counts-granulocytes (neutrophils, eosinophils, and basophils are involved in acute immune responses - inflammation, phagocytosis, and allergic reactions) and monocytes are (leukocytes that differentiate into macrophages and dendritic cells, important in chronic immune regulation, phagocytosis of pathogens, and tissue repair) varied significantly across the seasons. Granulocyte decreased from 76.86 ± 2.86% in pre-spring to 62.77 ± 2.03% in post-spring, while monocyte increased from 23.14 ± 2.86% to 37.23 ± 2.03% during the same period. High granulocyte levels are associated with infections or environmental stressors (Hrubec and Smith, 2010), but increased monocyte levels indicate recovery from infection or tissue healing (Faggio *et al.,* 2015). This inverse trend suggests a shift from active immune response to immunological stability under improved environmental conditions. Similar patterns have been reported in seasonal studies of *L. rohita* and *C. catla*, in which lower granulocyte and higher monocyte levels were associated with improved health during favorable environmental periods (Chatterjee *et al.,* 2006; Shah and Altindag, 2005).

Biometric Indices

The length-weight relationship (LWR) determines the growth pattern and morphometric condition of fish. In this study, a seasonal shift from negative allometric growth in pre-spring ($b=2.6887$) to near isometric in spring ($b=3.0109$) and positive allometric growth in post-spring ($b=3.0906$) in *B. gonionotus* as fish were thinner and less robust during the colder pre-spring season but experienced improved weight gain relative to length during favorable environmental conditions in post-spring period. These findings align with who found that *B. gonionotus* cultured in seasonal ponds in West Bengal exhibited negative allometric growth during early culture periods and shifted to positive allometric growth as conditions improved (Das *et al.,* 2019).

The condition factor (K), an indicator of the nutritional and health status of fish and reflects environmental suitability and well-being. In this study, the average K values increased gradually from pre-spring (1.35 ± 0.09) to spring (1.41 ± 0.11), reaching the highest in post-spring (1.57 ± 0.02) indicating improved body condition and the species is physiologically best adapted to warmer environmental conditions, because of an increase in temperature and primary productivity during the spring enhances feeding behavior and energy assimilation in *B. gonionotus*, leading to improved body condition (Bhatta *et al.,* 2013). These findings are aligning with Uddin *et al.* (2020), who reported seasonal variation in the condition factor of *B. gonionotus* in Bangladesh, with significantly higher K values during late spring and early summer. The VSI increased from 5.35 ± 1.66% (pre-spring) to 8.00 ± 1.64% (post-spring) in *B. gonionotus,* indicating enhanced feeding activity and nutrient assimilation under improved environmental conditions. Similar seasonal increases in VSI have been reported, associated with greater food availability, lipid storage, and better water quality (Rahman *et al*., 2015; Chakraborty *et al*., 2022).

Conclusion

The present study provides important insights into the seasonal effects on water quality, hematological status, and biometric indices of the farmed Thai silver barb. Seasonal fluctuations, particularly lower temperatures in pre-spring, negatively affected fish health and stress levels. Water temperature gradually increased from pre-spring to post-spring and positively influenced other water quality parameters. Stress indicators*, viz., ESR, MCV, blood glucose, total WBC, and granulocytes,* were found elevated during pre-spring, reflecting cold-induced stress. In contrast, PCV, MCH, MCHC, hemoglobin, RBC, and monocyte counts were found increased in the spring and post-spring, indicating improved physiological conditions and better adaptation to warmer temperatures. Biometric assessments revealed negative allometric growth in pre-spring, probably due to lower feeding activity and stress-induced metabolic suppression during colder periods, but positive allometric growth was observed in the spring and post-spring seasons. These findings emphasize the need for season-specific management practices in aquaculture, including water quality control, feeding strategy, and health monitoring, to ensure optimal fish health and sustainable production of *B. gonionotus*.

Acknowledgements:

The research was partially funded by Ministry of National Science and Technology (NST), Bangladesh.

Conflict of interest:

The authors declare that they have no conflict of interest.

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Azmine Rahman: Data curation, Methodology, Writing- Original draft preparation;
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