



Review Article

Impact of Environmental Stress on *Labeo rohita* PhysiologyIram Asad¹, Mubashar Hussain*, Sheeza Sakhawat, Arooj Fatima and Aniza Iftikhar

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Abstract | The *Labeo rohita* is one of the most valuable freshwater fish species, which has an important role in the aquaculture production in South Asian countries, including Pakistan, India, and Bangladesh, and is also a commercially important fish species in South Asia. Its growth, metabolism, immunity, reproduction, and survival are significantly affected by environmental factors like temperature, dissolved oxygen, pH, salinity, ammonia concentration, and water quality. Changes in these environmental factors may cause physiological stress that leads to alterations of biochemical pathways, declining feed efficiency, oxidative stress, immune dysfunction, and higher mortality rates. Temperature changes can impact metabolic rate, enzymatic activity, and oxygen consumption in particular, and inadequate dissolved oxygen will restrict the utilization of oxygen and growth performance. Higher ammonia levels and improper pH also affect osmoregulatory and haematological functions. *Labeo rohita* is able to tolerate environmental stressors within limits by the physiological mechanisms such as expression of heat shock proteins, antioxidant enzymes, endocrine regulation, and adaptive metabolic changes. But when environmental changes occur for extended periods or are especially harsh, the adaptive capacity is not enough to reduce the impact on aquaculture productivity. Important interactions between environmental parameters and fish physiological responses must be understood to manage aquaculture sustainability and climate resilience, as well as to enhance fish health.

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Introduction

Climate change has emerged as the world's major problem since the mid-nineteenth century. Both natural factors and anthropogenic activities are considered primary drivers of these changes, as shown in Figure 1 (Islam *et al.*, 2020). These changes alter temperature, precipitation, ocean acidification, and salinity levels in aquatic ecosystems (Shahjahan *et al.*, 2021; Yilmaz *et al.*, 2021). These hydrological

stressors significantly affect the flora and fauna of the aquatic ecosystem (Armobin *et al.*, 2023; Cox *et al.*, 2018; Sabbir *et al.*, 2010). The aquaculture sector is economically important, as it ensures food security for the growing masses and provides livelihoods for millions of people. Over the last few decades, aquaculture has been expanding rapidly compared to other agricultural sectors (Siddika *et al.*, 2025). Compared to other meat sources, fish are more nutritious, providing a higher proportion of quality

protein and essential fatty acids that are beneficial for heart health (Ashaf-Ud-Doulah *et al.*, 2021). Unlike most terrestrial animals, fish are exothermic animals, and their physiological processes are directly and indirectly influenced by environmental conditions. Minor temperature fluctuations can have drastic effects on the health of fish. For instance, a 1 °C rise in temperature can increase metabolic rate up to 10% (Zhang *et al.*, 2015). Therefore, the successful freshwater fish culture requires maintenance of optimum temperature, salinity level (0-5ppt), and other physicochemical parameters within desirable ranges (Ninawe *et al.*, 2018; Rahman *et al.*, 2022). Fluctuations in these conditions can lead to oxygen depletion, impair the immune system of fish, increase disease susceptibility, and may cause mortality. Fish refuse to feed, grow poorly, and lose immunity, which changes habitat patterns and ecological distribution. Severe changes also affect the metabolic functions of fish, ultimately reducing reproductive potential, affecting regional genetic variability, and potentially causing population relocation (Georges and Holleley, 2018; Uppanunchai *et al.*, 2018). Consequently, fish productivity decreases, the mortality rate increases, and aquaculture industries can face economic losses (Dawood *et al.*, 2020; Shahjahan *et al.*, 2018). This review focuses on the key factors in the environment that impact the performance of *Labeo rohita* and explores some of the physiological mechanisms behind stress adaptation and survival.

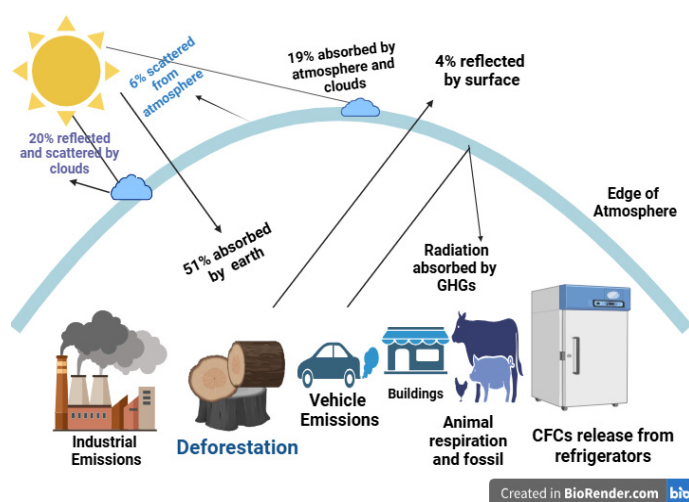


Figure 1: Anthropogenic causes of climate change.

Literature review

In Pakistan, both native and exotic freshwater species exist (Haseeb and Yousafzai, 2023). A total of 193 native species are present in the freshwater ecosystem (Iqbal *et al.*, 2023; Rafique and Khan, 2012). Pond-

based aquaculture produces 31 edible freshwater species (Inayat *et al.*, 2024). Rohu is distributed across both temperate and tropical areas, including Bangladesh, India, Myanmar, Nepal, Pakistan, and Vietnam. It is an obligate freshwater species that acquires freshwater habitat to complete its cycle and typically lives in the middle layer of the water column. The optimal water temperature for *Labeo rohita* to achieve the best performance is 28 to 30 °C (Rahi and Shah, 2012; Roychowdhury *et al.*, 2020).

During the summer season, water temperature in aquaculture ponds can increase up to 36 °C, which is 6-8 °C higher than the optimal range, making it imperative to examine the thermal stress compensatory mechanism (Islam *et al.*, 2020; Shahjahan *et al.*, 2021). *Labeo rohita* (rohu) meat is highly palatable, and due to its taste, it is used as a novel food source across the Indian subcontinent, particularly in Bangladesh (Islam *et al.*, 2015; Rahi *et al.*, 2022; Sabbir *et al.*, 2017). It contributes significantly to the GDP of the country; for example, the aquaculture sector contributes 3.57% to Bangladesh's total GDP (Lema *et al.*, 2024).

Temperature

Due to climate change, i.e., global warming, aquatic animal diversity and abundance decrease worldwide (Fey and Greszkiewicz, 2021). Water temperature is the most important environmental factor that regulates growth, reproduction, and diversity of species in aquatic ecosystems (Yoon *et al.*, 2022). Water bodies' temperature greatly influences physiological mechanisms such as reproduction, feeding, swimming, and nutritional adaptability (Enders and Boisclair, 2016; Lindmark *et al.*, 2022). Water temperature below or above thermal limits weakens immune systems, and aquatic species become highly susceptible to infectious disease (Azhar *et al.*, 2022; Cascarano *et al.*, 2021). Temperature also help determine the diversity of species in a habitat because species perform best at their optimal temperature, and as a result their survival rate, diversity, and abundance increase (Schulte *et al.*, 2011).

Fishes cannot regulate body temperature and depend entirely on water temperature, which is key factor in determining fish biological system functioning. An optimal range of temperature is necessary for proper growth and development. The growth of the embryo and organ formation are affected by an increase or

a decrease in temperature (Ashaf-Ud-Doula et al., 2021). Fishes are more sensitive to temperature changes at the larval and juvenile stage compared to the adult stage (Ashaf-Ud-Doula et al., 2021). *Labeo rohita* belongs to the family cyprinidae that constitute about 53.7% of the fish population in the Ganga River channels in Pakistan, Bangladesh, Nepal, and North India (Sheikh et al., 2017). They are eurythermal species that flourish at about 25–32°C water temperature (Azhar et al., 2022).

In the Indian Sub-continent, *Labeo rohita* performs best at 28–30°C; when temperatures fluctuate above and below this range, survival decreases and mortality increases (Mridul et al., 2024). At 28–30 °C, *Labeo rohita* daily weight gain, protein efficiency ratio, thermal growth coefficients, and survival rate increase, whereas at 32–36 °C these parameters decrease (Mridul et al., 2024). At 34°C, yolk and zygote damage happens, which slows down incubation time and hatching success rate, while at 36 °C, hatching success rate is zero (Matolia et al., 2024). In Pakistan, the Kotri downstream area stretches approximately 155km along the Indus River delta. This delicate ecosystem is adversely affected by climate change (Gleeson et al., 2012). Fluctuations in temperature patterns adversely impact the fish population (Khaliq et al., 2024). In winter and summer, water temperature ranges from 9–34 °C, while the optimal temperature for *Labeo rohita* survival and spawning is 25–28 °C. Cooler (9 °C) or hotter (34 °C) water negatively affects spawning and survival. Due to climate change, freshwater fish face environmental challenges in Pakistan. In southern Punjab, Pakistan, environmental factors such as light, air, and temperature patterns vary drastically throughout the year (Dastagir et al., 2016; Hussain et al., 2023).

In Sindh and Baluchistan, summer temperatures can reach up to 50 °C (Ashraf et al., 2022), while it drops below –2°C in Skardu and Baltistan (Raza et al., 2015). Fluctuations in water temperature increase energy demand, also increasing glucose for balancing carbohydrate metabolism (Forgati et al., 2017; Jia et al., 2020). Drastic fluctuations in water temperature affect food intake rate because below 25°C, digestive enzyme efficiency decreases (Ahmad et al., 2014). When water temperature drops or rises from 28 °C, it increases the mortality rate (Azhar et al., 2022). Higher temperatures accelerate biochemical reaction rates, whereas lower temperatures negatively affect

hormonal and cellular responses (Lindmark et al., 2022; Little et al., 2020). The temperature range that causes mortality of *Labeo rohita* is shown in Table 1.

Table 1: Temperature and mortality rate.

Temperature	Mortality rate	References
28°C	0%	(Azhar et al., 2022)
25°C	16%	(Azhar et al., 2022)
20°C	22%	(Brahmane et al., 2014)
15°C	43%	(Jayant Singh and Batta, 2026)
10°C	85%	(Jayant Singh and Batta, 2026)
30°C	1%	(Azhar et al., 2022)
33°C	2%	(Chatterjee, 2006)
35°C	3%	(Ashaf-Ud-Doula et al., 2019)

Seasonal variation, moisture content, and their effects on hemato-biochemical parameters

RBCs (red blood cells), HCT (haematocrit), Hb (hemoglobin), and WBCs (white blood cells) concentrations were higher during the summer season, followed by spring and winter, respectively. In contrast, MCHC (mean corpuscular hemoglobin concentration), MCHV (mean corpuscular hemoglobin volume), and MCH (mean corpuscular hemoglobin) concentration were higher in winter, followed by spring and summer, respectively. Moisture content plays a significant role in maintaining the shelf life of fish. Due to seasonal variation, moisture content also varies. Variation in moisture content is directly linked with biochemical variable, i.e., lipid concentration. In *Labeo rohita*, 70.81–74.76% moisture content is present. Fat and moisture content both have an inverse relationship. When the moisture content increases during winter, the fat concentration decreases in *Labeo rohita* (Habib et al., 2021).

In Anuppur, India, the GSI of *Labeo rohita* is highest during the monsoon season, followed by the pre-monsoon and post-monsoon periods. Fecundity is also highest in the monsoon season. During monsoon season, the GSI index of *Labeo rohita* from June to August is 10, 23, and 26, respectively, whereas in pre-monsoon, the average GSI is 1 and 3, while in post-monsoon, the average GSI is 1 and 12. The average weight of the ovary, fish body weight, and length are highest during the monsoon season (Mashi, 2021). Climate change disrupts natural seasonal patterns, which ultimately affects the spawning behavior of *Labeo rohita*. In Bhubaneswar, India, at 32 °C during

the monsoon season, testis lobules are engorged with spermatozoa, while oocyte growth reaches its maximum. The monsoon rainy season activates the hypothalamo–hypophyseal gonadal axis (Panda *et al.*, 2022).

Effect on gonadotrophin secretion

Environmental clues such as seasonal variation play a substantial role in determining the pre and post-spawning behavior of fish. The monsoon season acts as an important environmental cue which trigger spawning season (Bais, 2018). It is favorable for gonads maturation and promotes spawning, while in dry or cold season fish gonads development slows down. Seasonal variation affects the gonadosomatic index (GSI), which indicates the spawning time and duration in fish. It spawning season has a very short duration, typically from May to July. Rohu spawns in flowing waters, and monsoon rains increase water flow, which promotes their gonadal development and ultimately increases gonadotropin hormone secretions. Ovarian development initiates inside the ovary, followed by release of eggs by females, and male release of milt (sperm). Alterations in monsoon patterns alter water flow, which affects egg and milt quantity, delays gamete release, and disrupts the reproductive cycles of rohu. These alterations ultimately reduce the diversity, reproductive success, and abundance of *Labeo rohita* (Verma, 2024). The temperature range affecting reproduction is shown in Table 2.

Direct impact of water temperature fluctuations on Labeo rohita

Effect on embryonic development: Temperature rise adversely affects embryonic development by increasing incubation duration, decreasing hatching intensity, and increasing the mortality rate of the embryo. The 80% hatching success rate is observed at optimal temperature, while at up to 34 °C the hatching rate

declines quickly (from 80%-26%), accompanied by an increase in embryo mortality (Ashaf-Ud-Doulah *et al.*, 2021). The yolk sac provides substantial nutrients for embryonic growth and survival. Elevated temperature like 36°C, disrupt the embryo by darkening the yolk sac, which ultimately causes embryonic deformities and reduces viability (Ashaf-Ud-Doulah *et al.*, 2021).

Effect on gill morphology

Gills play a very important role in osmoregulation, excretion of nitrogenous wastes like ammonia, and respiration. The rise in water temperature (36 °C) elevates oxygen demand, which ultimately imposes greater physiological stress on the oxygen transport system, and as a result altering the morphology of rohu fingerlings' gills (Chen *et al.*, 2019). Abnormal cell growth (hyperplasia), separation of the outer cell layer (epithelial lifting), swelling of blood vessels (telangiectasis), tissue damage (epithelial necrosis), and enlargement of chloride cells are major pathological changes observed in gill lamellae and filaments due to temperature rise (Islam *et al.*, 2020).

Effect on erythrocytes physiology

Erythrocytes contain hemoglobin, whose concentration is a primary indicator of anemia and the physiological health of *Labeo rohita*. The size and quantity of erythrocytes are affected by temperature fluctuations, which ultimately affects hemoglobin quantity (Ashaf-Ud-Doulah *et al.*, 2019). At higher temperatures, a reduction in oxygen solubility increases metabolic demand. Prolonged exposure to hypoxia can lead to a weak immune system, impair growth, induce nuclear and cellular anomalies in RBCs, and consequently, the mortality rate rises (Ashaf-Ud-Doulah *et al.*, 2019).

RBCs carry oxygen from the gills to body tissues for efficient functioning of fish. Temperature fluctuation disrupts normal cell division, and when chromosomes

Table 2: Temperature range and *Labeo rohita* reproductive performance.

Area	Temp.	Ovulation %	Spawning time-hour	Fertility %	Hatching -hours	References
Islamabad (Punjab)	26.3	100	9	85	29	(Azhar <i>et al.</i> , 2022)
Bangladesh	32	100	8	88	13	(Ashaf-Ud-Doulah <i>et al.</i> , 2021)
India	28	100	6	85	24	(Iqbal <i>et al.</i> , 2023)
Barisal (Bangladesh)	29	100	7	86	24	(Minar <i>et al.</i> , 2012)
Punjab (India)	28	100	7	77	24	(Tiwana and Raman, 2012)
New Delhi (India)	29	100	7	82	22	(Sridhar <i>et al.</i> , 2014)

fail to integrate into the nucleus, then as a result, micronuclei form, acting as indicators of temperature-induced genotoxicity. Elevated temperatures increase the frequency of micronuclei in the *Labeo rohita* fingerlings, like 0.5%, 0.8%, and 1.4%, respectively, at 30°C, 33°C, and 36°C. Higher micronucleus formation at 36°C in the fingerlings disrupts the functioning of erythrocytes, decreasing the oxygen-delivering efficiency of RBCs. Therefore, *Labeo rohita*'s overall metabolism decreases and susceptibility to disease increases.

Effect on hemoglobin concentration

An extreme rise in temperature denatures hemoglobin, such as at 33–36°C, Hb concentration reduces in rohu. Reduction in HB levels decreases oxygen transportation to different tissues, causing sluggish behavior, weakened immune system, and hypoxia (Ashaf-Ud-Douhah *et al.*, 2019). At 36°C, WBC level increases, and blood glucose level rises. Elevated temperature activates adrenaline and cortisol release, which triggers gluconeogenesis and glycogenolysis, providing energy to the rohu to cope with thermal stress. Prolonged exposure to thermal stress disrupts metabolic homeostasis, contributing to physiological imbalance in rohu (Ashaf-Ud-Douhah *et al.*, 2019).

Effect on FCR

FCR measures feed efficiency in fish, calculated as feed intake/ total body weight gained. Temperature and feed quality have significant effects on FCR. The optimal temperature range, i.e., 24–26°C gives the best FCR value (Kausar and Sultan, 2006). Temperature above this range increases feed intake but reduces growth efficiency, ultimately resulting in poor FCR.

Effect on GH and IGH

The Hypothalamus-pituitary-liver (somatotrophic axis) is the primary initiator of growth and development. It is influenced by endogenous and exogenous factors, which regulate GH and IGFs (Reinecke, 2010). Growth hormone (GH) and insulin-like growth factor (IGF) play a significant role in the growth of rohu. GH activates liver cells to produce IGF-1, which increases cell proliferation, muscle growth, enhances development, and leads to better growth. GH also plays a significant role in steroidogenesis, sexual maturation, and gametogenesis (Rahman *et al.*, 2019). The optimal temperature for rohu growth

is 28–33°C. Exposure to high temperature, i.e., 36°C, reduces weight gain and specific growth rate, and increases FCR. Higher temperature suppresses growth by suppressing the expression of IGF-1, IGF-2, and GH in the liver and juvenile pituitary, respectively (Shahjahan *et al.*, 2021).

Indirect impact of temperature fluctuations on Labeo rohita

Due to climate change, the rate of evaporation of water from freshwater bodies increases, resulting in rising concentrations of calcium, magnesium, and other dissolved ions, which ultimately change the water PH (Parra and Baldisserotto, 2019). Warmer water increases the growth of algal blooms, with CyanoHABs growing faster in warmer temperature as compare to other algal blooms (Gobler, 2020). An increase in temperature also changes oxygen quantity in water bodies and increases oxygen demand in rohu.

Effect of fluctuation in water PH on growth and survival

Water quality plays a substantial role in the survival of aquatic organisms. For fish, water is the elixir of life. Physical, biological, and chemical characteristics of water determine its suitability for rohu (Raosaheb *et al.*, 2018). Pakistan is a water-stressed country, ranking 14th out of 17 extremely water risk countries (Maqbool, 2023). Due to climate change, the rate of evaporation of water from freshwater bodies increases, which ultimately increases water hardness. Moderate water hardness had a positive impact on the growth and survival of *Labeo rohita*, as the optimal range of water hardness provides calcium and magnesium, which are essential for overall health and bone development. The growth rate of rohu (fry stage) increases up to 150 mg/l, and further rise in water hardness above this limit does not favor growth and weight gain. A PH range of 6–9 supports optimal growth and survival (Parra and Baldisserotto, 2019). Conversely, water hardness less than 20mg/l and above 300mg/l causes stress and mortality of rohu, respectively (Bhatnagar *et al.*, 2004).

Effect of algal bloom on yield

In Chitwan, Nepal, elevated temperatures promote red algal blooms growth in shallow ponds, adversely affecting *Labeo rohita* farming. These blooms reduce rohu yield, increase nitrates concentration, and decrease oxygen quantity in shallow ponds. It causes approximately 10% reduction in overall yield and

20% reduction in survival rate. Dissolved oxygen concentration decreases 2 times, while nitrate concentration decreases 3 times in the pond due to a red algal bloom. Low DO causes physiological stress and reduces growth rate, while a lower concentration of nitrates reduces immunity, ultimately causing rohu death (Mandal *et al.*, 2018).

Effect of fluctuations of DO concentration on oxygen consumption

Environmental factors, such as temperature, alter the oxygen consumption in fingerlings (Burton *et al.*, 2011). Warmer conditions weaken the oxygen transport condition (Norin *et al.*, 2014). Rise in temperature increases oxygen demand of rohu fingerlings; at 36°C the oxygen consumption rate reaches 81mgO₂/kg/h, whereas at 30 °C it's consumption rate remains 57 mgO₂/kg/h. Increases in oxygen uptakes elevate the respiratory load on gills, and a weakened oxygen transport system exerts stress on the rohu's body, leading to lowered swimming ability, decreased energy level, and impaired growth and survival (Islam *et al.*, 2020). In the Indus River, fluctuations in DO affect the body composition of fish, and low temperature further weakens immune system of fish.

Salinity

Salinity is one of the abiotic factors of aquatic ecosystems. It adversely affects the growth, immunity, metabolism, and cognitive behavior (Siddika *et al.*, 2025). Due to climate change, sea level rise increases, which causes the intrusion of saline water into inland areas, especially coastal areas (Shirangi *et al.*, 2016). The aquaculture industry faces major challenges in Bangladesh due to these climatic changes (Islam, 2021; Lema *et al.*, 2024). The 2%, 4%, and 6% increase in salinity level decreases the survival rate of rohu from 98% to 83%, followed by 98-72%, followed by 98-64- 98%, respectively. Every 2% rise in salinity level causes an approximately 2% reduction in body weight (Siddika *et al.*, 2025).

Precipitation

Environmental factors, such as precipitation patterns, drastically change throughout the year (Dastagir *et al.*, 2016; Hussain *et al.*, 2023). Climate change is adversely affecting India's rainfall pattern. Warmer oceans ultimately lead to more intense rainfall patterns. Inter-annual variation in rainfall occurs in India, experiencing both high and low rainfall.

Rainfall below optimal levels leads to low water levels, oxygen depletion impacts growth rate, while above optimal levels leads to flooding, habitat deterioration ultimately decreases population. Climate change causes a reduction in natural breeders by reducing egg and sperm quantity, decreasing egg viability, reducing sperm motility, and lowering ovulation of eggs, which ultimately causes a reduction in the fertilization rate (Degani, 2020). Every living organism performs reproduction to ensure its survival over time. Favorable environmental conditions, such as optimal temperature, precipitation, and photoperiods, align best with the reproductive behavior of rohu. In India, from 1981 to 2010, rainfall pattern changes due to climate change. It increases at Cuttack (27.78 mm) and Puri (13.20 mm), while decreasing at Balasore (16.25 mm), Bolangir (11.25 mm), Angul (18.73 mm), Khurda (-7.4 mm), and Sambalpur (86.88 mm). In the Mahanadi River, fish spawning from 30-43 ml daily per net reduces to 6 ml daily per net due to rainfall fluctuations. *Labeo rohita* breeding starts earlier in hatcheries in Balasore, Khurda, Puri, and Mayurbhanj, which is mainly due to changing rainfall patterns (Sharma *et al.*, 2014).

Direct impact of precipitation on Labeo rohita

Effect on gonadotropin secretion: Environmental clues such as seasonal variation play a substantial role in determining the pre and post-spawning behavior of fish. The monsoon season acts as an important environmental cue which triggers spawning season (Bais, 2018). It is favorable for gonads maturation and promotes spawning, while in dry or cold season fish gonads development slows down. Seasonal variation affects the gonadosomatic index (GSI), which indicates the spawning time and duration in fish. Rohu spawns in flowing waters, and monsoon rains increase water flow, which promotes their gonadal development and ultimately increases gonadotropin hormone secretions. Ovarian development initiates inside the ovary, followed by the release of eggs by females, and the male release of milt (sperm). Alterations in monsoon patterns alter water flow, which affects egg and milt quantity, delays gamete release, and disrupts the reproductive cycles of rohu. These alterations ultimately reduce the diversity, reproductive success, and abundance of *Labeo rohita* (Verma, 2024). The overall impact of environmental factors on rohu is shown in Figure 2.

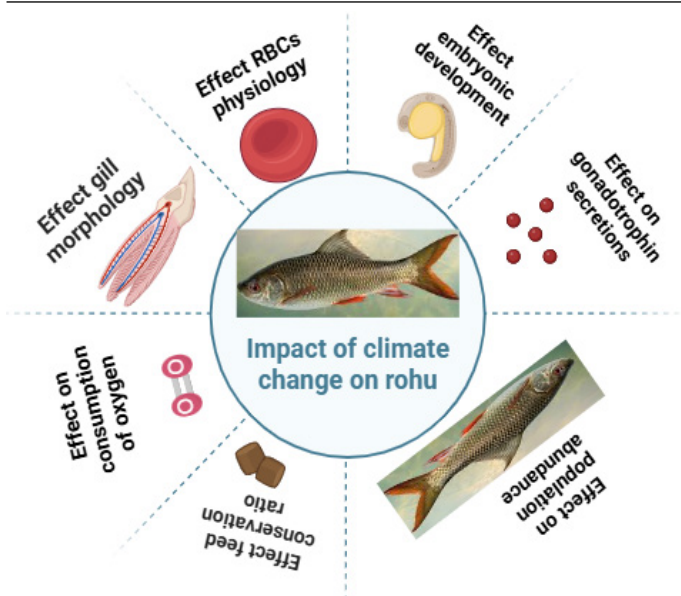


Figure 2: Overall impact of environmental factors on *Labeo rohita* (rohu).

Conclusion

In freshwater fish production systems, *Labeo rohita* is greatly influenced by the environmental conditions for good health, growth, and survival. Of the several environmental factors, temperature, dissolved oxygen, pH, and ammonia are the most important regulators of physiological performance. These parameter alterations directly impact metabolic activity, immune competence, respiration, osmoregulation, and reproductive efficiency. Adaptive physiological mechanisms, such as antioxidant response, hormonal regulation, and heat shock protein synthesis, can tolerate moderate fluctuations of the environment. But, when exposed to adverse circumstances over a period of time, oxidative stress, tissue damage, impaired immunity, feed conversion ratio, and mortality rates increase. These challenges are further magnified in aquaculture production systems by climate change and poor water quality. It is therefore important to ensure proper environmental management, provision of oxygen via aeration, monitoring of water quality, and adoption of climate-adaptive strategies for sustainable production of *Labeo rohita* in ponds. New research is needed on molecular stress markers, selection for environmental tolerance, and the integration of aquaculture to improve productivity and environmental adaptation.

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Novelty Statement

This study provides data on how environmental drivers affect economically and the local Fish species *Labeo rohita*.

Author's Contribution

Iram Asad and Mubashar Hussain conceptualized and wrote the original draft. Arooj Fatima, Sheeza Sakhawat, and Aniza Iftikhar critically reviewed the manuscript and make final editing.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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