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EXPLORING THE IMPACT OF ENVIRONMENTAL FACTORS ON THE GROWTH AND SURVIVAL OF NILE TILAPIA

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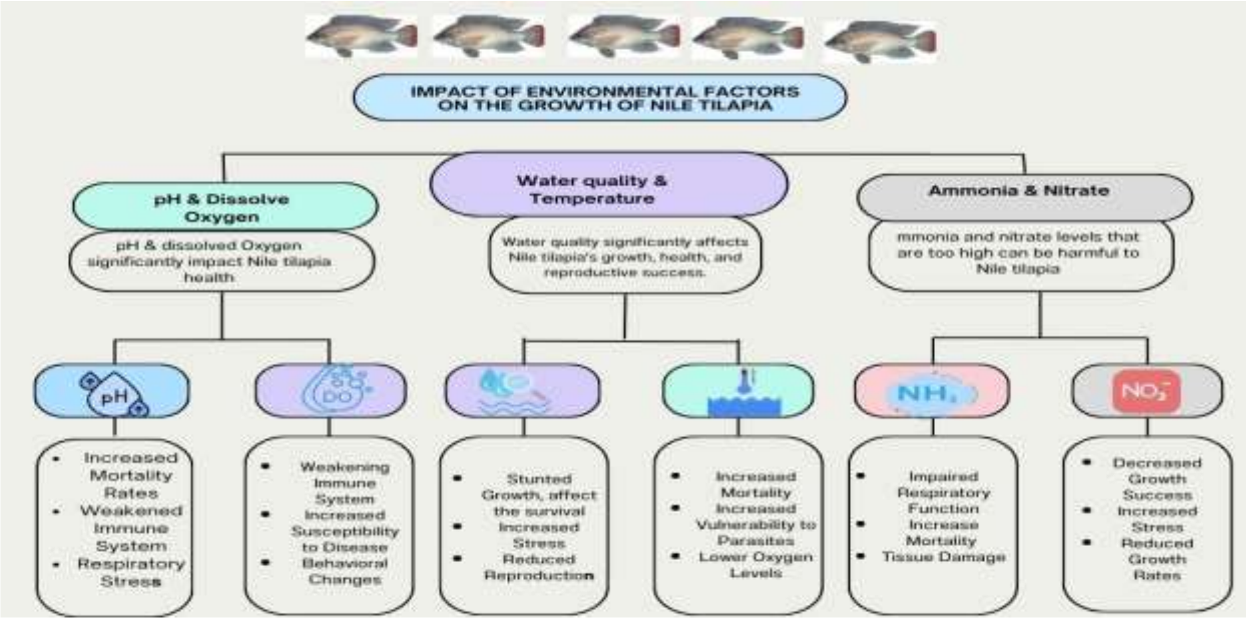
Abstract

The aquaculture industry is gaining popularity day by day because it can fulfil food demands. Nile tilapia is one of the most intensively farmed fish species because it fulfills the demand for animal protein. It contributes significantly to food security and minimizes the unemployment rate in the world's rising population. Nowadays Nile tilapia demands is increasing because of its adaptability, fast growth, and high market demand. But there are different environmental factors which has the potential to impact Nile tilapia. This review article's main objective is to highlight the environmental aspects affecting Nile tilapia's growth and economic output. The study's findings revealed ecological factors such as water quality factors, including nitrite concentrations and dissolved oxygen, pH, feeding density, and stocking densities, are important in tilapia production. High nitrite concentrations were linked to reduced growth and survival rates. Therefore, monitoring and controlling water quality is important to increase Nile tilapia growth and survival rates so that mitigation and adaptation strategies can be done better.



1. **Introduction**

Fish meal is an essential part of feed. Aquaculture is becoming popular day by day due to its diversity and expansion (Sarker et al., 2016). This sector has grown significantly in developing nations due to professionalization, and modernization activities (Arshad et al., 2023). Farmers are becoming more aware of management strategies and key inputs (Moreira et al., 2012). The number of fish fit for consumption by individuals has been increasing by 3.2% per year. In land finfish farming accounted for 65% of the growth in fish production between 2004 and 2014, indicating that aquaculture played an important role in fulfilling the demands of fish (Barange et al., 2018). The breeding and production of aquatic animals, including fish, crustaceans, mollusks, and aquatic plants, is known as aquaculture. Freshwater and saltwater populations are included in aquaculture, which is comparable to commercial fishing for controlled wild fish exploitation (Naiel MA et al., 2020).

3.7 million tons were produced overall, with a value of around 6 billion US dollars carps (grass, silver, and common) ranked first among finfish, with Nile tilapia (Oreochromis niloticus) ranking second in terms of production volume (Action et al., 2020). Fish farming is growing faster as compared to livestock (FAO, 2022). Though there has been significant improvement in fish farming there are fewer achievements and goals because of the lack of use of technology and technical skills. These are significant challenges that must be solved for better farming (De Juvenis et al., 2009). The most extensively farmed fish species is Nile tilapia (Oreochromis niloticus). Its quick growth, effective feed conversion, meat quality, and market acceptance both domestically and globally are the main causes behind this popularity (Schwarz et al., 2010). It can survive in diverse environments therefore it is the perfect choice for fish farmers.

Environmental elements such as salinity, dissolved oxygen, and water quality characteristics can impact the development of Nile tilapia (Oreochromis niloticus) Optimal temperature ranges from 25°C to 30°C, while deviations can lead to decreased growth rates (Azaza et al., 2008). Similarly, maintaining appropriate levels of dissolved oxygen is important. If oxygen amount is increased or decrese it can affect the metabolism and increase mortality rates. The pH of the water affects physiological processes and osmoregulation, if pH increases beyond a certain amount, it can affect the growth. These factors are important to study the physiological processes, behaviour and productivity of the fish (El-Sherif et al., 2009).

Indeed, it can also help to find the mitigation and adoption strategies to reduce the risks associated with climate change and other environmental factors which affect the fish growth. By understanding the impacts of different environmental conditions on Nile tilapia researchers and farmers can develop new techniques to increase growth rates, improve survival, and maintain an overall health system.

Therefore, it is very necessary to gain in-depth knowledge related to these parameters for optimisation of aquaculture as well as sustainable Nile tilapia farming (FAO 2012).
Maintaining a healthy stocking density, supplying the right amount of feed at the right rate and frequency, and regularly monitoring the water quality can all lead to the better development of aquaculture (Abd El-Hack et al., 2022). It is important to recognise how environmental conditions influence their growth and survival to maximise results and preserve fish health. This review summarizes the current understanding of the effects of environmental conditions on Nile tilapia, with implications for aquaculture management

Environmental Factor	**Description**	**Effect on growth**	**Effect on survival**	**Mitigation & Adaptation strategies**	**References**
Stocking density	Low: 10-20 kg/m³, Medium: 30-40 kg/m³, High: >50 kg/m³	Moderate densities optimize growth; very high densities lead to competition for resources	High densities increase stress and disease outbreaks, reducing survival	Maintaining optimal stocking densities, Implementing proper feeding strategies monitoring fish health	(Diana et al. 2004) (Baldwin et al. 2014)
Water quality	Measured in Nephelometric Turbidity Units	Clean water supports better growth; polluted water can affect the feeding and growth	Reducing oxygen uptake and survival, affect the reproductive process	Using filtration systems; reducing runoff and erosion around ponds	(Sriyasak et al., 2014) (Dias et al. 2012)
Water temperature	Optimal range is 25-30°C	Enhanced metabolic rate within optimal range and reduced growth outside this range	Increased mortality at temperatures below 20°C and above 35°C	Use of temperature control systems, reduce heat from ponds, selecting temperature-tolerant strains	(Handeland et al., 2008) (Charo et al., 2007)
Dissolve oxygen	Optimal level: >5 mg/L	Growth rates is maximum at optimal oxygen levels & growth rate is reduced at lower levels	low oxygen can lead to stress, disease susceptibility, & increase mortality	Aeration systems, regular water exchange to maintain oxygen levels	**(**Dong et al., 2011) (Diaz & Breitburg, 2009).
Water pH	Optimal range: 6.5-9.0	Growth rates is good at normal pH range; but very low or very high pH reduced growth	Extreme pH levels can cause stress and mortality	Regular monitoring and adjusting pH with lime to increase organic acids	(Makori et al., 2017) (White et al., 2014)
Ammonia & Nitrate Level	Ammonia optimum level is <0.05 mg/L but the optimum level for Nitrate is <0.1 mg/L	ammonia levels reduce growth due to stress; Nitrite interferes with oxygen transport in blood,	High ammonia concentrations can cause gill damage, reducing survival, however nitrate	Adding chloride to water to mitigate nitrite toxicity; maintaining good biofiltration, avoiding	(Levit 2010). (Stone and Thomforde 2004).

			increased mortality	overfeeding and overstocking	
Light	Natural daylight cycles or controlled lighting	Photoperiods can enhance growth rates due to increased feeding activity	Does not significantly affect survival but influences reproductive cycles	Use of artificial lighting to control photoperiod; optimizing light cycles for growth and reproduction	(Tian et al., 2015). (Qu et al., 2022).

Table 1: Represents the impact of environmental factors on the growth and survival of Nile Tilapia, also represents the adaptation and mitigation strategies

2. Environmental Factors Affecting Nile Tilapia

Life starts form a single cell and there are many factors which can affect the cell (Ather et al., 2024). It is important to give particular attention to the variables that affect the survival rate of tilapia fish. Studying the mechanism of these factors is important because it can help find mitigation and adaptation strategies to enhance the growth of Nile Tilapia. Here are the environmental factors that affect Nile Tilapia.

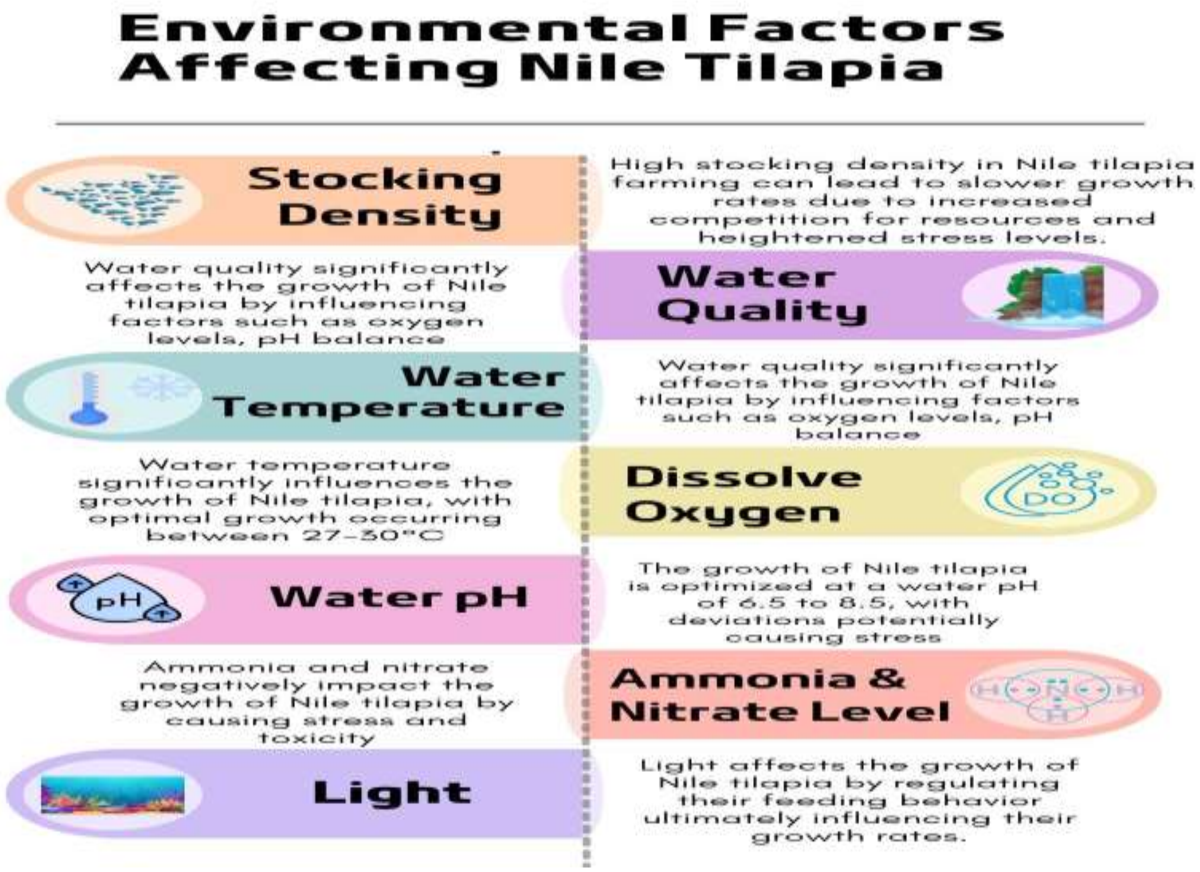


Fig 1 Represents the environmental actors affecting Nile tilapia

2.1. Stocking density

Stocking density is defined as the number of fish kept in a given volume of water. When a few fish are kept in a large pond, then they have more space and less waste is produced. Therefore, it can lead to faster growth. Fewer pathogens are present in large ponds; therefore, fish are generally healthier and experience less stress and sickness. However, in addition to lowering water quality, overcrowding can affect the fish's growth and survival, weaken their immune systems, and increase their chances of diseases but when there is a lot of fish then the fish growth is less because less food is available for the fish (Baldwin et al. 2014).

When Nile tilapia was kept in low population-density ponds grew faster than those put at higher densities. At high stocking density, Nile tilapia's slower growth rate has led to from increased energy expenditure and struggle for food and dwelling space (Diana et al. 2004). On the other hand, decreased competition for food at lower stocking densities may result in less efficient feed consumption and stunted growth. It's possible that the challenges associated with tracking food particles led to decrease feed consumption and decreased feed utilization efficiency. When there is a lot of Nile Tilapia fish, they produce more waste and can affect the water quality, it also affects the dissolved oxygen and produces harmful substances. Yield at low densities is not high enough to offset the cost of production, and waste of feeding materials may result in large increases in production costs. As a result, an optimal density level for the economic sustainability of tilapia production must be determined (De Silva et al., 2004).

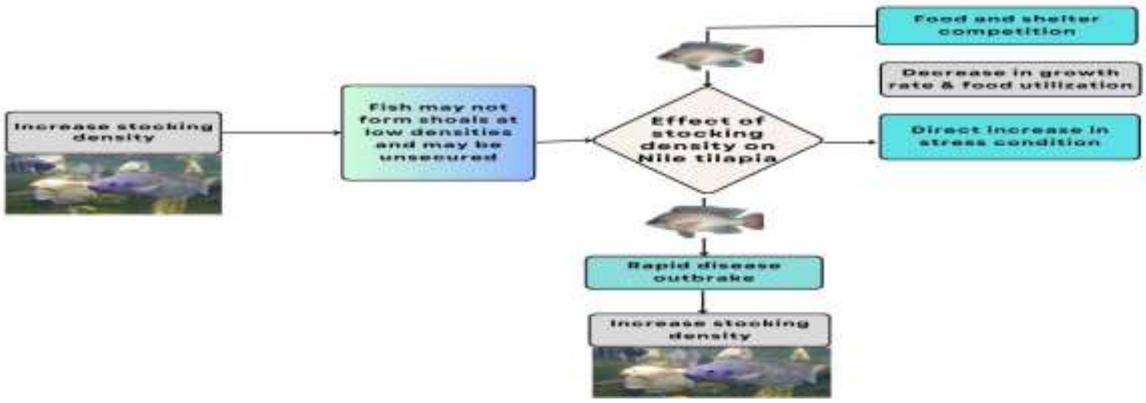


Fig 2: Represents the effect of stocking density on Nile tilapia

2.2. Water quality

Water's chemical, biological, and physical characteristics influence the distribution and functioning of aquatic species. the water used in aquaculture affects feeding, growth, and survival, all of which are influenced by intricate interactions with the weather and other variables. For instance, respiration and phytoplankton development are related to dissolved oxygen (DO) (Chainark and Boyd 2010). Fish excretion of ammonium and the intake of organic matter are associated with nitrogen waste (Sriyasak et al., 2015). Fish cannot eat properly when there are high ammonia levels, low oxygen levels, high carbon dioxide concentrations, and other problems with the water's quality. Fish could die due when there is less oxygen levels and poor water quality (Dias et al. 2012).

The density of different bacterial species in a fish culture can be influenced by physiochemical water properties like pH, nutrients, and poisonous chemicals. It's getting more and more crucial to keep fish pond water quality appropriate (Sriyasak et al., 2014). Water quality is an important factor in the growth of Nile Tilapia. Good water quality means the temperature and pH of the water are optimum, and there is a sufficient amount of oxygen and carbon present in the water. Polluted water can affect the growth of the fish and can become ill thus its survival. Therefore, if we keep the water clean, Nile Tilapia can grow faster, which is good for the people (Chaudhuri et al., 2012).

Fig 3: Represents the effect of water quality on Nile tilapia

2.3. Water temperature

Fish activities such as feeding, behavior, growth and ability to reproduce are affected by temperature. Water bodies' temperature fluctuations are mostly determined by their geographic position, which includes latitude, longitude, and altitude. The physicochemical properties of water are affected by significant temperature and precipitation changes that occur in the tropics between the wet and dry seasons. Warm water has less dissolved oxygen than cold water, the biota has less oxygen accessible to them as temperatures rise (Akin-Oriola et al., 2003). Most fish prefer the perfect environment for growth and survival, though this might vary depending on size and age. For every early life stage, there are different ideal temperatures, which reflect patterns of temporal and spatial distribution. Furthermore, research has been conducted on the growth and development of different fish species with respect to the effects of temperature (Handeland et al., 2008).

One of the key elements affecting tilapia growth is known to be the temperature of the water. Most tilapias survive at a temperature between 26 and 30 degrees Celsius, But if the temperature is 10 degrees Celsius then it can cause the death of Nile Tilapia. When the temperature drops below 20°C, activity and feed consumption will decline (Luan et al., 2010). Thus, introducing Nile tilapia to tropical and temperate locations will result in poor growth and death. Increasing the growing season or producing more crops annually in these settings will help improve tilapia production (Charo et al., 2007). The pH of the water also has adverse impacts on the physiological processes of tilapia. For Nile tilapia, the ideal pH range is 6.5 to 8.5. If the pH is above or below this range then the fish growth is less and fish are susceptible to diseases. Acidic conditions (pH < 6.5) can affect the gill function and decrease oxygen uptake, while alkaline conditions (pH > 8.5) also have severe consequences on the fish, which can cause ammonia toxicity (El-Sherif et al., 2009).

2.4. Dissolved oxygen

For aquatic animals that depend on oxygen dissolved oxygen is very important for them because it is a gaseous oxygen that has been dissolved in water. Through the processes of photosynthesis by aquatic plants or diffusion from the atmosphere, oxygen is dissolved in water by aquatic plants (Singh and Kumar, 2014). When the amount of dissolved oxygen in fresh water becomes low then the aquatic organism becomes hypoxic. Stress, poor appetite, growth, susceptibility to illness, and mortality have been found to be mostly caused by anoxia and hypoxia (Dong et al., 2011). In aquaculture, oxygen is essential for metabolism and growth. Aquaculture has become vital in developing countries for feeding the people. DO requirements vary by species in fish (Wilson, 2010).

Fish require different amounts of DO depending on their species. The DO concentration is commonly expressed as mg/L or percent saturation. 8–8.5 mg/L of DO is needed to support healthy growth rates; concentrations lower than 8 mg/L may have an impact on the development of larvae and mature eggs. Fish frequently experience changes in O2 availability, which can range from low O2 availability to oxygen deprivation depending on their habitat (Diaz & Breitburg, 2009). The amounts of DO affect the overall metabolism and several physiological processes in farmed fish, including nitrite and ammonia toxicity. Most fish survive in DO levels from 5 and 9 mg L^{-1}, while amounts below 3 mg

L−1 and over 9 mg L−1 are harmful to aquatic life. While tilapias are susceptible to low DO levels. Nile tilapia can tolerate short-term interaction with low DO levels of 0.1 mg L−1. However, DO values between 4.2 and 5.9 mg L −1 are the only ones where the species can show optimum performance (Dietrich et al., 2015).

2.5. Water pH

The optimum pH of water is important for the survival of Nile Tilapia. High and low pH can affect the fish. Therefore, the fish are more vulnerable to disease. Extreme pH can cause the death of species therefore maintaining the right pH ensures that the water quality supports the tilapia's health (Makori et al., 2017). A number of variables, such as the carbonate balance, soil composition, rock type, and pollutants discharged into the water, have a significant impact on the pH of water. Clean water's pH is primarily affected by the presence of carbonate minerals (CO42, HCO3−) and CO2. The amount of carbon dioxide (Co2) and carbonates (CO42, HCO3-) in clean water has the biggest impact on its pH (Co2). On the other hand, water with a lower pH contains acidic water (Kreger 2004). Another consequence of pH change in the aquatic environment is altering the amount of phosphate, nitrates, and organic matter used by primary producers (plants and algae). All of the species in the system would suffer from the incorporation of the organic and inorganic molecules, which would lower plant productivity. These species-specific environmental factors have an impact on animal physiology (White et al., 2014).

Fish survival and performance may be impacted when the pH of the water deviates from the range that is suitable for the species. Fish exposed to varying pH levels exhibit changes in their physiology and behavior. For tilapia culture, the water's ammonia content and concentration of hydrogen ions (PH) are also essential. There is no significant difference in the kind and quantity of species found in aquatic habitats based on changes in water pH. The variety and number of species in aquatic habitats are not significantly affected by rising or decreasing water pH. However, a considerable pH shift can have a significant impact on the variety and organism composition because fewer plants and animals are able to survive such extreme weather conditions in freshwater systems (Salih 2007).

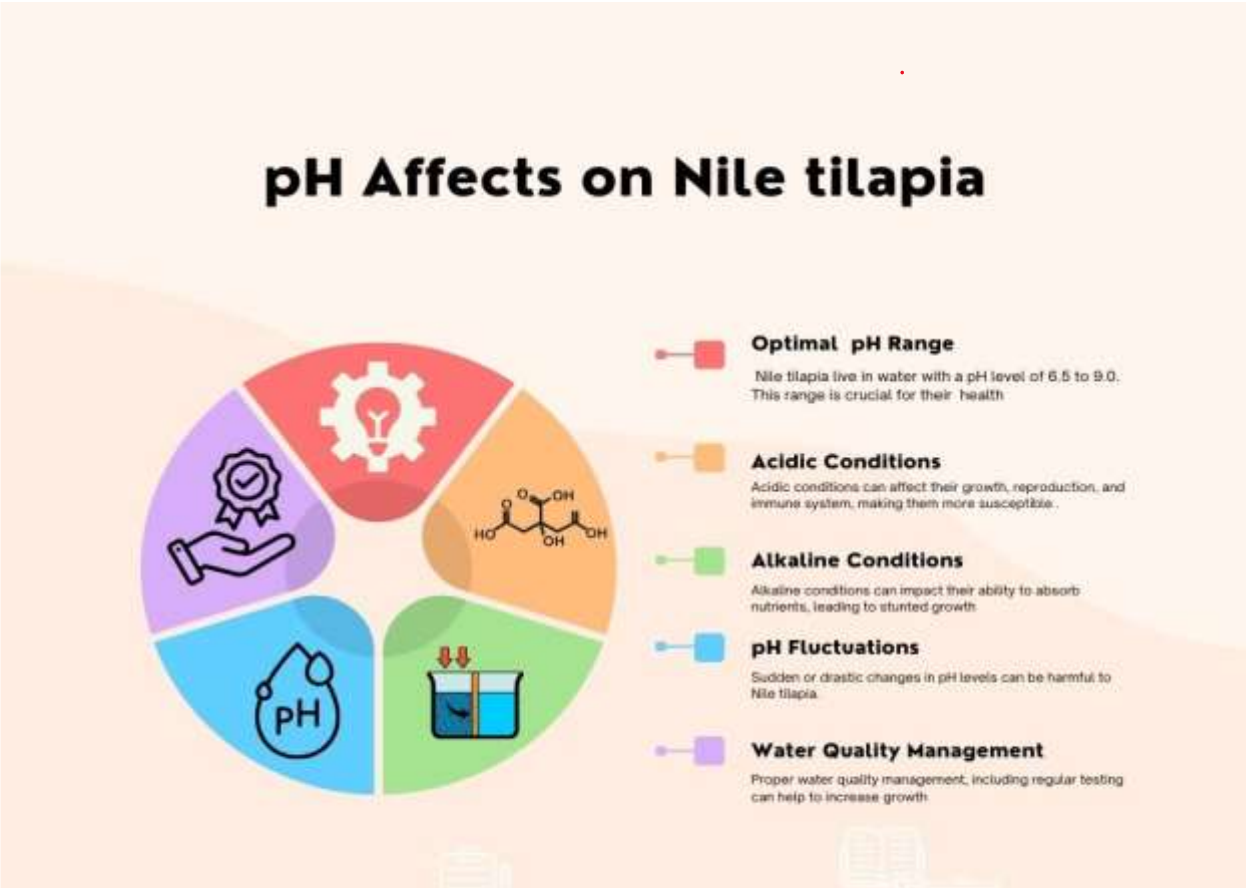


Fig 4: Represents the effect of pH on Nile tilapia

2.6. Ammonia and nitrate level

Higher concentrations of ammonia and nitrate are not suitable for the growth of Nile tilapia. Ammonia is harmful to fish and can damage the gills. It can affect the lungs of fish and affect the breathing process. Nitrate which is less toxic as compared to ammonia, can lead to poor quality of water. Ammonia is found in streams, rivers, and some water sources (Abd El-Hack et al., 2009). It is the most significant nitrogenous waste produced due to organic matter decomposition. Ammonia is found in streams, rivers, and some water sources. It is the most significant nitrogenous waste produced due to organic matter decomposition (Fatima et al., 2024). Particularly at low pH values, it dissolves readily in water. Depending on pH and temperature, water contains varying amounts of both ionized (NH4+) and un-ionized (NH3) ammonia. According to Stone and Thomforde (2004), fish are negatively impacted by a rise in the fraction of unionized nitrogen with pH. During phytoplankton outbreaks, ammonia and carbon dioxide are also discharged into the seas (Ummer K et al., 2024).
At higher temperatures and pH levels, ammonia is more harmful to marine life than nitrogen. A higher pH indicates a higher concentration of unionized ammonia. For every unit increase in pH, the NH3 to NH4 ratio rises by 10, and for every 10 units increase in temperature (Levit 2010). Ammonia and ammonium nitrogen are both produced by ammonium nitrogen. Both ammonia and ammonia nitrogen are transformed into nitrite (NO2) once ammonia has been produced. Fish farms are the major cause of contamination of water. These farms are connected with high nitrogen and nutrient levels, which can result in destroying the growth of algae. For Nile tilapia to better survival and growth, it is important to maintain the ammonia and nitrate levels by maintaining the water system (Abd El-Hack et al., 2009).

Parameter	Low Ammonia & Low Nitrate	Low Ammonia & High Nitrate	High Ammonia & Low Nitrate	High Ammonia & High Nitrate	References
Harmful Effects	No harmful effects at low Ammonia and Nitrate level	Increased susceptibility to disease, Reduced reproduction	Reduced growth and Increased stress	High mortality can cause growth inhibition, and major health issues	(Abd El-Hack et al., 2009)
Positive Effects	Optimal growth, High survival rate	Moderate growth and high survival rate	Moderate survival and reduced competition	There is no positive effect at higher concentration of Ammonia and Nitrate	(Stone and Thomforde 2004).
Mitigation Strategies	Regular monitoring, Maintain low feed waste	Regular water changes, Use of nitrate-absorbing plants	Biological filtration and reduce stocking density	Frequent water changes, Advanced filtration systems, Use of denitrifying bacteria	(Rashid et al., 2021)
Adaptation Strategies	Stable feed practices, Optimal management	Maintaining feeding strategies, and maintain water quality	Use of fish strains to improve aeration	Integrated water treatment systems, and regular	(Ciji et al., 2020)

				health monitoring	

Table 2: Represents harmful effects of ammonia and nitrate on the Nile Tilapia, and also represents the adaptation and mitigation strategies

Light

For fish to grow and survive, light is essential. Fish production indoors is influenced by the lighting conditions. The amount of photoperiod affects the nile tilapia's growth and response. Light has a direct impact on fish's ability to survive and respond to immunization (Tian et al., 2015). Light affects the growth of Nile tilapia by affecting their metabolic rates. Optimum light improves growth by maintaining the tilapia's growth. It also affects the fish's metabolic processes and has severe consequences on the survival rate of Nile tilapia. Insufficient light can affect the immune responses, and fish are susceptible to immune responses. For Nile tilapia better growth, it is necessary to maintain optimum lighting conditions (Hui et al., 2019).

Fish which receive inadequate light have poor growth, therefore the mortality rate increases in it. The extremely low light treatment reduced fish survival to 90.6%. Nile tilapia are visual carnivores that require a minimum of light intensity to feed and grow properly (Copeland et al., 2006). Bacterial multiplication is directly affected by changes in the physicochemical properties of aquaculture water, such as pH. Seawater pH usually ranges from 7.5 to 8.5, depending on several factors such as light, temperature, pressure, and the respiration activities of microorganisms (Qu et al., 2022).

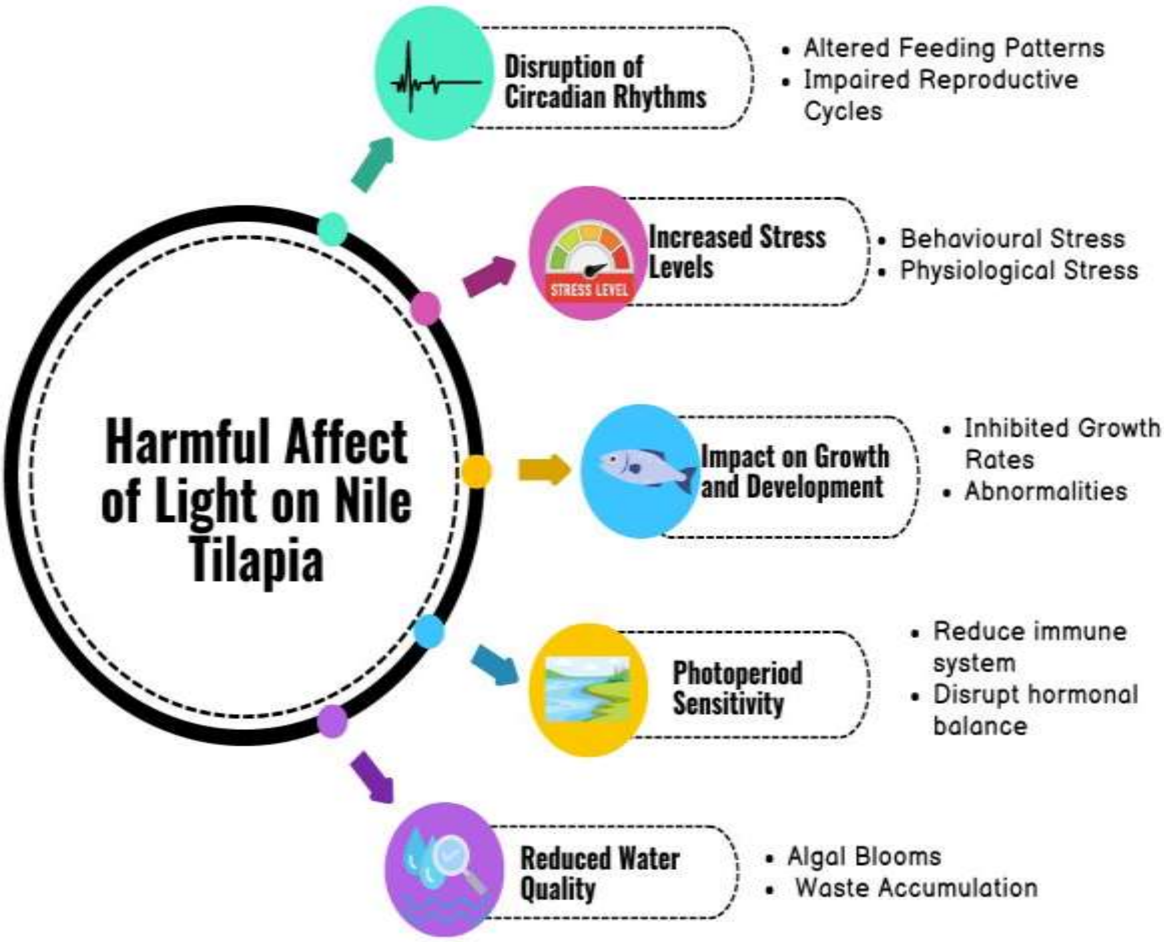


Fig 5: Represents the affect of light on Nile tilapia

3. Mitigation and adaptation strategies

Adopting mitigation and adaptation strategies for Nile tilapia can help to minimize the harmful effects of varying environmental factors. It can also help in policy making so that decision ca be taken in a good way. The mitigation strategies for Nile tilapia include the sustainable feed options, adopting advance water management techniques, and minimizing the pollutants and amount of nitrates from the water so that fish has better survival rate (Rashid et al., 2021). By adopting these strategies, farmers can help to reduce the amount of contaminated waste which is not good for fish. Adaptation strategies for Nile tilapia involve proper maintaining the farming practices to resist with changing environmental conditions. This include improving breeding programs to develop better fish strain, implementing disease management practices, and maintain feeding schedules for better fish survival. These strategies help farmers to adapt to challenges such as minimizing the effects of climate change (Ciji et al., 2020).

4. Summary

Aquaculture has become popular due to its diversity and expansion (Sarker et al., 2016). This sector has increased significantly in emerging countries as a result of advancement and modernization. In emerging countries, this industry is growing significantly as a result of modernization and professionalization efforts. Farmers are learning more about important inputs and management techniques Similar to commercial fishing for controlled wild fish exploitation, aquaculture involves both freshwater and saltwater populations (Naiel MA et al., 2020). Carps (grass, silver, and common) rated first among finfish with a total production volume of 3.7 million tons, valued at around 6 billion USA dollars. Nile tilapia (Oreochromis niloticus) placed second in terms of production volume (Action et al., 2020). The environmental factors that impact Nile tilapia (Oreochromis niloticus) development, health, and survival include salinity, temperature, pH, dissolved oxygen, and water quality indices. 25°C to 30°C is the ideal temperature range; variations can result in slower development rates (Azaza et al., 2008).

Maintaining enough levels of dissolved oxygen is important. If the amount of oxygen increases or decreases, it might influence metabolism and raise death rates. The pH of the water influences physiological processes and osmoregulation; if the pH rises above a specific level, it can have an impact on growth. These parameters are critical for studying the physiological processes, behaviour, and production of fish (El-Sherif et al. 2009). It can also help to find mitigation and adoption measures to minimize the hazards associated with climate change and other environmental factors that affect Nile tilapia growth and survival. This review article highlights the importance of research to understand the effects of environmental factors on Nile tilapia so that its affect can be minimized in future. Such research is important for sustainable aquaculture systems that can fulfill the demands of fish food.

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