Review Article

Journal of Advanced Veterinary Research
(2024) Volume 14, Issue 6, 1060-1064

Significant impact of physicochemical water parameters in tilapia aquaculture

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ARTICLE INFO

Recieved: 21 April 2024

Accepted: 22 June 2024

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Keywords:

Aquaculture, Water quality, Tilapia, Nile tilapia

ABSTRACT

Water quality is an important part of any aquaculture system. Water provides aquatic animals with oxygen, allows for waste removal, and is the conduit for their food. Similar to all other organisms, fish are heavily influenced and dependent on the characteristics of their environment. Non-optimum water physicochemical parameters as dissolved oxygen, pH, salinity, ammonia, temperature etc. can cause stress to the cultured fish and thus make them more susceptible to disease outbreaks. Nile tilapia is the most cultured fish in Egypt. While its sustainable production is hindered by many obstacles. One of them is the water quality, therefore the hygienic effects of the water parameters are important to be clear in culturing.

Introduction

Water is one of the most important available resources on the earth. Fish carry out all bodily functions in water and the physicochemical characteristics of water significantly affect fish life, mostly due to the close relationship between their bodily fluids and the water in the surrounding environment (Toni *et al*., 2019; Agyakwah *et al*., 2020). Therefore, water is a critical component of any fish-farming venture Water quality is expressed by a range of physical and chemical parameters and it is the most important factor when considering the management and maintenance of aquatic species (Ahmed *et al*., 2000; Sanders and Farmer, 2020). Water quality affects fish feeding, growth, disease burdens, health, performance, quality characteristics of farmed fish and survival rates (Chainark and Boyd; 2010; Pandit and Nakamura, 2010; dos Santos *et al*., 2017). Aquatic life becomes stressful when the water physicochemical and biological parameters have been altered, which vulnerable the organism for infection (Joseph *et al*., 2017). Therefore, the maintenance of a good water quality is essential for fish health and welfare as well as for the conservation of the aquatic environment (Mercante *et al*., 2018).

Hygienic effects of water physicochemical parameters with reference to the optimum range for tilapia culture

All living organisms have a tolerable limit of each water quality parameter in which they perform optimally. Sharp drop or an increase within these limits can cause an adverse effect on their metabolic functions (Joseph *et al*., 2017). Environmental conditions, such as temperature, pH, ammonia, salinity and oxygen availability, constitute major selection criteria in the habitat selection of fishes (Frisk *et al*., 2012).

Water temperature

Water temperature is one of the most significant environmental factors that influence the physiology and energetics of fish and defines the metabolic scope of an individual (Xie *et al*., 2011). Being cold-blooded poikilothermic animal, fish is affected by the temperature of the surrounding water which influences the body temperature, growth rate, food consumption, feed conversion and other body functions (Pandit and Nakamura, 2010). Besides, their distribution, survivability, and different physiological activities, including the immune response, fish is directly affected by the ambient temperature that of its surroundings (Bowden *et al*., 2007). Temperature change affects physiological processes in fish (growth, metabolism, reproduction, etc.), which leads to significant decreases in fish abundance, in extremes leading to distribution shifts (Cheng *et al*., 2013; Shahjahan *et al*., 2017). Fish immune response and the replication of pathogens are often correlated with water temperature, which manifest as temperature ranges for infection and clinical diseases (Marcos-López *et al*., 2010). Severe temperature elevation can be a stressor in itself (Balta *et al*., 2017; Samaras *et al*., 2018), therefore increasing water temperatures induce endemic diseases (Marcos-López *et al*., 2010; Rodkhum *et al*., 2011; Soto *et al*., 2012; Noraini *et al*., 2013). Lower temperature also negatively affect fish survival and growth performance (El-Sherif and El-Feky, 2009). Nile tilapia is a tropical species their distribution is limited by a lower lethal temperature of 11–12°C, and an upper lethal temperature of 42°C (FAO, 2021). Optimal rearing temperature for fingerlings is 25 – 30°C (El-Sherif and El-Feky, 2009), and for juveniles and fries 27 – 32°C (Pandit and Nakamura, 2010).

Water ammonia

Ammonia is a nitrogenous byproduct, one of the most common stressors to fish health and production (Shokr, 2020). Fish is the primary source of ammonia in aquaculture, fish excrete ammonia as a waste product after metabolism (Sanders and Farmer, 2020; Shokr, 2020). Also, when uneaten food or organic matter decomposes, ammonia is produced (Sanders and Farmer, 2020). Due to ammonia natural occurrence in the aquatic life, the suitable level for pond fishery is < 0.2 mg /L (Bhatnagar and Singh, 2010). Ammonia in the range > 0.1 mg /L affect fish at both

ISSN: 2090-6277/2090-6269/

cellular and tissue levels, causing gill and mucous producing membranes damage, disrupting the fish osmoregulatory, respiratory and excretory processes (Franklin and Loveson, 2019). Also, ammonia has a significant impact on fish growth and reproductive functions (Shokr, 2020). Ammonia in tilapia farms, considered as the main cause of increased mortality due to disease infection as ammonia toxicity decrease the fish oxidative resistance, resulting in lowering fish immune function rendering exposed fish susceptible to infection (Esam *et al*., 2022; Elshopakey *et al*., 2023).

Water dissolved oxygen

Water dissolved oxygen is a main limiting factor in fish farming because fish have aerobic metabolism requiring dissolved oxygen at efficient levels (Abdel-Tawwab *et al*., 2019). Depletion of dissolved oxygen in aquaculture water causes great stress on fish inducing immune suppression with subsequent susceptibility to infection (Abdel-Tawwab *et al*., 2014; Abdel-Tawwab *et al*., 2015). It's critical to ensure that the dissolved oxygen content is always higher than the lowest value as low dissolved oxygen level is associated with restricted growth and high mortality threat (Ferreira *et al*., 2011; Rahman *et al*., 2020). Both hypoxic and hyperoxic conditions cause negative influence on aquaculture (Shultz *et al*., 2011). Optimal oxygen saturation is a vital in survival, growth, and normal physiological functions of aquatic organisms, therefore, tightly controlled in intensive aquaculture facilities (Yang *et al*., 2017; Schäfer *et al*., 2021). Dissolved oxygen is also vital to the decomposition of harmful substances at the bottom of the pond. It takes 4570 g of oxygen to oxidize 1000 g of ammonia to nitrate; as the nitrification reaction was blocked under low dissolved oxygen concentration (Li *et al*., 2019; Zhang *et al*., 2020). Dissolved oxygen level at 4 or 5 mg/L or higher is considered as an ideal requirement in aquaculture production (Boyd, 2003). The recommended minimum dissolved oxygen requirements for tilapia fish is 5 mg/L (80% saturation) (Mallya, 2007).

Water pH

Water pH plays an important role in homeostasis of aquatic animals (Miron *et al*., 2008). Water ranging in pH 6.5-8.5 is usually the most suitable for pond fish production (Mohammad and Haque, 2021). Increase or decrease of pH is reported to cause disturbances in acid–base balance, ion regulation and ammonia excretion (Schlenk and Benson, 2001). pH levels that change abruptly cause acute stress and continually elevated or lowered pH levels can cause chronic stress (Zahangir *et al*., 2015).

Water electrical conductivity

Water electrical conductivity (EC), is a measure of the ability of an aqueous solution to carry an electric current, or is the measurement of the ability of water to pass through electricity (Choo-in, 2019). This ability depends on the presence of ions; on their total concentration, mobility, and valence; and on the temperature of measurement. It is an indicator of the type and number of ions present or dissolved in water or in solution, which are almost proportional to the amount of dissolved matter. Freshwater fish thrive over a wide range of electrical conductivity. The desirable range is 100-2,000 µS/cm and the acceptable range is 30- 5,000 µS/cm (Stone and Thomforde, 2004). The conductivity of water is a very important index to measure water quality, which can reflect the degree of dielectric in water (Xianhong *et al*., 2021). Interestingly, Canli and Canli, (2015) showed that low conductivity caused more copper toxicities in Nile tilapia.

Water salinity

Water salinity is one of the most important environmental determinants that influence survival, growth and distribution of fishes (Kang'ombe and Brown, 2008; Küçük, 2013). The term salinity refers to the total concentration of all dissolved ions in a natural water, it is the total dissolved solids (TDS) concentration, expressed in milligrams per liter or parts per million (Sanders and Farmer, 2020). Inadequate salinities can trigger negative responses, affecting the growth and survival of freshwater fish (Mohamed *et al*., 2021), while , salinity stress induced several severe impacts on aquatic animals (Nassar *et al*., 2021; Dawood *et al*., 2022). Hyper salinity has harmful effects on growth behavior, osmoregulation, physiological status and immunological responses among freshwater species (Jafari and Mazandarani, 2020; Bu *et al*., 2021), and the high water salinity levels can increase oxygen demand and decrease fish growth and well-being (Remen *et al*., 2008; El-Dahhar *et al*., 2011). Decreased salinity also negatively affect weight gain and antioxidant status of aquaculture fish (Gan *et al*., 2016).

Nile tilapia

Nile tilapia (*Oreochromis niloticus*) are among the most important farmed aquatic species in the world, cultured in more than 127 country worldwide (Cai *et al*., 2019; FAO, 2020), Tilapia is native to Egypt and other parts of tropical and subtropical Africa (Elgendy *et al*., 2022). Tilapia is currently the second largest farmed finfish group in the world, only after carps (Perschbacher, 2014). The cultivation of Nile tilapia has grown steadily in recent years, reaching a global production of 4.5 million tons (FAO, 2020). Water quality is a critical component in tilapia aquaculture system, sharp drop or an increase within these limits can cause an adverse effect on their metabolic functions (Joseph *et al*., 2017), and disease susceptibility (Yazdanpanah-Goharrizi *et al*., 2020), therefore, a regular monitoring is recommended (Kibaara *et al*., 2020). Moreover, there are many studies that evaluated the water quality parameters during tilapia fish farming.

Worldwide tilapia aquaculture water physicochemical parameters surveillance

Tilapia aquaculture water quality parameters recorded around the world as Suanyuk *et al*. (2008) investigated water quality parameters during the disease outbreak in infected red tilapia and Nile tilapia cultured in Thailand. They found the level of parameters included were salinity 1.2 %, pH 7.08 – 8.15 and temperature ranged from 25 to 32°C.

Li and Cai (2011) measured the water quality parameters of 34 ponds for farming juvenile tilapia; Water quality parameters in farmed tail-rot diseased juvenile tilapia were temperature 25.56°C, pH 7.75, dissolved oxygen 8.25 mg/L, and in farmed healthy tilapia: temperature 25.61°C, pH 7.51, dissolved oxygen 9.28 mg/L. As well as, Alsaid *et al*. (2013) reported that environmental conditions at temperature 33°C, salinity was 15 ppt, and pH was 6, which increased the susceptibility of red hybrid tilapia to *Streptococcus agalactiae* infection.

Kayansamruaj *et al*. (2014) recorded water quality parameters in-situ from earthen ponds and irrigation canals supplying water to tilapia ponds in Thailand, as pH: 7.5–8.0, salinity 0–0.4%, dissolved oxygen 5–10 ppm. Additionally, Asencios *et al*. (2016) determined the physiochemical parameters of water samples in farmed Nile tilapia from Piura, Peru between February and June 2014.The parameters were for nursery fish as temperature 25.4°C, dissolved oxygen 4.2 mg/L and pH 7.3, while for Grow-out fish as temperature 25.2°C, Oxygen 4.0 mg/L, pH 5.8 ± 0.8.

Assis *et al*. (2017) evaluated water dissolved oxygen concentration, water temperature and daily mortality data covering a 50-days period prior to the day of fish sampling in farmed Nile tilapia in Brazil. The dissolved oxygen ranged from 0.9 to 7.8 mg/L in the early morning (7 a.m.) and late afternoon (4 p.m.), respectively. In 42 of the 43 days of the period analyzed, the dissolved oxygen was lower than 3 mg/L inside the cages in the morning, creating a hypoxic condition. The water temperature ranged from 22.2 to 26.9°C. The farm had a history of outbreaks caused by Streptococcosis during the summer of the current year and francisellosis in the winter of the previous year, both with positive laboratory results, so they considered water parameter fluctuation as the main cause of *Streptococcus agalactiae* and *Francisella noatunensis* coinfection in farm-raised fish.

Makori *et al*. (2017) assessed the impact of earthen pond water physicochemical parameters on the growth of Nile tilapia in six earthen fishponds under semi-intensive culture system in Teso North Sub-County, Kenya. The authors found that mean values of physicochemical parameters were dissolved oxygen 4.86–10.53 mg/L, temperature 24-26°C, pH 6.1– 8.3 and conductivity was 35– 87 µS/cm. Moreover, they stated that dissolved oxygen and pH in the ponds were within the optimal levels for growth of tilapia, while temperature and conductivity were below optimal levels. As temperature and dissolved oxygen increased, the growth rate of tilapia increased. However, the increase in conductivity, pH and ammonia decreased fish growth rate. While, Mercante *et al*. (2018) monitored the water quality of six tilapia production systems located in three reservoirs of São Paulo state (Brazil) during 2014-2016. Their results showed that 41.2% of the temperature data were lower than 27ºC and the pH was neutral to alkaline.

Also, Ojwala *et al*. (2018) measured some selected physicochemical parameters in situ in Nile tilapia fish farms within Nakuru in Kenya from November 2016 to February 2017. Egerton fish farm had the highest concentration of dissolved oxygen (15.80 mg/L), and Kuresoi fish farm had the lowest level (8.35 mg/L). The highest and the lowest mean water temperature were 26.66 and 20.52°C in Arahuka and Subukia fish farms, respectively; the highest pH was recorded in Egerton (11.31), and the lowest was in Dundori (7.57), and the highest mean conductivity was 412.85 µs/cm at Egerton fish farm, whereas the lowest was 70.36 µs/cm in Kuresoi fish farm.

Baleta *et al*. (2019) showed that most incidents of fish mortality in tilapia cages in Magat Reservoir, Philippines occurred during the summer season (March to June). Farmers argued that, the primary causes of fish mortality include fluctuating temperature (91.25 %) and water quality (83.75 %).

Adamba *et al*. (2020) noticed that there were both positive and negative relationships between some water quality parameters and the prevalence of parasitic infestation in Nile tilapia in the springs of Lorwai swamp and lake Baringo, Kenya.

In addition, Kibaara *et al*. (2020) recorded water parameters of fish ponds in Kenya. Pond water temperatures ranged from 22.83°C in July 2016 in the Chogoria area within the Upper Zone to 31.59°C in September 2016; dissolved oxygen varied from 4.68 mg/L in December at Itugururu to 9.35 mg/L at Kiaritha in April; Water pH among the study ponds ranged from 5.21 to 7.96. The authors stated that the parameters were outside the recommended range for optimum Nile tilapia growth, which could explain the frequent fish deaths and low aquaculture production. Interestingly, Yazdanpanah-Goharrizi *et al*., (2020) found that in isolating Aeromonas hydrophila from cultured Oncorhynchus mykiss in Iran that, when the levels of dissolved oxygen have decreased and the levels of nitrite and ammonia have increased throughout the year, Aeromonasias is increased. Waruiru *et al*. (2021) investigated the physicochemical parameters of water in 31 farmed fishponds for Nile tilapia, African sharptooth catfish, goldfish and Common carb from December 2017 to April 2018 in Kirinyaga, Kenya. The parameters were pH 7.4, dissolved oxygen 5.9 mg/L and water temperature 25.3°C.

Tilapia aquaculture water physicochemical parameters surveillance in the Egyptian tilapia aquaculture

Eissa *et al*. (2010) analyzed the water parameters of Nile tilapia and Nile catfish earthen pond in Sharkiya Governorate, during an acute episode of mass mortality during the early summer of 2009. The results showed an abrupt increase in temperature from 25 to 30°C, pH from 6.5 to 8.8, and sharp decrease in dissolved oxygen from (6 to 3 ppm), these were the environmental stimulus that initiated and boosted the infection.

Exposure to extreme cold-water temperature, also, considered a significant constraint to tilapia fish survival, and associated with huge mortalities approached 98 % have been recorded in earthen-pond cultured tilapia within Barsiq farm, northern Egypt during the period from December 2013 to February 2014. Temperature, pH, and dissolved oxygen were 5.2 °C, 8.18 and 3.5 mg/L, receptively (Elgendy *et al*., 2015). Meanwhile, Abdel-Latif and Khafaga (2020) assessed the water quality parameters in three earthen ponds reared with Nile Tilapia in Behiera Governorate, Egypt with mass mortality during summer 2016, they reported that water parameters were dissolved oxygen 5.5–6 mg/L, Temperature 27.4–28°C and pH 8.4.

Ali *et al*. (2020) recorded the water quality parameters of 20 water samples collected from 4 different fish farms at different locations in Kafr El- Sheikh Governorate. The results revealed that mean value of pH 8.2 and dissolved oxygen 7.44 mg/L. In addition, El-Gohary *et al*. (2020) measured physicochemical water quality parameters in three farms for Nile tilapia culture in Kafr El-Sheikh, Egypt, in March and August 2017; All water physicochemical parameters were notably higher in August than March. At the farm level in relation to the studying period, Farm III displayed the highest levels of temperature, pH, and dissolved oxygen among all examined farms in August as follows: 30.8°C, 8.9, 4.7 mg/L, respectively. Meanwhile, electrical conductivity and total dissolved solids achieved the maximum values in farm IV during August were 3968 mho/cm, and 1978.6 mg/L, respectively. This refers to relation of the adverse impact of water quality and motile aeromonads as a repository of antimicrobial resistance in the aquaculture industry in Egypt.

Abdelsalam *et al*. (2021) investigated the high mortality rate linked to poor water quality parameters among Nile tilapia and African catfish polyculture in earthen ponds in Manzala, Egypt during early autumn of 2020. Their study indicated the presence of adverse water quality parameters, accompanied by increased bacterial counts in water, rendered farmed fish susceptible to bacterial diseases. While, Abdel-Moneam *et al*. (2021) investigated water chemical parameters in Nile tilapia farms with mass mortality episodes in Kafr El-Sheikh, Egypt. They found that the water temperature was 31.33°C, dissolved oxygen was 6.43 mg/L and total dissolved solids was 422.6 mg/L.

Furthermore, El-Son *et al*. (2021) highlighted the synergistic interactions between poor water quality and the presence of aquatic microbial pathogens such as Aeromonas hydrophila and Vibrio parahaemolyticus associated with high mortality rates (75–85 %) during the summer season in Manzala, Egypt.

Ghetas *et al*. (2021) performed physicochemical analysis of water sample in farmed Nile tilapia with Streptococcus mass mortality at Baltim region, Kafr El-Sheikh Governorate, Egypt, during the summer of 2019. The authors found that the dissolved oxygen value was lower than the optimum level (3.8 mg/L), water temperature 29.7°C and pH was 8.2, receptively. Moreover, they stated that these deteriorated parameters contribute to Streptococcus infection susceptibility.

Additionally, Reda *et al*. (2021) surveyed the water quality parameters in Egyptian fish farms with summer tilapia mortality outbreaks at different localities along the Nile Delta, including El- Abbassa, Sahl El- Husseineya, Idku, El- Ismailia, Port Said, Kafr El- Sheikh, Tell El- Kebir, El- Faiyum, El-Manzalah and El- Dakahlia. They noticed that water quality degradations in most surveyed fish farms were dissolved oxygen 6-8.1 mg/L, pH 8-8.6 and water temperature ranged from 28 to 32.5°C Moreover, they reported that the increase in water temperature with alkalinity of water pH increases fish susceptibility to bacterial diseases.

Conclusion

The water physicochemical quality parameters management is a critical step in aquatic environment. Temperature, ammonia, dissolved oxygen, pH, salinity, electrical conductivity, and other physicochemical parameters have an impact on all aquatic creatures, as well as affecting aquatic species' immunity, susceptibility to infection, and growth. All aquatic animals including tilapia fish have a bearable limit of each water quality parameter in which they can survive and optimally perform. Likewise, when the water physicochemical or even biological parameters altered, the aquatic life becomes stressful. Stress makes the aquatic animal vulnerable for infection.

Conflict of interest

The authors declare that they have no conflict of interest.

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