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EFFECTS OF MAGNETIC WATER ON PRODUCTIVE PERFORMANCE, BEHAVIOUR, AND SOME PHYSIOLOGICAL RESPONSES OF NILE TILAPIA FISH (*OREOCHROMIS NILOTICUS*) REARED UNDER NORMOXIA AND HYPOXIA CONDITIONS

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ABSTRACT

This study aims to examine the effects of magnetic water on behaviour, performance and some physiological parameters of Nile tilapia fish and the physicochemical properties of water. Forty-eight Nile Tilapia fish with 30.95±1.75g in weight were reared under normoxia conditions and classified into two groups (n=12/aquarium, 2 replicates). Group 1: fish raised in non-magnetized water (control). Group 2: fish raised in magnetic water using a magnetic field, 18000 Gauss (MW). Fish performance, behavioural and physiological responses were examined as well as water quality parameters of the fish aquarium were measured. At the end of the experiment, fish (n=6/aquarium, 2 replicates) of two groups were exposed to 8 hours of hypoxia. Fish behaviour was recorded and water quality parameters of the fish aquarium were measured. Results revealed that the body weight and body weight gain of fish were significantly *(p<0.05)* increased, however, feed conversion ratio was decreased for fish reared under the use of water magnetization. Magnetic water fish showed high comfort behavioural activities with low surfacing and eliminative behaviours. Water magnetization improved significantly the dissolved oxygen, ammonia, and turbidity of the fish aquarium. Magnetic water fish showed high total protein and globulin with a lower plasma glutathione reductase (GSH). Fish of magnetic water showed a significant increase in resting and a decrease in surfacing, chasing, and biting with lower plasma cortisol when exposed to hypoxia condition. The dissolved oxygen of magnetic water was significantly more than the dissolved oxygen of normal water after hypoxia exposure. These findings suggest that using magnetic water has significant performance and behaviour benefits, as well as reduced hypoxia stress effects in Nile tilapia fish.

Keywords: *Magnetic water, performance, normoxia, hypoxia stress, Nile tilapia*.

INTRODUCTION

Aquaculture is an important source of seafood than other fishing. Now aquaculture accounts for 46.8% of total global fish production (Bharathi *et al.,* 2019). Moreover, industrial aquaculture is growing rapidly in many developing countries due to the depletion of fisheries and market forces aimed at globalizing food sources (Goldburg and Naylor, 2005). Fish is one of the best and cheapest sources of lean meat, and more than half of the world's population relies on it for protein sources (Naga and Mahaboobi, 2016). Tilapia is the second worldwide cultured species after carps. The most

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common breed of tilapia farmed around the world is the Nile tilapia (*Oreochromis niloticus)* which accounts for roughly 75 percent of farmed tilapia (Hansh and Sharma, 2018).

Generally, good water quality includes temperature, dissolved oxygen, pH, ammonia, nitrate, and nitrite content that are necessary for the optimal growth of fish, reducing stress, and preventing the spread of diseases (Carbajal-Hernandez *et al.*, 2013).

A biological technique using the magnetic field is considered a simple simulation of what happens in nature, as water is subjected to a magnetic field to become more biologically active (Molouk and Amna, 2010). Magnetic water means passing water through magnetic tubes, putting a magnet in the water or through a magnetic field. The properties of water change to become very fertile and active, causing an increase in oxygen ratio, the velocity of dissolved salts, and amino acids in water (Al-Nuemi *et al.*, 2015).

Moreover, the magnetic field improves the parameters of the water quality. After exposing water to a magnetic field, there is a great change in pH, total dissolved solids, total hardness, conductivity, salinity, dissolved oxygen, evaporating temperature, minerals, organic matter, and the total count of bacteria (Yacout *et al.*, 2015). Also, decreasing water turbidity accelerates the degradation of organic waste (Alabdraba *et al.*, 2013)**.** Moreover, the main factors affecting the degree of magnetization are the quantity of water and the time of contact between the water and the magnetic field (Krzemieniewski *et al.*, 2002)**.** It is known that magnetized water can affect the growth of fish from the embryo to the adult stage (Formicki, 2008). Recent research reported that magnetic water treatment improves fish growth and water quality (Hassan *et al.*, 2018a).

Stress is any condition that causes physical or psychological discomfort and results in the release of stress-related hormones or specific physiological responses (Foster and Smith, 2007). It has been reported that different degrees of hypoxia seriously affect the growth, food intake, survival, behavior, and physiological activities of fish (Roman *et al.*, 2019). Fishes are exposed to acute or chronic stressors, for example, hypoxia stress either in nature or artificial conditions leading to adverse effects on fish behavior, growth, reproduction, immunology, and flesh quality (Burgos-Aceves *et al.*, 2018). Moreover, hypoxia can be lethal to many organisms, including mammals, birds, fish, reptiles, and invertebrates (Bickler and Buck, 2007). Hypoxia or low dissolved oxygen had principal categories of behavioral response as changes in activity, increased use of air-breathing and aquatic surface respiration (Donald, 1987). Also, the magnetic field can cause a sequence of modifications to water, from the primary effect on the dynamic forces of electro-solutions to the changes in the macromolecule state that affect the respiration rate of fish (Brizhik, 2014).

The aim of this study was to investigate the effects of water magnetization on fish performance, behaviours, physiological responses, and water properties of fish aquariums under normal and hypoxia stress.

MATERIALS AND METHODS

The experimental protocol and related fish treatment and care was approved by Institutional Animal Care and Use Committee (IACUC) with oversight of the facility of Veterinary Medicine, University of Sadat City (VUSC-019-1-19).

1- Magnetic device

The magnetic device consists of a cylindrical trunk of polyvinyl chloride (PVC) with similar-sized magnetic pieces. The magnetic pieces generate a magnetic field with a fixed intensity of 18000 gausses (Neferttari, NMC, Egypt). The water in the aquarium was magnetized every other day for an hour.

2- Fish management and experimental design

Forty-eight mixed-sex healthy Nile tilapia *Oreochromis niloticus* with an average weight of 30.95±1.75g were obtained from private fish breeding farm (Kafr El-Sheikh Governorate, Egypt). Fish were transported to the laboratory in plastic bags. At the time of the fish's arrival, they were acclimatized to the temperature of aquarium water by partial replacement of bag water with aquarium water and then the fish were released into the aquarium. During the 2 weeks adaption period, fish were fed on floating crumbles tilapia commercial ration to apparent satiation twice daily at 9:00 am and 2:00 pm, at a rate of 30% crude protein, 4.8% fiber, 5.3% crude fat and 4000 kcal total energy.

After adaptation period, the fish were randomly distributed into four identical shaped glass aquaria (100 cm length x 30 cm width x 40 cm height) with a capacity of 80 liters of water, (n=12 fish/aquarium, two replicates) supplied with normal water (non-magnetized), (group 1: control) or magnetic water (group 2: MW). Each aquarium was supplied with a glass aquarium thermometer with a suction cup, aquarium filter and pump (BAOLAI, BL1001F, China), an electrical aquarium air pump (Shark RS-610, China), air stones were connected to an air pump to distribute oxygen in the aquarium, and aquarium fish net (Nylon fishing nets with plastic handle) for handling and transporting fish. Fish were kept under a photoperiod of 12 h light: 12 h dark.

Throughout the experimental period all fish were fed a commercial diet at 3% of body mass, three times daily (8:00 am, 11:00 am, and 2:00 pm). The amount of feed given was adjusted every two weeks according to body weights in each group. Besides, fish were inspected periodically for activity and illness. The water in the aquarium (50% of the aquarium water) was regularly changed every week by dechlorinated water. Aquaria and tools were cleaned once a week.

After ten weeks of the experiment, six fish of each aquarium either magnetic water or control fish were been fasted and the amount of water was adjusted to 30 liters in each aquarium (5 liters per fish) (Luanna *et al.*, 2020). After that fasted fish were exposed to hypoxia by stopping the aeration through removing the air pump and the filters from the fish aquarium for 8 hours for one day and then the aeration was returned.

3- Performance parameters

All fish performance parameters were calculated according to Mahmoud *et al.*, (2019) as the following:

Body weight	-	Every 2 weeks (at 0, 2nd, 4thand 6th, 8th,10th weeks).
Weight gain (Wg)	-	Final weight – Initial weight
Feed intake (FI) (percent of biomass per day)	-	(total feed offered / (W1 + W2)* / 2) / day) × 100 (Irkin and Yigit, 2016).
Specific growth rate (SGR)	-	(logW2 - logW1) * / (t2-t1) * x 100
Feed conversion ratio (FCR)	-	Feed offered / weight gain

*W1 = initial weight, W2 = final weight. t2-t1 = feeding days.

4- Behavioural responses

Instantaneous scan sampling technique of observations was performed (Altmann, 1974) every week for 9 minutes for each aquarium, twice per day in the morning (9:00-10:00 am) and the afternoon (1:00-11:00 pm). Behavioural observations were recorded directly by using a digital timer. Each behaviour was observed for 60 seconds and count the number of fish that performed the recorded behaviour throughout this period. Fish behaviours were recorded in each treatment as described in Table (1). Under hypoxia conditions, the percentage of resting, surfacing, and aggressive behaviours (chasing and biting) were recorded.

Table 1: Behavioural patterns description (Fall, 2005).

Behavioural pattern	Description
Foraging	Searching for food.
Chafing	Rubbing any part of the body against any object such as wall, floor and equipment of the aquarium.
Resting	Fish are inactive and motionless with open eyes.
Surfacing	Fish gulp air at the water surface.
Schooling	Fish swim with each other.
Eliminative	Fish show dropped or hanged feces.
Aggressive behaviour	
Chasing	Fish chase toward other fish with opened mouth.
Biting	Fish bits any part of the body regions of another fish.
Mouth Pushing	Fish were stood face to face with their opened mouth against each other's.

5- Water quality measurement

Water quality parameters were measured twice a week. Dissolved oxygen (DO) was measured using a portable DO meter (HD3030, Trans-instruments Company, Singapore). Temperature and pH values were measured using a water-proof pH-temperature pocket tester (AD12, Romania). Ammonia and turbidity of water were measured using a spectrometer (T80, UV/VIS, England). During hypoxia stress dissolved oxygen, temperature, and pH were measured besides, DO was measured every two hours (at 2h, 4h, 6h, and 8h) after stress.

6- Physiological responses

At the end of the normoxia condition (10 weeks), the fish were fasted for 24 h prior to blood sampling. Five fish were taken from each aquarium and prepared for blood sampling. Sodium citrate syringes were used for blood collection from the caudal vein of fish. Blood was centrifuged at 3000rpm for 15 minutes to separate plasma and stored at –20 until used to determine the following parameters: total protein and albumin were determined using commercial kits (Diamond Diagnostics, Egypt) according to Tietz, (1994). Globulin levels were calculated by subtracting albumin values from total protein. After that, the albumin/globulin ratio (A/G) was calculated. The Alanine amino-transferase (ALT) and triglyceride were determined according to Young, (1990) and Mgowan *et al.* (1983) respectively. Immediately after blood sampling, the fish were dissected to obtain liver tissues that were washed and kept in cold phosphate buffer saline (pH 7.2) and then stored at –80 °C until used. The biochemical analysis of antioxidant enzyme activities such as glutathione reductase (GSH) in tissue was detected (Beutler *et al.*, 1963). In case of hypoxia condition, after 8 hours of hypoxia stress, three fish from each aquarium were taken for blood collection by sodium citrate syringes and separate plasma for cortisol analysis (Rifai *et al.*, 2018).

7- Statistical analysis

Statistical analyses were performed using IBM SPSS statistics (version 22). The proportion of fish that performed a behavioural pattern (foraging, chafing, resting, surfacing, schooling, elimination, chasing, biting, or mouth pushing) per minute was calculated. Data (behavioural patterns, performance parameters, water quality, and biochemical parameters) were analyzed with an independent T test. The obtained data were all expressed as mean ± S.E. A level of significance of $P \leq 0.05$ or $p \leq 0.01$ was regarded as statistically significant.

RESULT

1. Performance parameters

Fish reared under normoxia conditions in the magnetic water had significantly ($p<0.05$) higher body weight than those in the control group at the 2nd, 4th, 6th, 8th, and 10th weeks. Furthermore, fish of magnetic water showed higher weight gain (*p*=0.003) with a lower feed conversion ratio (*p*= 0.05) than normal water fish. However, specific growth rate and feed intake were not significantly affected by magnetic water (*P* > 0.05) as shown in Table (2).

Table (2): Effect of magnetic water (MW) on body weight (g), weight gain (g), specific growth rate (%/day), feed conversion ratio and feed intake (%/day) in Nile tilapia reared under normoxia conditions (mean±SE).

Weeks	Groups		*P*-value
	Control	MW	
Body weight (g)			
Initial	29.29±1.85	31.00±1.18	0.55
2	35.49±2.40	42.89±2.75	0.05
4	44.00±3.07	51.64±3.73	0.02
6	54.74±2.63	61.09±5.13	0.04
8	64.65±3.46	74.69±7.30	0.02
10	71.15±5.40	88.57±8.64	0.05
Weight gain (g)	53.13±3.48	58.41±6.54	0.003
Specific growth rate (%/day)	2.84±0.05	2.80±0.09	0.71
Feed conversion ratio	3.02±0.17	2.46±0.24	0.05
Feed intake (%/day)	2.44±0.09	2.45±0.12	0.97

2. Behavioural responses.

Generally, in normoxia conditions magnetic water had a significant effect on Tilapia fish behaviours, as shown in Table (3). Fish raised in magnetic water showed a higher percentage of resting and schooling behaviours than those in the control group (*P*= 0.001 and *P*= 0.01, respectively). On the other hand, surfacing and elimination activities were less in magnetic water fish (*P*= 0.001 and *P*= 0.002, respectively) than in the fish of the control group. Furthermore, aggressive behaviours such as biting and mouth pushing were significantly lower in fish kept in the magnetic water (*P*= 0.02 and *P*= 0.04, respectively). Foraging, chafing, and chasing activities of fish were not affected by magnetic water.

Table 3: Effect of magnetic water (MW) on overall behavioural responses of Nile tilapia reared under normoxia conditions (Mean±SE).

Behavioral patterns (%)	Groups		*P* – value
	Control	MW	
Foraging	72.48±3.59	67.89±5.40	0.48
Chafing	1.76±1.05	0.22±0.22	0.15
Resting	22.10±1.64	33.29±2.29	0.001
Schooling	1.16±0.83	6.68±1.95	0.01
Surfacing	49.56±7.02	16.53±4.12	0.001
Elimination	16.63±1.90	8.67±1.24	0.002
Aggressive behaviour			
Chasing	15.62±8.75	17.35±2.42	0.76
Biting	22.54±2.07	15.79±2.11	0.02
Mouth pushing	3.70±1.67	0.72±0.53	0.04

Figure (1) illustrated that under hypoxia conditions for 8 hours, water magnetization had a significant effect on the behavioral activities of fish. Fish raised on magnetic water showed a significantly (*P=0.01*) higher resting percentage than the control group. However, the control group showed a high percentage of surfacing (*p*=0.05) chasing (*p*=0.01) and biting (*p*=0.02) in comparison to behaviour of magnetic water fish.

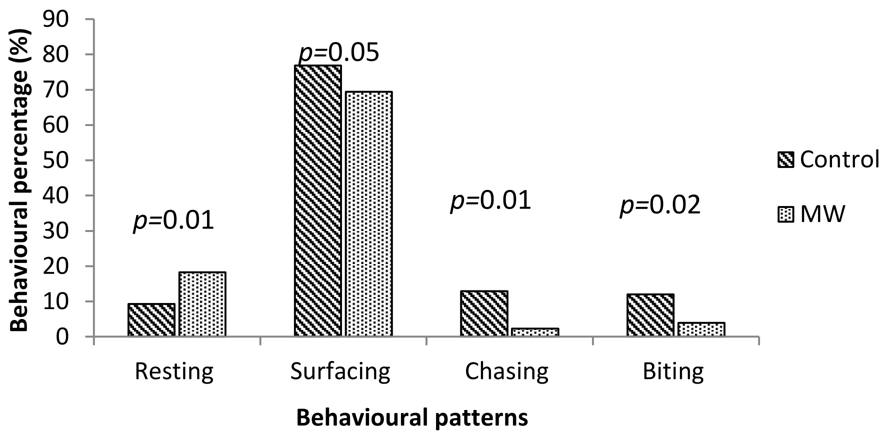

Figure (1): Effect of magnetic water (MW) on behavioural responses of Nile tilapia under hypoxia.

3. Water quality parameters.

As shown in Table (4), in normoxia conditions, magnetic water had a significant (*p*<0.05) effect on the properties of the aquarium's water. Water magnetization significantly (*P*= 0.001) improved the water dissolved oxygen level compared to the control group. Furthermore, water magnetization decreased significantly water pH (*P*=0.05), ammonia (*p*=0.03) and turbidity (*p*=0.04) compared to those of normal water. However, the temperature of the water was not significantly affected by using a magnetic field.

Table 4: Effect of magnetic water (MW) on overall water quality parameters of Nile tilapia aquarium under normoxia conditions (Mean±SE).

Water quality parameters	Groups		*P- value*
	Control	MW	
DO (ppm)	5.34±0.22	6.32±0.13	0.001
pH	8.93±0.03	7.00±0.03	0.05
Temperature (°C)	25.28±0.40	25.20±0.28	0.84
Ammonia (ppm)	0.27±0.02	0.23±0.02	0.03
Turbidity (NTU)	0.29±0.02	0.24±0.04	0.04

Under hypoxia stress for 8 hours, water magnetization significantly improved the parameters of water quality. Overall, the dissolved oxygen of magnetic water was significantly more (*p*=0.05) than the dissolved oxygen of normal water. However, there was no difference between control and magnetic water groups in overall temperature (*p*=0.63) and pH (*p*=0.97) under hypoxia (Figure 2).

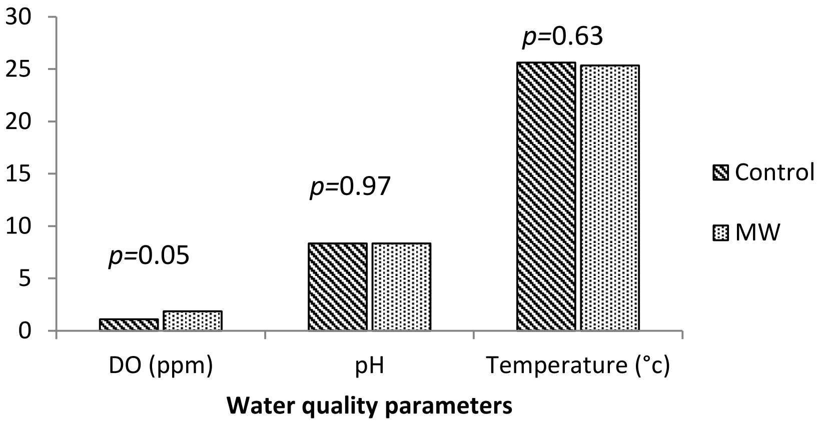

Figure (2): Effect of magnetic water (MW) on overall water quality parameters of Nile tilapia aquarium under hypoxia.

Results summarized in Table (5) showed that under hypoxia stress, fish aquariums in magnetic water groups showed higher dissolved oxygen levels than the dissolved oxygen of fish aquariums in control groups throughout two, four, six, and eight hours of hypoxia (*P*= 0.009, *P*= 0.01, *P*= 0.03, and *P*= 0.001, respectively).

Table 5: Effect of magnetic water (MW) on water dissolved oxygen (ppm) of Nile tilapia aquarium under hypoxia for 2,4,6,8 hrs (Mean±SE).

Parameters	**Groups**		***P* – value**
	Control	**MW**	
Dissolving oxygen (ppm)			
2hrs	3.07±0.07	3.52±0.07	0.009
4hrs	1.14±0.07	1.83±0.17	0.01
6hrs	0.90±0.03	1.30±0.10	0.03
8hrs	0.70±0.01	1.10±0.04	0.001

4. Physiological responses.

Results from Table (6) demonstrated that in normoxia conditions, magnetic water had a significant effect on some biochemical parameters of Nile tilapia fish. Fish in magnetic water had higher total protein (*P*= 0.001) and globulin (*P*= 0.004) with a lower A/G ratio (*P*= 0.04) than fish in the control group. The control group of fish had higher glutathione reductase (GSH) levels than the magnetized water group (*P*= 0.05). Albumin, triglycerides, and alanine aminotransferase (ALT) were not affected by the water magnetization of tilapia fish (Table 6).

Table 6: Effect of magnetic water (MW) on biochemical parameters of Nile tilapia reared under normoxia conditions (Mean±SE).

Parameters	**Groups**		***P*- value**
	Control	**MW**	
Total protein(g/dl)	3.35±0.06	4.35±0.23	0.001
Albumin (g/dl)	1.39±.05	1.39±0.08	0.97
Globulin (g/dl)	1.95 ±0.08	2.96±0.27	0.004
A/G ratio	73.82 ± 6.09	53.49±7.04	0.04
Triglyceride(mg/dl)	63.99±5.1	65.99±3.75	0.76
ALT (U/I)	6.25±0.39	7.83±0.23	0.22
GSH (mg/g)	1328.00±29.51	1221.67±22.56	0.05

The result in Figure (3) demonstrated that, under hypoxia stress, tilapia fish᾿s response was affected by water magnetization throughout 8 hours of hypoxia. The magnetized water fish group had a significantly lower cortisol level compared to the control group (p=0.05).

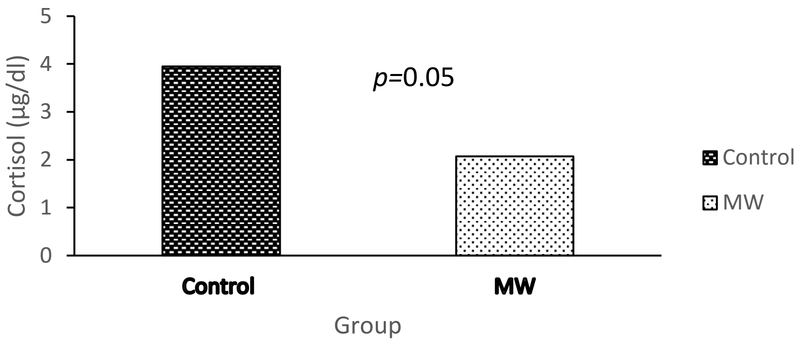

Figure (3): Effect of magnetic water (MW) on cortisol [µg/dl] of Nile tilapia under hypoxia condition (Mean±SE).

DISCUSSION

Good water quality is a main factor for the successful culture of aquatic organisms, including fish, shellfish, and crustaceans and it is essential for the survival rate and performance of the cultured species (Hassan *et al.,* 2018 b). Moreover, the magnetic field improves the water quality through enhancing dissolved oxygen, increasing mineral solubility, and reducing the total count of bacteria (Yacout *et al.*, 2015) with decreasing water turbidity by accelerating the degradation of organic waste (Alabdraba *et al.*, 2013).

Dissolved oxygen (DO) is the most important factor in fish farming that is required for fish growth and production (Abdel-Tawwab *et al.*, 2019). Also, hydrogen ion concentration (pH) is the master control parameter and affects the metabolism and other physiological processes in the aquatic environment (Ahmed and Abd El-Hamed, 2020). Water magnetization by magnetic device 18000 gauss (1.8 Tesla) in this study improved the water quality parameters of Nile tilapia aquarium. The improvement of the quality of magnetic water was obvious through increasing dissolved oxygen, decreasing ammonia and turbidity concentration with optimum pH.

The magnetic field increased the oxidation potential of chemical compounds and sped up the degradation of organic waste contained in the water (Lazur *et al.,* 2003). Besides, the magnetic field dissolved the minerals and acids at a higher rate and increasing the speed of chemical reactions and dissolving oxygen (Moon and Chung, 2000). Consequently, the concentration of organic matter in the magnetic water was reduced, which may have led to an increase in the dissolved oxygen of magnetic water (Yacout *et al.*, 2015) and the oxidization of NH4-N into NO2-N and NO3-N (Abdelkhalek *et al.,* 2021) that indicate reducing ammonia concentration and turbidity in magnetic water. The changes in pH values are considered within the permissible limit for Nile tilapia. Because pH values for optimum growth of Nile tilapia range from 5.5 to 9.0 (Rebouças *et al.*, 2016). Therefore, reduced pH may be attributed to the magnetic field affecting the hydrogen bonds between water molecules, resulting in the pH change of water in a fish aquarium (Hassan *et al.,* 2018 b). In addition, pH interacts with other water quality parameters such as ammonia. Hence, the lowering of pH values in magnetized water throughout the current experiment may be linked to low ammonia levels.

Results of the current study agreed with studies that reported increased dissolved oxygen and decreased ammonia and turbidity under water magnetization for Nile tilapia (Ahmed and Abd El-Hamed, 2020); Abdelkhalek *et al.*, 2021). A significant increase in water dissolved oxygen concentration with increased magnetic intensity compared to normal water (AL Ibady, 2015; Sithik *et al.,* 2009), decreased pH values (Shatalov, 2009), reduced ammonium concentrations (Hassan and Rahman, 2016) and water turbidity decreased (Alabdraba *et al.,* 2013).

Contrarily, there were no significant changes in water parameters under a constant magnetic field in the system with the European sheat Larvae (Krzemieniewski *et al.,* 2004), and common carp (Irhayyim *et al.,* 2020). Nevertheless, increasing the pH value with a magnetic field was demonstrated (Alkhazan and Sadddiq, 2010). Ammonia concentrations were not affected by the magnetic field system and the control system (Krzemieniewski *et al.,* 2004; Hassan *et al.,* 2019). The different findings could be attributed to the exposure duration, magnetic field intensity, rate of water movement, and sensitivity of different species of fish.

It is an interesting finding that; water magnetization had a significant effect on fish behaviour. Fish from magnetized water showed a higher percentage of resting and schooling with lower surfacing, elimination behaviors and aggressive activities compared to fish from non-magnetic water (table 3). Hence, the magnetic field improved fish performance by increasing body weight, weight gain and decreasing feed conversion ratio (table 2).

Unfortunately, there is no literature studying the effects of magnetic water on fish behaviour. Further, water quality improvement by water magnetization permits fish to perform their normal behaviour without any stress. Hence, fish showed high resting and stayed in groups or schools with less aggression that may reflect on feed consumption and fish growth with fewer waste products (elimination). Besides, the dissolved oxygen was enough for the tilapia fish to breathe or perform their activities in magnetizing water so showed low surfacing behavior. Moreover, there is no common mechanism that has been concerned about the effect of the magnetic field on growth performance (Irhayyim *et al.,* 2020). This may be explained by the improvement of the surrounding environmental conditions of fish (physiochemical properties of water) under water magnetization may improve the transfer of nutrients to all parts of the body and is related to metabolism (Liu *et al.,* 2008) and increased the solubility of minerals, which improved the nutrient utilization and growth of fish (Tyari *et al.,* 2014). Moreover, water can receive signals produced from magnetic forces, which have a direct effect on living cells and their vital action (Smirnov, 2003).

These results were in agreement with the results that concluded that magnetic water improved the performance of Nile tilapia (Hassan *et al.,* 2018 b; Abdelkhalek *et al.,* 2021), carp fish (Irhayyim *et al.,* 2019) and juvenile sea cucumbers (Zhao *et al.,* 2015). Also, weight gain and specific growth rate of Nile tilapia (Ahmed and Abd El-Hamed, 2020), common carp (Irhayyim *et al.*, 2020) and Tilapia fry (Abdel Hakim *et al.,* 2016) were improved by using water magnetization. In contrast, there was no significant difference in the growth of European sheatfish, Silurus glanis larvae reared in the system modified by the constant magnetic field (Krzemieniewski *et al.,* 2004). These differences may be attributed to different fish species, management, environmental condition, and different durations or intensities of water magnetization.

Biochemical parameters can be used to evaluate the health of aquatic organisms and ecosystems (Loghmannia *et al.*, 2015). Magnetic water had a beneficial effect on immunological markers in Nile tilapia. Elevated blood globulin may have a supportive effect on fish health and immunity, which may increase the consumption of protein to build somatic cells and improve fish growth (Yacout *et al.,* 2015). These results agree with (Ahmed and Abd El-Hamed, 2020) who found Tilapia fish showed the highest total protein and globulin after being exposed to a magnetic field. Contrarily, there were no significant changes in biochemical parameters such as total protein and globulin under the effect of the magnetic field in either Nile tilapia fry (Abdel Hakim *et al.,* 2016) or Jade Perch Scortum barcoo juveniles (Hassan *et al.,* 2019).

Pro-oxidant compounds are reactive oxygen species (ROS) that can damage DNA, proteins, and lipids (Morel and Barouki, 1999), whereas antioxidants are any substance that can prevent or reduce the oxidation of a target molecule (Halliwell and Gutteridge, 2007). Glutathione is the most powerful antioxidant enzyme that protects cellular proteins against reactive oxygen species in the body (Yacout *et al.,* 2015). Magnetic water could efficiently affect the oxidant-antioxidant balance through stimulating the activity of proteins and antioxidant enzymes that can influence free radicals and overall biochemical processes (Yacout *et al.,* 2015). However, magnetic water in this study improved all parameters such as performance, behaviour, water quality, and some immunological markers of tilapia fish; the glutathione reductase was decreased in magnetized water fish than in the control group. The magnetic field may be enhancing antioxidant activity by decreasing the harmful effects of free radicals by decreasing the chemical reactions that cause damage to DNA, proteins, and lipids (Khudiar and Ali, 2012). For this reason, plasma glutathione concentration in magnetic water fish was decreased. These results were dissimilar from some studies reported that goats (Yacout *et al.,* 2015) and rabbits (Khudiar and Ali, 2012) received magnetic water showed higher glutathione reductase activity. This difference might be attributed to the intensity of the magnetic field, period of exposure, species, and different management (Abdel Tawab Rameen *et al.,* 2011).

When the supply of oxygen is cut off or consumption exceeds resupply, oxygen concentrations can decline below levels that will sustain animal life (Díaz et al., 2012). The stress response is usually activated by a wide range of physiological and behavioral mechanisms in order to compensate for the imbalances produced by the stressor and recover the homeostatic status of fish (Souza *et al.,* 2019). In addition, it is initiated and controlled by hormonal systems such as the production of corticosteroids (mainly cortisol) by the hypothalamus-pituitary-interrenal (HPI) axis (Martos-Sitcha *et al.,* 2014). Cortisol is generally used as a short-term and long-term stress condition index (Barton, 2002).

In the current study fish kept in magnetic water and exposed to hypoxia for 8 hours showed more resting with less surfacing, fewer aggression activities, and low cortisol concentrations. These results indicated that fish in magnetic water endure hypoxia stress compared to fish in normal water. The ability of fish to withstand decreasing dissolving oxygen for 8hrs that reached 1 ppm may regard in the improvement of oxygen concentration in magnetic water that enables fish to show normal behavior and well performance throughout this period.

The plasma levels of cortisol increase quickly after exposure to acute stress and the standard conditions are returned within a few hours (Bianca, 2009). When spotted wolf fish were exposed to a gradually decreasing oxygen level in the tank; they showed a significantly elevated plasma cortisol level (Lays *et al.,* 2009).

CONCLUSION

It is concluded that water magnetization improved water quality parameters; dissolved oxygen increased and ammonia and turbidity reduced. Fish behaviour and consequently the performance (body weight, weight gain and specific growth rate), immunity and antioxidant activities of tilapia fish were improved under water magnetization. Moreover, under hypoxia condition, fish kept in magnetic water can tolerate the effect of stress and showed behavioural (increased resting, less surfacing, and less aggressive) and physiological adaptation (low cortisol).

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آثار المياه الممغنطة على الأداء الإنتاجي ، والسلوك ، وبعض الاستجابات الفسيولوجية لأسماك البلطي النيلي تحت الظروف الطبيعية وضغط نقص الأكسجين

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تهدف هذه الدراسة إلى دراسة تأثير المياه الممغنطة على السلوك والأداء الإنتاجى وبعض الدلالات الفسيولوجية لأسماك البلطي النيلي والخصائص الفيزيائية والكيميائية للمياه. تم تربية 48 سمكة من أسماك البلطي النيلي (30.9± 75.جم) تحت ظروف طبيعية وتم تصنيفها إلى مجموعتين (العدد / 12 = حوض سمك ، 2 مكررات) المجموعة الأولى: تم تربيتة الأسماك في مياه غير ممغنطة (مجموعة ضابطة) المجموعة الثانية: تم تربيتة الأسماك في المياه الممغنطة باستخدام المجال المغناطيسي، 18000 جاوس. تم فحص أداء الأسماك والاستجابات السلوكية والفسيولوجية وكذلك معايير
جودة المياه لأحواض الأسماك. في نهاية التجربة، تعرضت الأسماك (العدد / 6 = حوض السمك، 2 مكررات) من كل مجموعة إلى 8 ساعات من نقص الأكسجين. تم تسجيل سلوك الأسماك وقياس معايير جودة المياه لأحواض الأسماك. أوضحت النتائج أن وزن الجسم ومعدل الزيادة للأسماك قد زاد معنوياً (P < 0.05) ، بينما انخفض معدل التحويل الغذائي للأسماك التي تمت تربيتها باستخدام مغنطة الماء. أظهرت أسماك الميا ه الممغنطة أنشطة سلوكية مثل زيادة سلوك الراحة مع انخفاض سلوك الصعود لسطح المياه وسلوك الإخراج مقارنة بأسماك الماء غير الممغنطة. أدت مغنطة الماء إلى تحسن كبير في الأكسجين المذاب والأمونيا والعكارة في حوض الأسماك. أظهرت أسماك المياه الممغنطة نسبة عالية من البروتين الكلي والجلوبيولين مع انخفاض الجلوتاثيون في البلازما. أظهرت أسماك المياه الممغنطة زيادة معنوية في الراحة وانخفاض سلوك الصعود لسطح المياه والمطاردة والعض مع انخفاض الكورتيزول البلازمي عند تعرضها لحالة نقص الأكسجين. كان الأكسجين المذاب في المياه الممغنط أكثر بكثير من الأكسجين المذاب في الماء العادي بعد التعرض لنقص الأكسجين. تشير هذه النتائج إلى أن استخدام المياه الممغنطه له فوائد كبيرة في الأداء الإنتاجى والسلوك ، بالإضافة إلى تقليل آثار الإجهاد الناجم عن نقص الأكسجين في أسماك البلطي النيلي.