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
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 (Krzemieniowski 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.

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight</td>
<td></td>
</tr>
<tr>
<td>Weight gain (Wg)</td>
<td>Every 2 weeks (at 0, 2nd, 4th and 6th, 8th, 10th weeks).</td>
</tr>
<tr>
<td>Feed intake (FI) (percent of biomass per day)</td>
<td>- (total feed offered / (W1 + W2)* / 2) / day) x 100 (Irkin and Yigit, 2016).</td>
</tr>
<tr>
<td>Specific growth rate (SGR)</td>
<td>- (logW2 - logW1) / (t2-t1) * x 100</td>
</tr>
<tr>
<td>Feed conversion ratio (FCR)</td>
<td>- Feed offered / weight gain</td>
</tr>
</tbody>
</table>

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).

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

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 −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).

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

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).

<table>
<thead>
<tr>
<th>Behavioral patterns (%)</th>
<th>Control</th>
<th>MW</th>
<th>$P$ – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foraging</td>
<td>72.48±3.59</td>
<td>67.89±5.40</td>
<td>0.48</td>
</tr>
<tr>
<td>Chafing</td>
<td>1.76±1.05</td>
<td>0.22±0.22</td>
<td>0.15</td>
</tr>
<tr>
<td>Resting</td>
<td>22.10±1.64</td>
<td>33.29±2.29</td>
<td>0.001</td>
</tr>
<tr>
<td>Schooling</td>
<td>1.16±0.83</td>
<td>6.68±1.95</td>
<td>0.01</td>
</tr>
<tr>
<td>Surfacing</td>
<td>49.56±7.02</td>
<td>16.53±4.12</td>
<td>0.001</td>
</tr>
<tr>
<td>Elimination</td>
<td>16.63±1.90</td>
<td>8.67±1.24</td>
<td>0.002</td>
</tr>
<tr>
<td>Aggressive behaviour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chasing</td>
<td>15.62±8.75</td>
<td>17.35±2.42</td>
<td>0.76</td>
</tr>
<tr>
<td>Biting</td>
<td>22.54±2.07</td>
<td>15.79±2.11</td>
<td>0.02</td>
</tr>
<tr>
<td>Mouth pushing</td>
<td>3.70±1.67</td>
<td>0.72±0.53</td>
<td>0.04</td>
</tr>
</tbody>
</table>
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 behavior of magnetic water fish.

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).

<table>
<thead>
<tr>
<th>Water quality parameters</th>
<th>Control</th>
<th>MW</th>
<th>$P$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$DO$ (ppm)</td>
<td>5.34±0.22</td>
<td>6.32±0.13</td>
<td>0.001</td>
</tr>
<tr>
<td>$pH$</td>
<td>8.93±0.03</td>
<td>7.00±0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Temperature ($^\circ$C)</td>
<td>25.28±0.40</td>
<td>25.20±0.28</td>
<td>0.84</td>
</tr>
<tr>
<td>Ammonia (ppm)</td>
<td>0.27±0.02</td>
<td>0.23±0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>0.29±0.02</td>
<td>0.24±0.04</td>
<td>0.04</td>
</tr>
</tbody>
</table>

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).
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).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Groups</th>
<th>$P$ – value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolving oxygen (ppm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2hrs</td>
<td>Control</td>
<td>3.07±0.07</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>3.52±0.07</td>
</tr>
<tr>
<td>4hrs</td>
<td>Control</td>
<td>1.14±0.07</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>1.83±0.17</td>
</tr>
<tr>
<td>6hrs</td>
<td>Control</td>
<td>0.90±0.03</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>1.30±0.10</td>
</tr>
<tr>
<td>8hrs</td>
<td>Control</td>
<td>0.70±0.01</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>1.10±0.04</td>
</tr>
</tbody>
</table>

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

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).

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Groups</th>
<th>$P$- value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total protein (g/dl)</td>
<td>Control</td>
<td>3.35±0.06</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>4.35±0.23</td>
</tr>
<tr>
<td>Albumin (g/dl)</td>
<td>Control</td>
<td>1.39±0.05</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>1.39±0.08</td>
</tr>
<tr>
<td>Globulin (g/dl)</td>
<td>Control</td>
<td>1.95±0.08</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>2.96±0.27</td>
</tr>
<tr>
<td>A/G ratio</td>
<td>Control</td>
<td>73.82±6.09</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>53.49±7.04</td>
</tr>
<tr>
<td>Triglyceride (mg/dl)</td>
<td>Control</td>
<td>63.99±5.1</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>65.99±3.75</td>
</tr>
<tr>
<td>ALT (U/l)</td>
<td>Control</td>
<td>6.25±0.39</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>7.83±0.23</td>
</tr>
<tr>
<td>GSH (mg/g)</td>
<td>Control</td>
<td>1328.00±29.51</td>
</tr>
<tr>
<td></td>
<td>MW</td>
<td>1221.67±22.56</td>
</tr>
</tbody>
</table>
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).](image)

**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 oxidation 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

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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 Saddiq, 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
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 (Diaz 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 dissolved 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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تهدَّف هذه الدراسة إلى دراسة تأثير المياه الممغنطة على السلوكيات والأداء الإنتاجي وبعض الدلالات الفسيولوجية لأسماك البلطي النيلي والخصائص الفيزيائية والكيميائية للمياه. تم تربية 48 سمكة من أسماك البلطي النيلي (30.9 ± 7.5 سم) تحت ظروف طبيعية وتم تصنيفها إلى مجموعتين (العدد / والعدد / 2 مكررات) المجموعة الأولى: تم تربية الأسماك في مياه غير ممغنطة (مجموعة ضابطة) المجموعة الثانية: تم تربية الأسماك في المياه الممغنطة باستخدام المجال المغناطيسي، 18000 جاوس. تم فحص أداء الأسماك والاستجابات السلوكية والبيولوجية وكذلك معايير جودة المياه.

تغذية الأسماك لأحواض الأسماك، في نهاية التجربة، تعرضت الأسماك (العدد / 6 = حوض السمك، 2 مكررات) من كل مجموعة إلى 8 ساعات من نقص الأكسجين. تم تسجيل سلوكي الأسماك وقياس معايير جودة المياه لأحواض الأسماك. أوضحت النتائج أن وزن السمك ومعدل الزيادة للأسماك قد زاد معنويًا (P < 0.05)، بينما انخفض معدل التحويل الغذائي للأسماك التي تحت تربية باستخدام مغناطيسية الماء. أظهرت أسماك المياه الممغنطة نشاطاً سلوكياً مثل زيادة سلوكي الراحة مع انخفاض سلوكي الصعود لسطح المياه وسلوك الإخراج مقارنة بأسماك الماء غير الممغنطة. أدت مغناطيسية الماء إلى تحسين كبير في الأكسيجين المذاب والأمونيا والكربون في حوض الأسماك. أظهرت أسماك المياه الممغنطة نسبة عالية من البروتين الكلي والجلوبيولين مع انخفاض الجلوبيولين في اللاما. أظهرت أسماك المياه الممغنطة زيادة معنوية في الراحة وانخفاض سلوكي الصعود لسطح المياه والمطاردة والعص مع انخفاض الكورتيزول البلازمي عند تعرضها لحالة نقص الأكسجين. كان الأكسيجين المذاب في المياه الممغنطة أكثر بكثير من الأكسيجين المذاب في المياه العادية بعد تعرض نقص الأكسيجين. تشير هذه النتائج إلى أن استخدام المياه الممغنطة له فوائد كبيرة في الأداء الإنتاجي والسلوك، بالإضافة إلى تقليل آثار الإجهاد الناجم عن نقص الأكسيجين في أسماك البلطي النيلي.