Egypt .J. Aquat. Biol. & Fish ., Vol. 10, No.3:165 -183(2006)ISSN 1110 – 6131

EFFECT OF CHRONIC EXPOSURE TO SUBLETHAL LEVELS OF MERCURY ON TOTAL PRODUCTION, PHYSIOLOGICAL FUNCTIONS AND ECONOMICAL EFFICIENCY OF TILAPIA FISH, WITH REGARD TO PROPERTIES OF PONDS WATER

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Key words: Tilapia, growth, production, feed utilization, mortality, blood, serum, biochemical composition, mercury residues, water quality.

ABSTRACT

The effects of chronic exposure to sublethal doses of mercuric chloride (0.310, 0.155 and 0.078 mg L^{-1}) on growth rate, physiological parameters, chemical composition of tilapia species and properties of ponds water were studied for 180 days. Tilapia species (*Oreochromis niloticus, Sarotherodon galilaeus* and *Oreochromis aureus*) with an average initial size of 13 cm for total length and 50 g for body weight were stocked in fiberglass tanks (6 m^2 area of each) at a rate of 15 fish m^{-2} (1:1:1) and fed on artificial diet containing 30 % protein. The physico-chemical properties of ponds water were slightly varied with different mercury levels. The plankton organisms (phyto - and zooplankton) were gradually decreased with increasing the mercury concentration in fish ponds. The final body weight, daily weight gain and production of tilapia fish were significantly decreased with increasing the mercury level. The lowest values of these parameters (171.5g, 0.67g, 1.518 ton $feddan^{-1}$ for *O. niloticus*; 144g, 0.52g, 1.053 ton $feddan^{-1}$ for *S. galilaeus* and 153.5 g, 0.56 g and 0.995 ton $feddan^{-1}$ for *O. aureus*) were observed in the pond containing highest mercury level (0.310 mg/L). The other growth performance (specific growth rate, percentage weight gain and normalized biomass index), feed utilization (feed conversion ratio, protein efficiency ratio and protein productive value) and survival efficiency of tilapia were also affected with sublethal levels of mercury. The net returns and profitability of the reared fish were also decreased with increasing mercury concentration in ponds water. The lowest hematocrit (28.5, 29.0

and 30 %) and hemoglobin (5.5, 5.0 and 5.2 g/100 ml blood) of the three fish species were obtained from the pond containing 0.310 mg/L $HgCl_2$. At the same mercury levels, the serum protein of the three fishes decreased to 7.0, 6.6 and 6.5 g/100 ml serum, while serum glucose increased to 81.0, 79.0 and 78.5 mg/100 ml serum. The biochemical composition of fish muscles was also influenced with different sublethal levels of mercury, where the muscle protein and glycogen were slightly decreased and lipid increased with increasing the mercury level. The mercury residues in liver, gills and muscles of the reared fish were increased with increasing the mercury concentration in ponds water and its value in liver was higher than that in gills and muscles.

INTRODUCTION

Recently, attention has been focused on fish farming, since it has a great potential for achieving new sources of fish production and since most natural resources are overexploited. So, the interest in aquaculture has been directed mainly towards the development of pond culture (Ishak, 1985). Tilapia species are successfully cultured in the Egyptian fish farms, since they have high growth rate, can be fed on artificial diets and have high tolerance to different water quality (Bayoumi, 1987). Fish can also be a source of threat to human health by transporting the toxic materials directly to the consumers. Since heavy metals are widely distributed in aquatic habitats due to the industrial effluents and the wide use of chemicals in agriculture, the aquatic habitats with their water quality are considered the main factor controlling the state of health and disease of fish. The toxicity of heavy metals and their effects on physiological and biochemical parametes of freshwater fish have been reported by many investigators (Ghazaly & Said, 1995; Iqbal *et al.*, 1997; El-Nagar *et al.*, 2001; Mahmoud 2002). Mercury, like other heavy metals, may find its way to the water system and affects aquatic life, particularly fish, through its interference with their metabolic processes (Kumari and Banerjee, 1993). Mazhar *et al.* (1987) exposed the Nile catfish (*Clarias gariepinus*) to sublethal levels of mercuric chloride and noticed a progressive fall in RBCs count, hematocrit and an increase in WBCs count. Similarly, Misra and Behera (1992) found the decline of erythrocyte count, hematocrit and hemoglobin in blood of *Channa punctatus* on exposure to sublethal concentration of mercuric chloride. Same observations were also mentioned by Shakoori *et al.* (1994) for grass carp (*C. idella*) and Marie (1999) for Nile tilapia (*O. niloticus*). The present study was conducted to determine the effects of sublethal doses of mercury on growth rate, physiological properties and economical efficiency of three tilapia species (*O. niloticus, S. galilaeus* and *O. aureus*), in addition to its effects on water quality and plankton fertility in fish rearing ponds.

MATERIALS AND METHODS

Site of work and fish used

The present work was carried out in rectangular fiber glass tanks (3 x 2 m) with 0.85 m depth. These tanks were filled with freshwater and supplied with sublethal doses of mercuric chloride as follows; the control one was maintained without mercury, the other tanks contained 0.310, 0.155 and 0.078 mg L^{-1}, while the tanks were duplicated with the same experimental treatments. The water in ponds was continuously aerated by mean of an electric compressor, faeces and other remains were removed daily by sucking. The fish used were *Oreochromis niloticus, Sarotherodon galilaeus* and *Oreochromis aureus* with an average starting body weight of 50g/fish and 13 cm for total length. The fish were stocked in tanks at a rate of 15 fish m^{-2} (90 fish $pond^{-1}$), 30 *O. niloticus*, 30*S. galilaeus* and 30 *O. aureus*. The supplementary feed was pelleted diets containing 30 % crude protein and formulated from fish meal, soybean, rice bran, yellow corn and sunflower oil (commercial diets). The fish fed six days a week, once per day at a level of 3 % of the average body weight.

Physico-chemical and hydro-biological aspects

Water temperature, dissolved oxygen and pH value were daily determined (9.00 am and 2.00 pm) by using a simple thermometer, oxygenometer (Cole Parmer Model 5946) and pH meter (Orion Digital Model 210). Total alkalinity, ammonia, nitrate and phosphate were monthly estimated, using methods described by Arnold *et al.* (1980). Samples of plankton were taken biweekly from 10 liters of tanks water. The phytoplankton organisms were collected by a fine nylon net of 20 micron mesh size, then identified and counted by Sedwick Rafter Counting Cell, through a research microscope (200 X). The zooplankton individuals were collected, using a nylon net of 50 micron mesh size and counted by Tray Counting Cell through microscope (100 X).

Growth and feed utilization

The total length (cm) and body weight (g) of reared fish (15 fish from each species in each treatment) were measured biweekly. Specific growth rate (SGR), percentage weight gain (PWG), normalized biomass index (NBI), feed conversion ratio (FCR), protein efficiency ratio (PER) and protein productive value (PPV) were calculated according to the following equations;

SGR = (Ln final weight – Ln initial weight) x 100 / Period (days)

PWG = (Final weight – Initial weight) x 100 / Initial weight

NBI = Final weight – Initial weight / 100

FCR = Food consumed (g) / Weight gain (g)

PER = Weight gain (g) / Protein consumed (g)

PPV = Increasing of body protein (g) / Protein consumed (g) x 100

Meanwhile, the total survival rate (TSR) and condition factor (k) of experimental fish in each treatment were estimated by applying these formulae;

TSR = Survived fish number x 100 / Total fish number

K = Body weight x 100 / (Total length)^3.

Production and economical efficiency

The total fish production and economical efficiency (net returns and profitability) of rearing ponds were determined in different treatments at the end the experiment (180 days) according to the following equations:

Fish production (ton feddan^{-1}) = 4200 [Weight gain (g) x Number of survived fish /10^6]

Net returns (LE feddan^{-1}) = Price of produced fish (LE) – Total costs (LE)

Profitability (percent) = Price of produced fish (LE) / Total costs (LE) x 100

(feddan = 4200 m^2, hectar = 10000 m^2, hectar = 2.38 feddans)

Blood and biochemical composition

The blood samples (10 fish were examined from each species in each treatment) were taken over heparinized vials by severing the caudal peduncle of fish (Dabrowska *et al.,* 1989). The hematocrit percent was measured by drawing the blood directly from fish into a heparinized hemopipette, then centrifuged at 3000 r.b.m. (Hesser, 1960). Hemoglobin content was estimated by Van Kampen & Zijfstra method (1961). Serum glucose was determined by using Boehringer Manneim Kits as described by Trinder (1969) and serum lipid by Zollner & Kirsch method (1962). Protein in serum and muscles were determined according to Gornall *et al.* (1949). Glycogen in fish muscles was measured by using the anthrone reagent (Handel, 1965), while total lipid in muscles was extracted by mixture of chloroform with methanol (2:1) and estimated using Bligh & Dyer (1959) method.

Mercury residues in fish tissues

The examined tissues of fish (liver, muscles and gills) were completely dried at 75 °C for about 48 hours. Half gram of dry weight of each sample was digested with the digestion solution (65% HNO_3 and 30 % H_2O_2) using the digestor (Milestone, MLS-1200 mega) and microwave digestion system with MDR technology. Concentration of mercury (Hg) was determined by the atomic spectrophotometer (Perkin-Elmer, 2380, Germany).

Statistical analysis

The differences between means of experimental and control values in different treatments were considered unsignificant if $P > 0.05$, significant if $P < 0.05$ and highly significant if $P < 0.01$ using t-test of significance as described by Berlly & Lindgren (1990) with applying the following equations;

$$\text{Calculated value} = \overline{X}_1 - \overline{X}_2 / \sqrt{(SE)_1^2 + (SE)_2^2}$$

$$\text{Standard error (SE)} = \text{Standard deviation (SD)} / \sqrt{n}$$

where, X_1 = Mean of the first group.
X_2 = Mean of the second group.
SE_1 = Standard error of data in first group.
SE_2 = Standard error of data in second group.
n = Number of cases in each group.

RESULTS

a- Effect of mercury on water quality and plankton

The present results (Table 1) showed that water temperature was not clearly varied with different sublethal levels of mercuric chloride, while the dissolved oxygen was slightly decreased with increasing mercury concentration in fish ponds and had its lowest value (2.61 ± 0.36 mg L^{-1}) in pond containing highest mercury level (0.310 mg L^{-1}). The other chemical properties of ponds water (alkalinity, ammonia, nitrate, phosphate and pH value) were increased with the highest mercury concentration to 186.0, 0.7, 0.51, 3.75 mg L^{-1} and 8.61, respectively. Table (1) reveales also that, the number of phytoplankton (Chrysophyta or diatoms, golden yellow algae; Chlorophyta, green algae and Cyanophyta, blue green algae) and zooplankton (Ciliophora, *Cilliata* spp; Rotifera, *Brachionus* sp.; Cladocera, *Daphnia* sp. and Copepoda, *Cyclops* sp.).

organisms were decreased with increasing of sublethal doses of $HgCl_2$ in ponds water. The lowest numbers of phyto and zooplankton organisms (145, 220, 105, 135 cell/m^3 for phytoplankton groups and 61, 75, 44 cell /m^3 for zooplankton individuals, respectively) were observed at highest mercury level (0.310 mg L^{-1}).

b- Effect of mercury on growth and feed utilization

The influences of mercuric chloride levels on the final body weight (FBW) and daily weight gain (DWG) of the three tilapia species were summarized in Table (2), the lowest values (171.5, 0.67g; 144.0, 0.52g and 153.5, 0.56g for the three fish species, respectively) were observed at highest mercury level (0.310 mg L^{-1}). As shown in Table (3), the specific growth rate (SGR) and normalized biomass index (NBI) were gradually decreased with increasing the mercury level in ponds, their minimum values (0.67, 1.21 for *O. niloticus*; 0.59, 0.94 for *S. galilaeus* and 0.60, 1.02 for *O. aureus*) were obtained from the pond containing 0.310 mg L^{-1} $HgCl_2$. The feed conversion ratio (FCR) of reared fish was not affected with different mercury levels in ponds water, while the values of protein efficiency ratio (PER) and protein productive value (PPV) were decreased to 1.02, 1.27; 0.95, 1.01 and 0.96, 0.94 for the three fish species respeetively when the $HgCl_2$ level increased to 0.310 mg L^{-1}. Table (3) showed also that the survival rate was decreased with increasing the mercury level in ponds water and had its lowest values (60.00, 53.33 and 46.67 % for three fish species) at 0.310 mg L^{-1} $HgCl_2$. Meanwhile, the condition factor of fish was increased to 2.62 ± 0.52 for Nile tilapia, 2.47 ± 0.50 for galilae fish and 2.55 ± 0.50 for aurea fish in the pond with highest mercury level (0.310 mg L^{-1}).

c- Effect of mercury on production and economical efficiency

The total fish production (TFP), net return (NR) and profitability (P) of reared fish were also affected with different levels of mercuric chloride (Table 4). Their values were slightly decreased with increasing the mercury concentration in ponds water and reached to its minimum limit (1518, 1053, 995 kg feddan^{-1}; 2486, 331, 227 L.E. feddan^{-1} and 0.21, 0.03, 0.02 % for the three fish species, respectively) at the pond with 0.310 mg L^{-1} $HgCl_2$.

d- Effect of mercury on blood and biochemical composition

The data presented in Table (5) indicated that the blood parameters, serum analysis and biochemical composition of fish muscles were highly affected with sublethal levels of mercuric chloride. The hematocrit and hemoglobin contents were decreased to 28.5, 29.0, 30.0 %

and 5.5, 5.0, 5.2g /100 ml blood for the three fish species at highest mercury level (0.310 mg L^{-1}). On the other hand, glucose and lipid levels in serum of the three fish species were increased to 81.0, 79.0, 78.5 mg /100 ml serum and 3.2, 3.1, 3.35 g/100 ml serum with increasing the mercury concentration to 0.310 mg L^{-1} as compared with the control group (without mercury). In the contrast, the serum protein was decreased to 7.0, 6.6 and 6.5 g/100 ml serum (for the three fish species) at highest mercury level (0.310 mg L^{-1}). The protein and glycogen in fish muscles had its minimum values (12.5, 12.0, 12.0g /100g fresh tissue and 0.86, 0.90, 0.85 mg /100g fresh tissue for the three fish species) in pond containing 0.310 mg L^{-1} $HgCl_2$, while the total lipid had its maximum values (9.1, 8.9 and 9.0 g/100 g fresh tissue respectively).

e- Mercury residues in fish tissue

Table (5) also cleared that the greatest bioaccumulation of mercury metal was observed firstly in the liver then in gills and lastly in fish muscles. The maximum values of mercury residue (2.42, 3.10 and 2.65 mg/g dry weight for the three fish species) were observed for fish reared in pond containing 0.310 mg L^{-1} mercuric chloride.

DISCUSSION

The present study revealed that, the sublethal levels of inorganic mercuric chloride ($HgCl_2$) caused a disturbance for water quality (physico-chemical properties) in fish ponds. The dissolved oxygen decreased while other chemical properties and pH increased. Similar observations were detected by Draz *et al.* (1993) who mentioned that heavy metals (including mercury) may find their way to the water system and affect on the physico-chemical parameters (water temperature, pH value, dissolved oxygen, organic matter and chloride content) of ponds water. Similarly, Perschbacher & Wurts (1999) reported that the total alkalinity and other chemical properties in ponds of channel catfish were gradually increased with increasing the heavy metals concentration, while dissolved oxygen decreased. On the other hand, mercury, like other heavy metals, influences the aquatic life (plankton organisms) of water in fish ponds. Starodub *et al.* (1987) cited that individual and combined heavy metals toxicity lead to decreasing of freshwater green algae in fish ponds. In addition, Siriwardena *et al.* (1995) noticed that the heavy metals (including mercury) caused a decline in number of small aquatic organisms (phyto and zooplankton) in fish ponds.

The present work also showed a decreasing in growth performance in tilapia species with increasing mercury level in ponds water. This may be attributed to these factors; a- the mercury level reduced the dissolved oxygen in ponds due to falling of chlorophyta (decreasing of photosynthesis process). b- mercury decreased the natural food organisms (phyto and zooplankton) in fish ponds c- mercury reduced the activities of digestive enzymes in tilapia bodies (Sastry and Gupta, 1979).

It was also noticed that there is no clear differences between the feed conversion ratio in control fish and fish under experimental treatments, while the protein efficiency ratio and protein productive value were decreased at highest level of $HgCl_2$. Similar observations were detected by Barak and Mason (1990) on five species of freshwater fish from Eastern England and Draz *et al.* (1993) on three tilapia species. They added that the highest sublethal level of mercury (0.310 mg L^{-1}) affected also on fish bone, leading to decreasing of total length of reared fish (dwarfism cases) consequently reduce the condition factor which is a relation between the total length and body weight.

Furthermore, the decreasing of fish production and profitability of tilapia species reared in ponds containing sublethal levels of mercury as cleared in the present study, may be due to the reduced growth rate, metabolic activity and increased mortality of fish. Draz *et al.* (1993) reared three species of tilapia under chronic exposure to some heavy metals and noticed that there were a significant difference in final body weight between treated and non treated fish. They added that the growth parameters of reared fish were gradually decreased with increasing the heavy metal level in ponds water.

The present results also showed that the hematocrit and hemoglobin of tilapia fish were decreased at highest mercury level, while serum glucose was significantly increased. The decreasing of hematocrit and hemoglobin in different freshwater fish (tilapia species) as a result of exposure to sublethal concentrations of mercury was observed also by Misra & Behera (1992) on *Channa punctatis*; Kumari & Banerjee (1993) on *Clarias batrachus*, Shakoori *et al.* (1994) on *Ctenopharyngodon idella* and Marie (1999) on *Oreochromis niloticus*. These investigators attributed the decrease in hematocrit and hemoglobin to the decreased production of erythrocytes coupled with an enhanced rate of their destruction in the hemopiotic organs and to interhepatic, interasplenic hemorrhage, due to the action of heavy metal accumulation. The significant increase in serum glucose and decreasing in muscle glycogen of tilapia fish, when exposed to mercury may be attributed to a-inhibition of gluconeogenesis processes that lead to mobilization of liver glycogen into blood glucose (Salmeron *et al.* 1990), b-increasing secretion of catecholamines from the adrenal medulla, which in turn enhance the breakdown of glycogen and increase blood sugar (El-Sabbagh, 1996), c-accumulation of heavy metals in the pancreatic islets and damage to the insulin produced Beta cells (Zaghloul, 1997). Concerning the present experiment, exposure of tilapia species to mercury caused a decrease of serum and muscle protein. This agrees with that postulated by Saeed (1998) on *O. niloticus* and El-Nagar *et al.* (2001) on *O. aureus*. In contrast, lipid in serum and muscles of fish was increased with increasing of mercury level in ponds water in the present study. A similar finding was reported by Ghazaly & Said (1995) in *O. niloticus* reared under chronic exposure to mercury concentrations.

The increasing of mercury residues in fish tissues (liver, gills and muscles) with increasing mercuric chloride levels in fish ponds and its highest concentration in liver than that in gills and muscles was also noticed by Salah El-Deen *et al.* (1996) who mentioned that, the greatest mercury residues were observed in fish liver due to the high movement of mercury from different tissues to the liver for detoxification.

CONCLUSION

The present investigation demonstrated that the sublethal concentrations of inorganic mercury ($HgCl_2$) in the aquatic areas deteriorate fish culture systems and leads to degradiation of water fertility in fish farms. Mercury toxicity decreased the growth rate and production of tilapia species, consequently reducing economical efficiency of rearing ponds. Mercury also caused an increase of serum glucose and lipid coupled with decreasing hematocrit, hemoglobin, serum protein and muscles protein and glycogen. Bioaccumulation of mercury was much higher in fish liver than in gills and muscles.

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Table 1 Physico-chemical properties and hydro-biological aspects of tilapia ponds containing sublethal levels of mercuric chloride

Item	Control		Mercuric chloride concentrations					
	Without mercury		0.310 mg L^{-1}		0.155 mg L^{-1}		0.078 mg L^{-1}	
	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE	Range	Mean ± SE
Physico-chemical pro.								
Water temperature (°C)	23.00 – 27.50	25.50 ± 1.80	24.50 - 28.00	26.50 ± 1.75	23.00 – 26.50	24.50 ± 1.33	25.00 – 29.00	27.00± 1.65
Dissolved oxygen (mg L^{-1})	3.50 - 7.00	5.42 ± 0.75	1.20 - 3.50	2.61 ± 0.36	2.50 – 4.80	3.22 ± 0.41	2.75 – 5.66	4.00±0.52
Total alkalinity (mg L^{-1})	120.50 - 162.00	148.50 ± 4.50	165.00 – 211.00	186.00 ± 6.71	154.50 – 196.00	170.50 ± 5.80	140.00 – 185.00	161.00 ± 5.20
Ammonia (mg L^{-1})	0.22 - 0.60	0.48 ± 0.03	0.41 – 0.81	0.70 ± 0.06	0.36 – 0.75	0.66 ± 0.05	0.30 – 0.71	0.60 ± 0.05
Nitrate (mg L^{-1})	0.18 - 0.45	0.32 ± 0.02	0.28 – 0.62	0.51 ± 0.03	0.22 – 0.58	0.48 ± 0.03	0.20 – 0.54	0.40 ± 0.03
Phosphate (mg L^{-1})	0.94 - 2.03	1.36 ± 0.45	1.56 – 3.22	3.05 ± 0.50	1.17 – 2.86	2.50 ± 0.47	1.00 – 2.50	2.07 ± 0.47
pH value	6.00 - 8.00	7.20 ± 0.80	6.90 – 9.20	8.61 ± 0.84	6.60 – 9.00	8.00 ± 0.84	6.50 – 9.00	7.70 ± 0.82
Hydro-biological asp.:								
Phytoplankton								
Chrysophyta spp.	200 - 365	280 ± 8	120 – 185	145 ± 6	135 – 200	176 ± 7	150 – 285	194 ± 7
Chlorophyta spp.	300 - 540	400 ± 16	180 – 350	220 ± 11	210 – 385	275 ± 14	260 – 420	310 ± 14
Cyanophyta spp.	190 - 340	220 ± 7	68 – 165	105 ± 5	96 – 188	136 ± 6	110 – 200	161 ± 6
Total number (cell m^{-3})	690-1245	900 ± 31	368-700	470 ± 22	441 - 773	587 ± 27	520 - 905	665 ± 27
Zooplankton								
Cilliophora spp.	115 - 210	166 ± 5	95 – 184	105 ± 3	100 – 190	147 ± 4	105 – 196	153 ± 4
Rotifera spp.	72 - 125	90 ± 3	47 – 95	61 ± 2	52 – 100	70 ± 2	55 – 110	75 ± 2
Cladocera spp.	88 - 170	110 ± 4	52 – 100	75 ± 3	60 – 120	86 ± 3	65 – 130	90 ± 3
Copepoda spp.	45 - 90	60 ± 2	30 – 65	44 ± 3	35 – 70	50 ± 1	40 – 72	50 ± 1
Total number (cell m^{-3})	320 - 595	426 ± 14	224 - 444	285 ± 11	247 - 480	353 ± 10	265 - 508	368 ± 10

Table 2 Growth rate, food consumption and total production of three tilapia species reared under different sublethal levels of mercuric chloride for 24 weeks.

Item	Control			Mercuric chloride concentrations								
	without mercury			0.310 mg L^{-1}			0.155 mg L^{-1}			0.078 mg L^{-1}		
	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia
Initial weight / fish (g)	51.00	50.50	52.00	51.00	50.00	52.00	51.50	50.50	52.00	51.00	50.00	52.00
Final weight / fish (g)	213.50	176.50	196.00	171.50	144.00	153.50	183.00	152.50	165.50	195.50	161.00	178.50
Gain in weight / fish (g)	162.50	126.00	144.00	120.50	94.00	101.50	131.50	102.00	113.50	144.50	111.00	126.50
Daily weight gain / fish (g)	0.90	0.70	0.80	0.67	0.52	0.56	0.73	0.57	0.63	0.81	0.62	0.70
Initial length/ fish (cm)	13.00	13.00	13.50	13.00	13.00	13.50	13.00	13.00	13.50	13.00	13.00	13.50
Final length/ fish (cm)	22.50	19.30	20.80	18.70	18.00	18.20	14.60	18.30	18.70	20.50	18.50	18.80
Gain in length (cm)	9.50	6.30	7.30	5.70	5.00	4.70	6.60	5.30	5.20	7.50	5.50	5.30
Food consumed / fish (g)	496	410	451	394	331	353	421	351	381	450	370	411
Food consumed / pond (kg)	14.880	11.40	12.628	7.092	5.296	4.942	7.999	5.967	6.096	9.000	6.290	6.987
Food consumed / m^2 (kg)	2.480	1.845	2.105	1.182	0.883	0.824	1.333	0.995	1.016	1.500	1.048	1.165
Food consumed / feddan (ton)	10.416	7.749	8.840	4.964	0.707	3.459	5.599	4.177	4.267	6.300	4.403	4.891
Production / pond (kg)	4.875	3.402	4.032	2.169	0.504	1.421	2.499	1.734	1.816	2.890	1.887	2.151
Production /m^2 (kg)	0.813	0.567	0.672	0.362	0.251	0.237	0.416	0.289	0.303	0.482	0.315	0.358
Production / feddan (ton)	3.415	2.381	2.822	1.518	1.053	0.995	1.749	1.214	1.271	2.023	1.321	1.505

* Area of pond = 6 m^2
* Feddan = 4200 m^2, hectar = 10000 m^2.

Table 3 Growth performance, feed utilization and survival efficiency of three tilapia species reared under different sublethal levels of mercuric chloride for 24 weeks.

Mercury levels	Fish species	Growth performance			Feed utilization			Survival efficiency			Condition factor (K)
		SGR[1]	PWG[2]	NBI[3]	FCR[4]	PER[5]	PPV[6]	TFN[7]	SFN[8]	TSR[9]	
0 (control)	Nile tilapia	0.80 ± 0.33	319 ± 0.62	1.63 ± 0.46	3.05 ± 0.60	1.09 ± 0.41	4.17 ± 0.85	30	30	100.00	1.87 ± 0.45
	Galilae tilapia	0.70 ± 0.31	250 ± 0.60	1.26 ± 0.45	3.25 ± 0.60	1.02 ± 0.40	4.47 ± 0.85	30	27	90.00	2.46 ± 0.50
	Aurea tilapia	0.75 ± 0.32	277 ± 0.60	1.44 ± 0.45	3.13 ± 0.60	106 ± 0.40	3.47 ± 0.80	30	28	93.33	2.18 ± 0.50
0.310 (mg L-1)	Nile tilapia	0.67 ± 0.30	236 ± 0.60	1.21 ± 0.44	3.27 ± 0.60	1.02 ± 0.40	1.27 ± 0.44*	30	18	60.00	2.62 ± 0.52
	Galilae tilapia	0.59 ± 0.30	188 ± 0.55	0.94 ± 0.40	3.52 ± 0.60	0.95 ± 0.39	1.01 ± 0.44*	30	16	53.33	2.47 ± 0.50
	Aurea tilapia	0.60 ± 0.30	195 ± 0.55	1.02 ± 0.42	3.48 ± 0.60	0.96 ± 0.38	0.94 ± 0.30*	30	14	46.67	2.55 ± 0.50
0.155 (mg L-1)	Nile tilapia	0.71 ± 0.31	255 ± 0.60	1.32 ± 0.44	3.20 ± 0.60	1.04 ± 0.40	1.98 ± 0.45*	30	19	63.33	2.43 ± 0.50
	Galilae tilapia	0.62 ± 0.30	202 ± 0.57	1.02 ± 0.40	3.44 ± 0.60	0.97 ± 0.38	1.90 ± 0.45*	30	17	56.67	2.49 ± 0.50
	Aurea tilapia	0.64 ± 0.30	218 ± 0.57	1.14 ± 0.40	3.36 ± 0.60	0.99 ± 0.38	1.75 ± 0.40*	30	16	53.33	2.50 ± 0.50
0.078 (mg L-1)	Nile tilapia	0.75 ± 0.32	283 ± 0.60	1.45 ± 0.43	3.11 ± 0.60	1.07 ± 0.41	3.11 ± 0.76	30	20	66.67	2.27 ± 0.50
	Galilae tilapia	0.65 ± 0.31	222 ± 0.57	1.11 ± 0.40	3.33 ± 0.60	1.00 ± 0.38	3.60 ± 0.80	30	17	56.67	2.54 ± 0.51
	Aurea tilapia	0.69 ± 0.31	243 ± 0.57	1.27 ± 0.42	3.25 ± 0.60	1.03 ± 0.40	2.43 ± 0.60	30	17	56.67	2.67± 0.53

[1] SGR = Specific growth rate.
[2] PWG = Percentage weight gain.
[3] NBI = Normalized biomass index.
The values expressed as mean ± SE.
* Difference from control is significant ($p < 0.05$).

[4] FCR = Feed conversion ratio.
[5] PER = Protein efficiency ratio.
[6] PPV = Protein productive value.

[7] TFN = Total fish number.
[8] SFN = Survived fish number.
[9] TSR = Total survival rate.

Table 4 Total production, economical efficiency and profitability of three tilapia species reared under different sblethal levels of mercuric chloride for 24 weeks.

Item	Control			Mercuric chloride concentrations								
	without mercury			0.310 mg L^{-1}			0.155 mg L^{-1}			0.078 mg L^{-1}		
	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia	Nile tilapia	Galilae tilapia	Aurea tilapia
Fish production / fedda (kg)	3415	2381	2822	1518	1053	995	1749	1214	1271	2023	1321	1505
Price of one kg fish sold (LE)	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5	9.5
Price of produced fish / fed (LE)	32443	22620	26809	14421	10004	9453	16616	11533	12075	19219	12550	14298
Food consumed / feddan (kg)	10416	7749	8840	4964	3707	3459	5599	4177	4267	630	4403	4881
Price of one kg diet (LE)	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80	1.80
Feeding costs / feddan (LE)	18749	13948	15912	8935	6673	6226	10078	7519	7681	11340	7925	8804
Other costs / pond (LE)	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50	7.50
Other costs / feddan (LE)	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Total costs / feddan (LE)	21749	16948	18912	11935	9673	9226	13070	10519	10681	14340	10325	11804
Net returns / pond (LE)	15.28	5.30	11.28	3.55	0.47	0.32	5.05	1.45	1.99	6.97	2.32	3.54
Net returns / feddan (LE)	10694	3708	7897	2436	331	227	3538	1014	1394	48.79	16.25	2494
Profitability (%)	0.49	0.22	0.42	0.21	0.03	0.02	0.27	0.10	0.13	0.34	0.15	0.21

LE = Egyptian lever.
Other costs = Price of net and other used materials plus salaries of labors and fishermens.

Table 5 Blood properties, biochemical composition and mercury residues of three tilapia species reared under different sublethal levels of mercuric chloride for 24 weeks.

Mercury levels	Fish species	Blood and serum analysis					Biochemical composition[3]			Mercury residues[4]		
		Ht[1]	Hg[2]	Glucose	Protein	Lipids	Protein	lipids	glycogen	Liver	Gills	Muscles
0 (control)	Nile tilapia	44.50 ±2.50	11 02±1.75	65.00±5.50	12.65± 1.80	1.06±0.86	17.20±1.85	7.50±1.11	1.61±0.85	0,13±0.003	0.13±0.003	0.13±0.003
	Galilae tilapia	42.00 ±2.20	10.50±1.66	63.50±5 20	12.00±1 80	1.50±0.85	16.50±1.85	7.60±1.12	1.57±0.85	0.15±0.005	0.15±0.005	0.15±0.005
	Aurea tilapia	43.00±2 20	10,30±1.50	64.00±5.50	12.50±1 80	1.60±0.85	13.70±1.85	7.45±1.10	1.58±0.85	0.14±0.004	0.14±0.004	0.14±0.004
0.310 (mg L⁻¹)	Nile tilapia	28 50±1 75*	5.50±1.21*	81.00±6.50	7.00±1.10*	3 20±0.91	12.50±1.50	9 10±1 10	0.86±0.66	2.42±0.04*	1.60±0.02*	1.05±0.02*
	Galilae tilapia	29.00±1.80*	5.00±1.20*	72.00±5.70	6.60±1.15*	3 10±0.90	12.00±1.50	8 90±1 10	0 90±0.65	3.10±0.05*	1.95±0.03*	1.20±0.03*
	Aurea tilapia	30.00±1 82*	5.20±1.20*	78 50±5.50	6.50±1.15*	3 35±0.90	12.00±1.50	9.00±1.10	0.85±0.65	2.65±0.04*	1.71±0.03*	1.16±0.03*
0.155 (mg L⁻¹)	Nile tilapia	31 50±1 86*	6.20±1.25*	70 00±5 50	8.20±1.30*	2 50±0.85	13.50±1.55	8.50±1 12	0 92±0.75	2.11±0.04*	1.31±0.02*	0.86±0.01*
	Galilae tilapia	30.00±1 84*	6.00±1.25*	73.00±5.50	7.50±1.21*	2 20±0.85	13.00±1.55	8.30±1 12	0.97±0 75	2.66±0.04*	1.58±0.02*	1.00±0.02*
	Aurea tilapia	32.00±1 90*	6.00±1.25*	72.00±5 20	7.80±1.20*	2 65±0.85	13.00±1.55	8.20±1.10	0 90±0.75	2.18±0.04*	1.42±0.02*	0.95±0.02*
0.078 (mg L⁻¹)	Nile tilapia	33 00±1 91*	7.50±1.28	70 00±5 00	9.00±1.30	2 10±0 85	15.20±1.55	8.00±1.10	0.95±0.75	1.85±0.03*	1.02±0.02*	0.64±0.01*
	Galilae tilapia	31.50±1 85*	7 20±1 28	71 50±5 00	8.60±1.30	1 95±0 76	15.00±1.55	8 00±1 10	1.02±0.20	2.08±0.03*	1 25±0.02*	0.93±0.03*
	Aurea tilapia	34.00±2 00*	7.60±1.28	71.00±5 00	8.80±1.30	2 00±0.77	14.00±1.55	7.95±1.10	0.96±0.75	1.90±0.03*	1.15±0.02*	0.77±0.01*

[1] Ht = Hematocrit value (percent)
[2] Hg = Hemoglobin content (g/ 100 ml blood)
[3] Biochemical composition expressed as g/100 g fresh tissue
[4] Mercury residues expressed as g/100 g dry weight
* Difference from control is significant ($P < 0.05$)

The values expressed as mean ± standard error.
Initial protein in the three fish bodies = 11.0 g/100 fresh tissue.
Serum constituents expressed as g/ 100 ml serum.