Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Effects of dietary magnesium supplementation on the growth performance, body composition, and immune indices of juvenile Persian sturgeon, *Acipnser persicus*

Mir Emad Mir Rasekhian[1], Hossein Khara[2*], Hamid Reza Pourali[3]

1. Department of Aquaculture, Guilan Sciences and Researches Branch, Islamic Azad University, Rasht, Iran
2. Department of Aquaculture, Lahijan Branch, Islamic Azad University, Lahijan, Iran
3. Agricultural Research, Education and Extension Organization (AREEO), International Sturgeon Research Institute, Rasht, Iran

** Corresponding author's E-mail: h.khara@liau.ac.ir*

ABSTRACT

The present experiment was carried out to investigate the effects of different levels of dietary magnesium on growth performance, proximate composition, and immune response of juvenile Persian sturgeon, *Acipenser persicus.* Fish were fed with six different rations including T1: 32, T2: 185, T3: 380, T4: 592, T5: 790, and T6: 935 mg kg^{-1} Mg in diet for 8 weeks. At the end of the experiment, samples were collected for estimating the proximate composition and immunological parameters. Results of the present study showed that dietary Mg level significantly influences on growth performance and proximate body composition. Body weight, BWI, and DG were increased by up to 592 mg kg^{-1} dietary Mg, while decreased by its higher levels. The significant increase in lysozyme activity (by 790 mg kg^{-1} of dietary Mg) and immunoglobulin (by 935 mg kg^{-1}) were observed in fish fed with different levels of magnesium supplementation compared to control group, which may be due to immune enhancement. The dietary Mg level of 592 mg kg^{-1} was suitable for Persian sturgeon based on the growth performance.

Keywords: Magnesium requirement, Diet, Persian sturgeon, *Acipenser persicus*.
Article type: Research Article.

INTRODUCTION

Magnesium (Mg), as an essential mineral, is the third most abundant ion in ocean water with the concentration of more than 50 mmol L^{-1} (Rankin & Davenport 1981). It plays an important role in activation of enzymes (at least 300 enzymatic reactions) involved in the normal metabolism of lipids, proteins, and carbohydrates (Davis & Gatlin, 1996; Davis & Lawrence 1997; Lall 2002; Vormann 2003). It is essential for the maintenance of intra- and extracellular homeostasis (Houston 1985), transferring phosphate groups, and controlling ATP-dependent ion pumps (Bijvelds *et al*. 1998). Mg also plays a key role in immune mechanism (Lall 2002; Tam *et al*. 2003), and is a main component of bone in fish (Houston 1985). The deficiency signs of Mg in fish include anorexia, sluggishness, reduced growth, muscle flaccidity, vertebral deformity, high mortality which have been reported for several species (Lall 2002). Since the level of Mg in freshwater is apparently insufficient to meet the metabolic requirements of fish, therefore adding the element in the diet of fish reared in fresh water is so unavoidable (Steffens 1989). Fish can uptake magnesium both from water and food (Bijvelds *et al*. 1997; Lall 2002). The necessity of Mg has been recognized for several species of fresh water fish such as common carp, *Cyprinus carpio* (Ogino & Chiou 1976); rainbow trout, *Oncorhynchus mykiss* (Ogino *et al*. 1978; Knox *et al*. 1981; Shearer 1989); channel catfish, *Ictalurus punctatus* (Gatlin *et al*. 1982; Lim and Klesius 2003); guppy, *Poecilia reticulata* (Shim

Caspian Journal of Environmental Sciences, Vol. 20 No. 3 pp. 557-564 Received: Nov. 01, 2021 Revised: Jan. 22, 2022 Accepted: March 16, 2022
DOI: 10.22124/CJES.2022.5691

Publisher: University of Guilan, Iran

& Ng 1988); tilapia, *Oreochromis niloticu* (Dabrowska *et al*. 1989); far eastern catfish, *Silurus asotus* (Yoon *et al.* 2014); Japanese seabass, *Lateolabrax japonicus* (Huang *et al*. 2016); white shrimp, *Litopenaeus vannamei* (Roy *et al*. 2009); blue tilapia, *Oreochromis aureus* (Reigh *et al*. 1991); common carp, *Cyprinus carpio* (Kandeep 2013) and Pacific white shrimp, *Litopenaeus vannamei* (Jahan *et al*. 2018). Dietary Mg requirements vary for different species or even for the same species at different environment (Han *et al*. 2011). The extra Mg from the diet could be either reabsorb or secret as a function of nutritional status (Liang *et al*. 2011). A reduction in growth was observed when high levels of Mg were fed in a purified diet (Shearer 1989). Therefore, estimation of dietary Mg requirements in cultured aquatic animals is a priority. In order to assess the dietary mineral supplementation for aquatic animals, growth performance, and whole body composition are the main parameters to be measured. The effect of the element on immune function should also be taken into consideration, but this has been seldom addressed. Obviously, changes in immune parameters should be considered as important criteria to assess the nutritive value of Mg for fish meal. Persian sturgeon, *Acipenser persicus* is one of the most important sturgeon species in the south coast of the Caspian Sea, caught for both meat and caviar production. It is considered as an endangered species by the International Union for Conservation of Nature and Natural resources (Sturgeon Specialist Group 1996) due to overfishing and destruction of habitat, which is the subject of restoration and restocking schemes (Mohseni *et al*. 2008; Williot *et al*. 2001). There are many studies about sturgeons around the world (Madadi & Khara, 2016; Badan-Ara Marzdashti *et al.* 2018; Shirangi *et al*. 2019; Fathollahi *et al.* 2020; Barimani *et al.* 2021). However, no study was found about Mg requirements in these fish species. Given the previous Mg studies for other freshwater fish, it is necessary to supplement Mg in the diet of this commercially-important fish species. To date, no study has been conducted about the effects of minerals on sturgeons. This study was performed to investigate the effects of Mg levels on growth performance, survival, body composition, and immune parameters of Persian sturgeon.

MATERIALS AND METHODS

Diet preparation

Composition and the chemical proximate of the basal diet is given in Table 1. Mg sulphate ($MgSO_4$. 7 H_2O) was supplemented to the basal diet at the levels of 0 (T_0), 150 (T_{150}), 350 (T_{350}), 550 (T_{550}), 750 (T_{750}), and 900 (T_{900}) (Karl *et al*. 1992; Allen *et al*. 2005; Roy *et al*. 2009; Liang *et al*. 2012; Han *et al*. 2012). Fish meal and soybean meal were used as the protein sources, fish oil as the lipid source, wheat flour and corn gluten as carbohydrate sources of the basal diet. The analysed Mg contents in the six diets were: 32 (0), 185 (150), 380 (350), 592 (550), 790 (750), 935 (900). All dry ingredients were thoroughly mixed for 20 min, then fish oil was added and mixed for 15 min. Double deionized water was added to make a homogenous ingredients. The pellets (2 mm in diameter) were made using an experimental pellet- making machine and air-dried at 30 °C for 24 hours, then stored at 4 °C until used. Control diet was prepared in the same way without adding magnesium.

Fish husbandry and feeding trial

Juvenile Persian sturgeon were obtained from Dr. Dadman International Sturgeon Research Institute, Rasht, Guilan Province, Iran, then were randomly distributed into 18 circular fiberglass tanks at a density of 20 fish per tank (50 L), where three tanks were assigned to each diet. Fish were allowed to become acclimatized to the experimental condition for 2 weeks prior to beginning the experiments in circular fiberglass tanks. During the acclimation, fish were fed twice daily with the basal diet. Fish were kept under natural light/dark cycle at 12:12 hours. The tanks were supplied with constant flow freshwater of 0.4 ± 0.2 L sec^{-1} and supplemental aeration was provided to maintain dissolved oxygen levels near saturation. Water temperature was maintained at 15 ºC throughout the trial. Mean dissolved oxygen, and pH were 7.1 ± 0.2 mg L^{-1} and 7.7 ± 0.1, respectively. Magnesium concentrations of waterborne were 2.5 to 3.7 mg L^{-1}during the trial period.

Before initiation of the experiment, fish were deprived of feed for one day. Fifteen fish per tank randomly sampled for analysis. The initial body weight and length were 4.8 ± 0.6 g (mean ± SE), and 9.93 ± 0.3 cm, respectively. The experimental diets were carefully hand-fed to triplicate tanks four times per day (08.00, 12.00, 16:00, 20.00 hours) till apparent satiation, and feeding trial lasted for 8 weeks. One hour after feeding, the faeces were removed by siphoning and feed intake of each tank was measured (Abdel-Tawwab *et al*. 2006). During the experimental period, fifteen fish per each replicate was randomly weighed every 14 days.

Table 1. Ingredient and chemical composition of the basal diet.

Ingredients	Amount (g kg^{-1} dry weight)
Fish meal	540
Wheat meal	180
Corn meal	50
Milk powder	50
Fish oil	40
Soybean meal	80
Yeast	30
Mineral premix[1]	13
Vitamin premix[2]	17
Ascorbic phosphate ester	1
Proximate chemical composition (%)	
Crude protein	40
Crude fat	19
Ash	9

[1]Mineral mix (g kg^{-1} diet): Iron, 5 mg; Zinc, 15mg; Copper, 3 mg; Calcium lactate, 327 mg; NaCl, 43.5 mg; Potassium Iodate, 0.3 mg.
[2]Vitamin mix (mg kg^{-1} of diet): Vitamin A , 5000 IU ; Vitamin D3 , 500 IU; Vitamin E , 3 mg; Vitamin K_3 , 1.5 mg ; Vitamin B_2 , 1 mg; Calcium pantothenate, 4 mg; Vitamin B_3, 15 mg, Vitamin B_6, 0. 3 mg.

Sampling and analytical methods

At the end of the trial, fish in each tank were anesthetized with 0.5 g L^{-1} clove powder (Yarmohammadi *et al*. 2012), then body weight (to the nearest 0.01 g) and total length (to the nearest 1 mm) of all fish were individually measured 24 hours after the last feeding to evacuate their gut before measuring. After weighing and measuring length, fish were returned to their tank for recovery. Body weight increase (BWI), condition factor (CF), specific growth rate (SGR), daily growth rate (DG), feed conversion ratio (FCR), protein efficiency ratio (PER) were calculated as follows:

BWI (%) = 100 × (final body weight - initial body weight) / initial body weight

CF = 100 × (body weight) / total length^3

SGR (% day^{-1}) = 100 × (Ln final body weight - Ln initial body weight) / days of the trial

DG = 100 × (final body weight - initial body weight / initial body weight - days of the trial)

FCR = feed intake / weight gain

PER = Wet weight gain (g) / Protein intake (g)

Fifteen fish per group (five fish in each replicate) were sacrificed with an overdose of 1000 mg L^{-1} clove solution. Thereafter, samples immediately frozen at -20 °C. Fish composition were analysed according to AOAC (1995) standard methods. To find the moisture content, samples were placed in oven drying at 105 °C to reach constant weight. Crude fat was measured by Soxhlet method, based on extraction of the lipids. Crude protein content was assayed by Kjeldahl method by measuring the total nitrogen (N × 6.25). In order to measure ash content, samples were burned for 6 h in a Gallenkamp furnace at 550 °C. To assess the immune parameters, five fish were randomly collected from each replicate. The blood was withdrawn from the caudal vessel using a 2 mL syringe. The sampling lasted less than 1 min for each fish after anaesthetization. Blood were transferred to test tubes, centrifuged at 1600 *g* for 10 min, then plasma separated and stored in Eppendorf tubes at -80 ºC for subsequent assays of immune parameters including immunoglobulin (IgM), and lysozyme concentrations. IgM was determined by immune turbidimetric method, measured by spectrophotometer at 360 nm absorbance. Lysozyme was measured by turbidimetric assay as described by Ellis (1990). 1.75 mL^{-1} of *Micrococcus lysodeikticus* suspension (Sigma; containing 0.375 mg mL^{-1}, 0.05 M PBS, pH 6.2) were mixed with 250 mL of each sample and the optical density was measured after 15 and 180 seconds by spectrophotometer at 670 nm. PBS was used as a blank and results were expressed according to amounts of lysozyme (mg) per one mg of sample calibrated by standard curve determined with hens' egg white lysozyme (Sigma) in sterile sodium phosphate buffer.

Statistical analyses

Data are presented as means ± standard error (SE). To evaluate normality of data and homogeneity of variances, one Sample Shapiro-Wilk and Levene's test were used, respectively. All data subjected to one-way analysis of

variance to determine whether significant differences occurred among treatments. When significant differences were observed, Duncan's multiple range tests by $p < 0.05$ were performed (Zar 2010).

RESULTS

Growth performance

All measured growth parameters are reported in Table 2. The body weight was significantly different ($p < 0.05$) among the treatments. T_{550} exhibited the most body weight compared to all other treatments. No significant different was observed in body length among treatments ($p > 0.05$). CF in fish fed the basal diet was significantly higher than in the other feeding regime ($p < 0.05$), whereas there was no significant difference in CF among other treatments. T_{550} exhibited the most BWI, SGR, and DG compared to all other treatments. FCR was significantly improved in T_{550} with the level of 559 mg kg^{-1} magnesium compared to other treatments. PER in T_{900} was significantly higher than in the other treatments.

Body composition

The proximate composition of carcass at the end of the experiment is shown in Table 3. Significant differences ($p < 0.05$) were observed among the groups for all body composition including moisture, ash, crude fat, and crude protein at the end of the trial.

Immune parameters

Lysozyme level was significantly changed among treatments ($p < 0.05$; Fig. 1). The highest level and lowest level of lysozyme were found in T_{750} and T_0, respectively. Significant differences in IgM concentrations were recorded among the treatments after 56 days ($p < 0.05$; Fig. 2). The highest and lowest level of IgM were found in T_{900} and T_{750}, respectively.

Table 2. Changes in final weight, final length, body weight increase (BWI), condition factor (CF), specific growth rate (SGR), daily growth rate (DG), feed conversion ratio (FCR), and protein efficiency ratio (PER), in Persian sturgeon *Acipenser persicus* after 8 weeks of applying different experimental diets.

	Mg supplementation levels (mg Kg^{-1})					
Growth performance	**0 (32)**	**185 (150)**	**380 (350)**	**592 (550)**	**790 (750)**	**935 (900)**
Initial weight (g)	4.7 ± 0.35	4.8 ± 1.9	4.5 ± 3.6	4.2 ± 0.06	4.1 ± 0.5	4.2 ± 4.9
Final weight (g)	10.9 ± 1.4^{ab}	11.2 ± 1.2^{a}	11.6 ± 1.5^{a}	12.3 ± 1.1^{a}	10.6 ± 1.0^{ab}	9.7 ± 0.8^{b}
Initial length (cm)	9.6 ± 0.5	10.2 ± 0.3	10.7 ± 0.3	9.8 ± 0.9	10.0 ± 0.7	9.3 ± 0.2
Final length (cm)	13.3 ± 1.8	14.1 ± 1.6	14.3 ± 2.2	14.5 ± 2.0	13.6 ± 1.0	13.8 ± 2.0
BWI[1] (%)	122.4 ± 1.7^{bc}	128.6 ± 1.8^{bc}	136.1 ± 1.9^{b}	150.3 ± 2.1^{a}	117.0 ± 1.6^{c}	98.0 ± 1.4^{d}
CF[2]	0.5 ± 0.1^{a}	0.4 ± 0.0^{ab}	0.4 ± 0.0^{ab}	0.4 ± 0.0^{ab}	0.4 ± 0.0^{ab}	0.4 ± 0.0^{ab}
SGR[3] (% day^{-1})	1.5 ± 0.01^{ab}	1.5 ± 0.02^{ab}	1.6 ± 0.02^{a}	1.7 ± 0.01^{a}	1.4 ± 0.01^{ab}	1.2 ± 0.02^{b}
DG[4] (%)	1.7 ± 0.02^{ab}	1.8 ± 0.03^{ab}	1.9 ± 0.03^{a}	2.1 ± 0.02^{a}	1.6 ± 0.02^{ab}	1.4 ± 0.03^{b}
FCR[5]	1.5 ± 0.01^{ab}	1.6 ± 0.02^{ab}	1.6 ± 0.02^{ab}	1.7 ± 0.01^{a}	1.5 ± 0.01^{ab}	1.3 ± 0.02^{b}
PER[6]	2.1 ± 0.01^{ab}	2.1 ± 0.01^{ab}	2.1 ± 0.01^{ab}	2.0 ± 0.01^{b}	2.2 ± 0.01^{ab}	2.4 ± 0.02^{a}

Note: Values are mean ± SE from all fish of each treatment (n = 60). Different superscripts in the same row indicate significant differences ($p < 0.05$) between feeding strategies by One-Way ANOVA and Duncan's tests.

Table 3. Changes in proximate composition (as % of wet weight) in Persian sturgeon, *Acipenser persicus* after 8 weeks of applying different experimental diets.

	Mg supplementation levels (mg Kg^{-1})					
Proximate composition	**0 (32)**	**150 (185)**	**350 (380)**	**592 (550)**	**790 (750)**	**935 (900)**
Moisture (%)	78.7 ± 0.07^{ab}	82.6 ± 0.1^{a}	82.3 ± 0.7^{a}	77.2 ± 0.2^{b}	81.7 ± 0.09^{a}	82.2 ± 0.6^{a}
Crude fat (%)	10.0 ± 0.0^{cd}	21.6 ± 1.2^{a}	16.8 ± 0.6^{b}	8.9 ± 0.5^{cd}	7.5 ± 0.1^{d}	10.5 ± 0.5^{c}
Crude protein (%)	57.5 ± 0.3^{c}	63.1 ± 0.1^{b}	64.2 ± 0.6^{a}	67.02 ± 0.2^{a}	68.07 ± 0.6^{a}	58.6 ± 0.1^{c}
Ash (%)	14.0 ± 1.0^{bc}	14.1 ± 0.7^{bc}	16.1 ± 1.0^{b}	13.6 ± 0.5^{bc}	15.0 ± 1.0^{b}	20.4 ± 0.5^{a}

Note: Values are mean ± SE from all fish of each treatment (n = 15). Different superscripts in the same row indicate significant differences ($p < 0.05$) between feeding strategies by One-Way ANOVA and Duncan's tests.

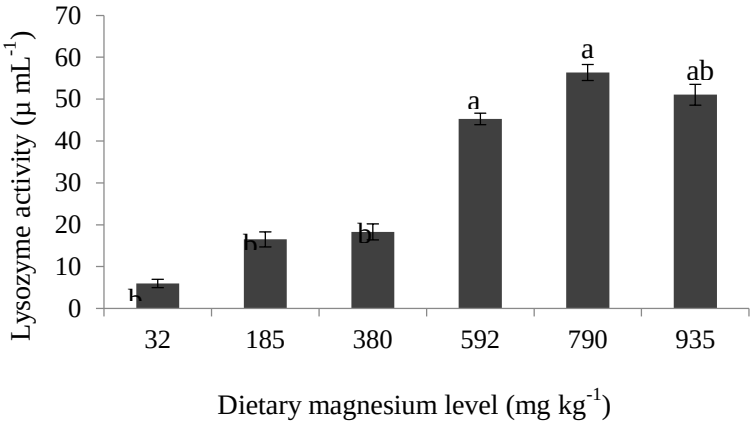

Fig. 1. Serum lysozyme activity of Persian sturgeon, *Acipenser persicus* fed different Magnesium supplemented diets for 8 weeks. Data are presented as mean ± SE (n = 15). Bars with different superscript (s) are significantly different ($p < 0.05$).

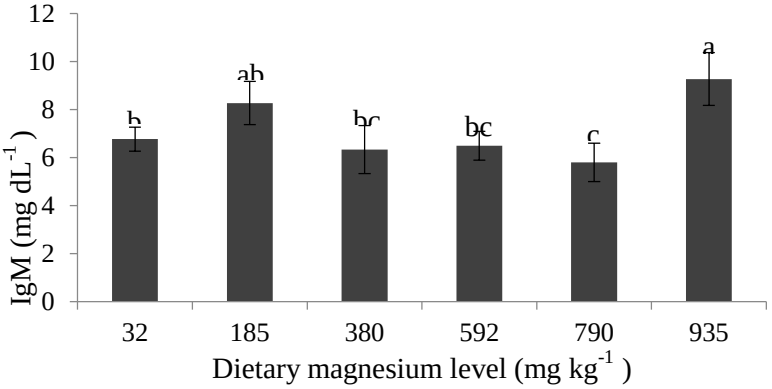

Fig. 2. Serum IgM of Persian sturgeon, *Acipenser persicus* fed different Magnesium supplemented diets for 8 weeks. Data are presented as mean ± SE (n = 15). Bars with different superscript (s) are significantly different ($p < 0.05$).

DISCUSSION

The present study was carried out to determine which dietary level of Mg is optimum for growth, body composition and immune parameters in Persian sturgeon. Unfortunately, poor and inconsistent knowledge is available on the growth and immune response of sturgeon fed with dietary Mg or mineral supplementation. Indeed, the effects of dietary magnesium on growth patterns, proximate composition and immune parameters of this species was assessed for the first time in this study. Results of the present study showed that dietary Mg level significantly influence on growth performance and feed utilization. Mg concentration of waterborne was 2.5 to 3.7 mg L^{-1}during the experiment, which was insufficient to meet the metabolic requirement of Persian sturgeon. In the present study, body weight, BWI, and DG were increased T_{550}, then decreased in the higher levels of dietary Mg. Although no significant difference in body length was revealed after 8 weeks, T_{550} exhibited the highest body length. CF in T_0 was significantly the highest. FCR and PER enhanced in T_{900}, indicating a higher utilization of the dietary protein for growth. In channel catfish, *Ictalurus punctatus*, a Mg dietary level of 400 mg kg^{-1} was required for optimum growth and survival (Lim & Klesius 2003). In addition, Japanese seabass, *Lateolabrax japonicus*, (Huang *et al*. 2016); common carp, *Cyprinus carpio* (Kandeep 2013) and Pacific white shrimp, *Litopenaeus vannamei* (Jahan *et al*. 2018) required 520 mg kg^{-1}, 0.4 g 100 g^{-1} and 150 mg kg^{-1} respectively. Dietary Mg significantly influenced on the growth performance in grass carp, *Ctenopharyngodon idella*, and a dietary Mg of 637 mg kg^{-1} level was sufficient for its optimum growth (Liang *et al*. 2011). On the other hand, in juvenile Gibel carp, *Carassius auartus*, dietary magnesium did not enhance the growth performance, so that, Mg requirement of fish could be met by Mg uptake from the rearing water (Han *et al*. 2011). These contradicting results suggest that Mg requirement changes depending on species, and Mg concentration of rearing water could significantly affect the magnesium requirement of fish (Shearer and Asgard 1992). It has been found that tilapia, *Oreochromis aureus* reared in freshwater with the Mg level of 0.1 mg L^{-1} required a dietary Mg of 500 mg kg^{-1} (Reigh *et al*. 1991), whereas waterborne Mg concentration of 4.8 mg L^{-1} was sufficient for tilapia fed low Mg diet (Van der Velden *et al*. 1991a). It seems that when tilapia fed low Mg diets, it can absorb Mg from water (Van der

Velden *et al*. 1991a). In the present study, Persian sturgeon reared in freshwater, whereas the main habitat of this species is brackish water (Caspian, Azov, Black and Baltic Seas; Billard & Lecointre 2001). Therefore, the low waterborne Mg concentration in the present study is not sufficient for the optimum growth. From the point view of body composition, T_{550} and T_{750} exhibited the lowest and highest rate (%) of body lipid and protein, respectively revealing that the main source of energy was lipid in these treatments. Nutritional modification has recently been used to reduce the severity of infection (Chandra, 1996; Scrimshaw & San Giovanni 1997). Lysozyme occurs predominantly in fish mucus and serum (Ellis 1999). An increase in the lysozyme concentration in fish bloodstream could be the result of infections or invasion by foreign material (Siwicki & Studnicka 1987; Moyner *et al*. 1993). In the present study, the significant increase in lysozyme activity of fish fed with different magnesium supplementation was observed compared to control group, suggesting an immune enhancement. Dietary magnesium has been shown to be important in disease resistance and immune response because of its necessity in the control of both physiological functions and structural components of the body, including antibody protein synthesis (Karppanen 1993). Several factors such as nutritional status, seasonal variation, sexual maturation, salinity, pH, water temperature, stresses and infections are involved in variation of lysozyme activity (Saurabh & Sahoo, 2008). Serum immunoglobulins provide disease protection in animals and human beings which are major components of the humoral immune system (Watts *et al*. 2001). The IgM results showed significantly higher values in fish fed with the different diets of Mg, compared to the control group exhibiting that the Mg supplementation can stimulate the antibody production in fish (Panigrahi *et al*. 2004). The increased lysozyme and IgM contents measured in blood serum of fish fed with the different diet of magnesium supplementation, are signs of an inflammatory response which has previously been classified as a subacute enteritis (Baeverfjord and Krogdahl, 1996), or maybe as a result of a hypersensitivity reaction (Pedersen, 1989; Rumsey *et al*. 1994; Baeverfjord and Krogdahl 1996).

CONCLUSION

In conclusion, dietary magnesium supplementation enhances the growth performance of juvenile Persian sturgeon. Based on the growth performance, the dietary suitable Mg level for Persian sturgeon was 592 mg kg^{-1}. The lysozyme activity and IgM were increased in blood serum of fish fed with the different dietary magnesium supplementation.

ACKNOWLEDGMENT

This study was carried out in Rasht Islamic Azad University, Guilan, Iran. The authors also are grateful for the help of Dr. Dadman International Sturgeon Research Institute, Rasht, Guilan, Iran.

REFERENCES

Badan-Ara Marzdashti, R, Aghamaali, MR, Varasteh, A, Nowruzfashkhami, MR, Sabkara, F 2018, Purification and characterization of lysozyme in Persian sturgeon, *Acipenser persicus* (Borodin, 1897) from the Southwest Caspian Sea. *Caspian Journal of Environmental Sciences*, 16: 359-367

Baeverfjord, G & Krogdahl, A 1996. Development and regression of soybean meal induced enteritis in Atlantic salmon, *Salmo salar* L., distal intestine: a comparison with the intestines of fasted fish. *Journal of Fish Diseases*, 19: 375-387.

Barimani, S, Hedayatifard, M, Motamedzadegan, A, Bozorgnia, A 2021, Sturgeon caviar and cardiovascular diseases, Caspian Sea wild and farmed beluga, *Huso huso* caviar and their lipid quality indices. *Caspian Journal of Environmental Sciences*, 19: 401-413.

Bijvelds, MJC, Flik, G & Bonga, SEW 1997. Mineral balance in *Oreochromis mossambicus*: dependence on magnesium in diet and water. *Fish Physiology and Biochemistry*, 16: 323-331.

Bijvelds, MJC, Van der Velden, JA, Kolar & ZI, Flik, G 1998. Magnesium transport in freshwater teleosts. *Journal of Experimental Biology*, 201: 1981-1990.

Billard, R & Lecointre, G 2001. Biology and conservation of sturgeon and paddlefish. *Reviews in Fish Biology and Fisheries*, 10: 355-392.

Chandra, RK 1996. Nutrition, immunity and infection: from basic knowledge of dietary manipulation of immune responses to practical application of ameliorating suffering and improving survival. Proceedings of the National Academy of Sciences, USA, 93: 14304-14307.

Dabrowska, H, Meyer-Burgdorff, K & Gnther, KD 1989. Interaction between dietary protein and magnesium level in tilapia (*Oreochromis niloticus*). *Aquaculture*, 76: 277-291.

Davis, DA & Gatlin, DM 1996. Dietary mineral requirements of fish and marine crustaceans. *Reviews in Fisheries Science*, 4: 75-99.

Ellis, AE 1990. Lysozyme assays. In: JS, Stolen, TC, Fletcher DP, Anderson, SL, Kaattari & AF, Rowley (Eds.), Techniques in fish immunology, Poland, SOS Publications, pp. 101-103.

Fathollahi, R, Khara, H, Pajand, Z, Shenavar, A 2021 Effects of sodium chloride and methylthioninium chloride on Persian sturgeon, *Acipenser persicus* (Borodin, 1897): A histopathological and bacteriological study. *Caspian Journal of Environmental Sciences*, 19: 75-83.

Gatlin, DM, Robinson, EH, Poe, WE & Wilson, RP 1982. Magnesium requirement of fingerling channel catfish and signs of magnesium deficiency. The *Journal of Nutrition*, 2: 112-118.

Han, D, Liu, H, Liu, M, Xiao. X, Zhu, X, Yang, Y & Xie, S 2012. Effect of dietary magnesium supplementation on the growth performance of juvenile gibel carp, *Carassius auratus gibelio*. *Aquaculture Nutrition*, 18:512-520.

Huang, F, Li, J, Wang, L, Song & K, Mai, KS 2016. Interactive effects of dietary magnesium and vitamin E on growth performance, body composition, blood parameters and antioxidant status in Japanese seabass (*Lateolabrax japonicus*) fed oxidized oil. *Aquaculture Nutrition*, 22: 708-722.

Houston, AH 1985. Erythrocyte magnesium in freshwater fishes. *Magnesium*, 4: 106-128.

Jahan, I, Reddy, AK, Arun Sudhagar, S, Harikrishna, V, Singh, Sh, Varghese, T, Srivastava, PP 2018. The Effect of Fortification of Potassium and Magnesium in the Diet and Culture Water on Growth, Survival and Osmoregulation of Pacific White Shrimp, *Litopenaeus vannamei* Reared in Inland Ground Saline Water. *Turkish Journal of Fisheries and Aquatic Sciences*, 18: 1235-1243.

Kandeep, C 2013. Dietary Magnesium Requirement of *Cyprinus carpio* VAR. *Communis*. *Indian Journal of Natural Sciences*, 3: 1236-1276.

Karppanen, H 1993. Epidemiological aspects of magnesium in human health and diseases. In: Ronneberg R, Fallen H (Eds.) Magnesium in prophylaxis and therapy Nycomed Pharma AS, Oslo, Norway, pp. 6-12.

Knox, D, Cowey, CB & Adron, JW 1981. Studies on the nutrition of salmonid fish. The magnesium requirement of rainbow trout (*Salmo gairdneri*). *British Journal Nutrition*, 45: 137–148.

Lall, SP 2002.Theminerals. In: JE, Halver & RW, Hardy (Eds.) Fish Nutrition, 3rd Edition, Academic Press Inc., San Diego, CA, pp. 259-308.

Liang, J, Tian, LX, Liu, Y, Yang, H & Liang, G 2012. Dietary magnesium requirement and effects on growth and tissue magnesium content of juvenile grass carp. *Aquaculture Nutrition*, 18: 56-64.

Lim, C & Klesius, PH 2003. Influence of dietary levels of magnesium on growth, tissue mineral content, and resistance of channel catfish *Ictalurus punctatus* challenged with *Edwardsiella ictaluri*. *Journal of World Aquaculture Society*, 34: 18-28.

Madadi, Z & Khara, H 2016, Spermatological parameters of wild and cultured beluga (*Huso huso* Linnaeus, 1758) and their effects on fertilization rate, hatching rate, larval growth and survival rates. *Caspian Journal of Environmental Sciences*, 14: 273-279.

Mohseni, MR, Ozorio, OA, Pourkazemi, M & Bai, SC 2008. Effects of dietary L-carnitine supplements on growth and body in beluga sturgeon (*Huso huso*) juveniles. *Journal of Applied Ichthyology*, 24:646–649.

Moyner, K, Roed, KH, Sevatdal. S & Heum, M 1993. Changes in nonspecific immune parameters in Atlantic salmon, *Salmo salar* L., induced by *Aeromonas salmonicida* infection. *Fish and Shellfish Immunology*, 3:253–265.

Ogino, C & Chiou, JY 1976. Mineral requirements in fish – II. Magnesium requirement of carp. *Bulletin of the Japanese Society of Scientific Fisheries*, 42: 71-75.

Ogino, C, Takashima & F, Chiou, JY 1978. Requirement of rainbow trout for dietary magnesium. *Bulletin of the Japanese Society of Scientific Fisheries*, 44: 1105-1108.

Panigrahi, A, Kiron, V, Kobayashi, T, Puangkaew, J, Satoh, S & Sugita, H 2004. Immune responses in rainbow trout Oncorhynchus mykiss induced by a potential probiotic bacteria *Lactobacillus rhamnosus* JCM 1136. *Veterinary Immunology and Immunopathology*, 102: 379–388.

Pedersen, HE 1989. Allergenicity of soy proteins. In: Applewhite TH (Ed) World Congress on Vegetable Protein Utilization in Human Foods and Animal Feed status, American Oil Chemists Society, Champaign, IL pp. 204–212.

Rankin, JC & Davenport, J 1981, Animal osmoregulation. London, Blackie. 99 p.

Reigh, R, Robinson, E & Brown, PB 1991, Effects of Dietary Magnesium on Growth and Tissue Magnesium Content of Blue Tilapia *Oreochromis aureus*. *Journal of the World Aquaculture Society*, 22: 192-200.

Roy, LA, Davisi, DA & Nguyen, TN 2009, Supplementation of Chelated Magnesium to Diets of the Pacific White Shrimp, *Litopenaeus vannamei*, reared in Low-salinity Waters of West Alabama. *Journal of the World Aquaculture Society*, 40: 248-254.

Rumsey, GL, Siwicki, AK, Anderson, DP & Bowser, PR 1994. Effect of soybean protein on serological response, non-specific defense mechanisms, growth, and protein utilization in *rainbow trout*. *Veterinary Immunology and Immuno*, 41: 323-339.

Saurabh, S & Sahoo, PK 2008. Lysozyme: an important defence molecule of fish innate immune system. *Aquaculture Research*, 39: 223-239.

Scrimshaw, NS & SanGiovanni, JP 1997. Synergism of nutrition, infection, and immunity: an overview. *The American Journal of Clinical Nutrition*, 66: 464S–477S.

Shearer, KD & Asgard, T 1992. The effect of water-borne magnesium on the dietary magnesium requirement of the rainbow trout (*Oncorhynchus mykiss*). *Fish Physiology and Biochemistry*, 9: 387–392.

Shearer, KD 1989. Whole body magnesium concentration as an indicator of magnesium status in rainbow trout (*Salmo gairdneri*). *Aquaculture*, 77: 201–210.

Shim, KF & Ng, SH 1988. Magnesium requirement of the guppy (*Poecilia reticulata* Peters). *Aquaculture*, 73: 131-141.

Shirangi, A, Kalbassi, MR, Khodabandeh, S, Lignot, JH 2019, Effects of cortisol treatment on the salinity tolerance of Persian sturgeon, *Acipenser persicus* Juveniles. *Caspian Journal of Environmental Sciences*, 17: 131-142

Siwicki, AK & Studnicka, M 1987. The phagocytic activity of neutrophils and serum lysozyme activity in experimentally infected carp, *Cyprinus carpio* L. *Journal of Fish Biology*, 31: 57-60.

Steffens, W 1989. Principles of Fish Nutrition. Ellis Horwood, Chichester, UK, pp 384.

Tam, M, Gomez, S, Gonzalez-Gross, M & Marcos, A 2003. Possible roles of magnesium on the immune system. *European Journal of Clinical Nutrition*, 57: 1193-1197.

Van der Velden, JA, Spanings, FAT, Flik, G, Zegers, C, Kolar, ZI & Wendelaar Bonga, SE 1991a. Growth rate and tissue magnesium concentration in adult freshwater tilapia, *Oreochromis mossambicus* (Peters), fed diets differing in magnesium content. *Journal of Fish Biology*, 39:83-91.

Vormann, J 2003. Magnesium: nutrition and metabolism. Mol Aspects Med, 24:27-37.

Watts, M, Munday, BL & Burke, CM 2001. cDNA sequences and organization of IgM heavy hain genes in two teleostean fish. *Developmental & Comparative Immunology*, 19:153-164.

Williot, PL, Sabeau, J, Gessner, G, Arlati, P, Bronzi & T, Gulyas Berni, P 2001. Sturgeon farming in Western Europe: recent developments and perspectives. *Aquatic Living Resources*, 14: 367-374.

Yarmohammadi, M, Shabani, A, Pourkazemi, M, Soltanloo, H, Imanpour, MR, Ramezanpour, S, Smith-Keune & C, Jerry, DR 2013. Effects of starvation and re-feeding on compensatory growth performance, plasma metabolites and IGF-I gene expression of Persian sturgeon (*Acipenser persicus*, Borodin 1897). *Iranian Journal of Fisheries Sciences*, 12: 456-483.

Yoon, TH, Lee1, DH, Won, SG, Ra, CS & Kim, JD 2014. Effects of dietary supplementation of magnesium hydrogen phosphate ($MgHPO_4$) as an alternative phosphorus source on growth and feed utilization of juvenile far eastern catfish (*Silurus asotus*). *Asian-Australasian Journal of Animal Science*, 1976-5517.

Zar, JH 2010, Biostatistical Analysis. Northern Illinois University, 5th Edition, 944 p.

Bibliographic information of this paper for citing:

Mir Rasekhian, M,E, Khara, H, Pourali, H,R 2022 Effects of dietary magnesium supplementation on the growth performance, body composition, and immune indices of juvenile Persian sturgeon, *Acipnser persicus*. Caspian Journal of Environmental Sciences, 20: 557-564.