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Research Article

Effect of dietary *Ganoderma lucidum* extract on growth performance, blood biochemical parameters, and antioxidant status in juvenile beluga (*Huso huso*)

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Abstract

In the present study, the dietary effect of *Ganoderma lucidum* extract (GLE) on growth performance, antioxidant status, and some blood biochemical parameters was investigated in *Huso huso*. The fish were divided into four groups and fed with different concentrations of 0, 0.5, 1, and 2 g/kg GLE for 6 weeks. The results showed that the growth indices including weight gain and specific growth rate were increased significantly compared to the control group. However, the food conversion rate was significantly decreased in 1 and 2 g/kg GLE-supplemented groups. An increasing trend of serum total protein and IgM was observed in the groups fed with GLE, while the fish fed with 1 and 2 g/kg GLE showed significant differences compared to the control group (p<0.05). The serum glucose level decreased in the groups fed with GLE compared to the control group, however, it was not significant. The triglycerides and cholesterol levels were significantly reduced in 1 and 2 g/kg GLE added groups compared to 0.5 g/kg GLE and control group (p<0.05). An increase in the serum total antioxidant capacity was observed in GLE-supplemented groups, which significantly raised in 1 and 2 g/kg GLE (p<0.05). Serum malondialdehyde decreased in the groups fed with GLE, which significantly reduced in 2 g/kg GLE compared to the other groups (p<0.05). In conclusion, dietary GLE showed a proper effect on growth performance, antioxidant capacity, hypolipidemia, and immunity in *H. huso*.

Keywords: Lingzhi mushroom, Sturgeon, Growth, Blood biochemistry, Antioxidant enzymes

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Introduction

The increasing demand for seafood has caused a remarkable development in the aquaculture industry and therefore, aquatic health management is critical for farming fish species. In the meantime, different stressors, pathogens, and environmental pollutants lead to disease outbreaks in fish farms. Immune and antioxidant systems play an essential role in combating different stresses and diseases in fish (Galina *et al*., 2009). Using bioactive compounds as nutritional supplements in the fish diet seems to boost the immune and antioxidant systems against stressors (Amar *et al*., 2004; Martinez-Álvarez *et al*., 2005; Hoseinifard *et al*., 2018).

Ganoderma lucidum commonly known as 'Reishi' or 'Lingzhi' is a medicinal fungus with several interesting compositions such as polysaccharides, terpenoids, nucleotides, steroids, fatty acids, proteins, flavonoids, alkaloids, antioxidants, glycopeptides, vitamins, and minerals, which triterpenoids and polysaccharides are the major components (Zjawiony, 2004; Paterson, 2006; Liu *et al*., 2016). *G. lucidum* has been widely used as an oriental mushroom for centuries to improve some disorders like hypertension, bronchitis, immunological disease, anorexia, hepatitis, and cancer (Boh *et al*., 2007; Zhao *et al*., 2016).

Because of the great properties and multifunctional ingredients of *G. lucidum*, it has a high potential to treat several diseases and use in the nutraceutical and pharmaceutical industries (Li *et al*., 2013; Stojković *et al*., 2014).

A few researches have been reported on the effect of *G. lucidum* as a nutritional supplement in aquatic animals. Dietary *G. lucidum* polysaccharides increased immune inflammatory response and antioxidant enzyme activity in (*Cyprinus carpio*) against CCl4, which caused hepatocyte lesions (Liu *et al*., 2015). *G. lucidum* polysaccharides revealed the desirable effect on the survival and growth performance of *Ctenopharyngodon idella* (Chithra *et al*., 2016). Yin *et al*. (2009) reported *G. lucidum* extract can increase the immune system status of common carp (*Cyprinus carpio*) against *Aeromonas hydrophila*. In other research, *G. lucidum* extract enhanced the survival rate, growth performance, digestive enzymes, and antioxidant activities in giant freshwater prawn (*Macrobrachium rosenbergii*) (Mohan *et al*., 2016). *G. lucidum* extract showed beneficial effects on growth and health status as well as antioxidant enzymes stimulation in the red hybrid Tilapia (*Oreochromis* sp.) (Wan *et al*., 2021). *G. lucidum* polysaccharides increased both specific and non-specific immunity as effective immunostimulants against *Vibrio harveyi* in pearl gentian grouper (*Epinephelus* sp.) (Zhang *et al*., 2022).

The effect of *G. lucidum* extract as a dietary supplement on sturgeons has not been reported so far. Sturgeons are valuable fish species belonging to the Acipenseridae family. Unfortunately, conservation threats have endangered sturgeons critically (Carmona *et al*.,

2009). The culture of these highly endangered species, especially the great sturgeon (*Huso huso*), can relieve the pressure on the sturgeon populations in the Caspian Sea (Hoseinifar *et al*., 2011). The great sturgeons or beluga are suitable fish species for aquaculture because of their valuable caviar and meat (Mohseni *et al*., 2008, Yadolahi et al., 2022).

In aquatic animals, stress happens in the conditions of water physicochemical changes, nutritional deficiencies, water pollution, xenobiotics, and diseases (Hwang and Lin, 2002; Yeganeh Kari *et al.,* 2022). Therefore, using the proper dietary supplements which can improve growth performance, and increase the immune and antioxidant systems may enhance the survival of fish in culture (Trichet, 2010; Taleghani *et al*., 2019). The present study aimed to evaluate the dietary effect of *G. lucidum* extract (GLE) on growth performance, some serum biochemical parameters, and antioxidant status in beluga (*H. huso*) juvenile.

Materials and methods

Experimental setup

120 healthy juvenile beluga (*H. huso*) with an average weight of 34.63±4.77 g were collected from the Culture and Breeding Center of Shahid Rajaei (Sari, Iran). After two weeks adaptation period, ten fish were randomly distributed into separate tanks as four groups with three replications. Each tank with 500 cm^3 size and 250 L volume of water was supplied with an inlet water flow rate of 2.47 L min^{-1}. Based on the previous studies (Chithra *et al.,* 2016; Mohan *et al.,* 2016), the groups received different concentrations of 0, 0.5, 1, and 2 g/kg GLE in the diet. Ingredients of the diet were mixed well with GLE and then made into pellets. The composition of experimental diets is shown in Table 1.

Fish were fed 4% of body weight four times a day (Adel *et al*., 2016) for 6 weeks. Water physicochemical parameters of fish tanks were checked daily during the experimental period including temperature 25±1°C, dissolved oxygen 6.5 mg/L and 7.2−7.4 pH.

Table 1: Dietary ingredients and proximate composition.

Ingredients (g/kg)	Ganoderma lucidum extract (g/kg)			
	0	**0.5**	**1**	**2**
Fish meal	460	460	460	460
Soybean oil	58	58	58	58
Wheat flour	150	150	150	150
Soybean meal	100	100	100	100
Meat meal	90	90	90	90
Cellulose	2	1.5	1	0
Vitamin mixture[a]	35	35	35	35
Mineral mixture[b]	25	25	25	25
Fish oil	60	60	60	60
Binder	20	20	20	20
Ganoderma lucidum extract	0	0.5	1	2
Proximate composition (%)				
Dry matter	91.3	91.5	91.2	91.5
Crude protein	39.6	39.5	39.7	39.7

Table 1 continued:				
Crude lipid	16.9	16.9	16.8	16.7
Ash	10.0	9.8	10.1	10.2
Crude fiber	2.5	2.6	2.5	2.3
Moisture	8.0	7.9	8.0	8.2
NFE[c]	22.3	22.7	22.1	22.6
Gross energy (kcal g^{-1})	3.6	3.6	3.6	3.6

a Unit/kg of mixture: vitamin A, 1,600,000 IU; D3, 400,000 IU; E, 40 IU; K3, 2000 mg; H2, 240 mg; B1, 6000 mg; B2, 8000 mg; B3, 12,000 mg; B5, 40,000 mg; B6, 4000 mg; B9, 2000 mg; B12, 8000 mg; vitamin C, 60000 mg; inositol, 20,000 mg; BHT, 20,000 mg. [b]Unit/kg of mixture: mineral: Fe, 26,000 mg; Zn, 12,500 mg; Se, 2000 mg; Co, 480 mg; Cu, 4200 mg; Mn, 15,800 mg; I, 1000 mg; choline chloride, 12,000 mg. [C] Nitrogen-free extracts (NFE) = dry matter - (crude protein + crude lipid + ash + fiber).

Ganoderma lucidum extract

The fruiting bodies of *G. lucidum* were provided from Iran Ganoderama (Karaj, Iran). The *G. lucidum* specimens were cut into small pieces and mixed to obtain powdered samples for extraction. The GLE was performed according to the procedure described by Taofiq *et al*. (2017). Briefly, the powder of *G. lucidum* was extracted in a Soxhlet apparatus using ethanol. Eventually, the dried ethanolic extracts were obtained by rotary evaporator under reduced pressure (Stuart RE 300, UK).

Growth parameters

The initial and final body weight and length of each fish in different groups were measured at the beginning and the end of the experiment. The weight gain (WG), length gain (LG), specific growth rate (SGR), condition factor (CF), and feed conversion ratio (FCR) were calculated as follows:

WG (g) = final weight (W_2, g) - initial weight (W_1, g)
LG (cm) = final length (L_2, cm) - initial length (L_1, cm)
SGR (%) =100 (ln final weight− ln initial weight) / number of days
CF (%) = 100× final weight (g) / final length $(cm)^3$
FCR = feed intake (g)/weight gain (g)

Serum biochemical parameters

At the end of the experiment, six fish from each group were randomly sampled. Blood samples were collected from the caudal vein and transferred to the non-heparinized microtube for serological examination. The serum samples were separated by 1006 ×g centrifuging for 10 min. The serum biochemical parameters including total protein, albumin, immunoglobulin G (IgM), glucose, triglyceride, cholesterol, aspartate aminotransferase (AST), alanine transaminase (ALT), and alkaline phosphatase (ALP) were analyzed by commercial kits (Pars azmoon, Iran) using an auto-analyzer (Cobas Mira plus, Germany).

Antioxidant and oxidative stress analysis

Serum total antioxidant capacity (TAC) was measured using commercial kit (Teb Pazhouhan Razi (TPR), Iran) according to the manufacturer protocol.

Serum malondialdehyde (MDA) was evaluated based on a thiobarbituric acid reaction by commercial kit (Teb Pazhouhan Razi (TPR), Iran).

Statistical analysis

Statistical analysis was performed using SPSS version 22. Data were analyzed using a One-way test of variance (ANOVA) to compare means. Duncan's test was performed to analysis of significant differences among groups. The statistical significance level was $p<0.05$. Data are presented as mean± standard error (SE).

Results

Growth and feed utilization indices

In this study, the growth indices including WG, LG, and SGR were increased significantly in the groups supplemented with GLE compared to the control group ($p<0.05$). The highest increase was observed in 2 g/kg GLE. However, it was not significantly different from the group fed with 1 g/kg GLE ($p>0.05$). FCR decreased in GLE supplemented-group with significant differences in 1 and 2 g/kg GLE compared to the other groups ($p<0.05$). There was no significant difference in CF of all groups ($p>0.05$; Table 2).

Table 2: Growth performance of *Huso huso* fed diets supplemented with *Ganoderma lucidum* extract for 6 weeks.

Growth parameters	*G. lucidum* extract (g/kg)			
	0	0.5	1	2
W_1 (g)	34.21 ± 4.9	34.87 ±4.7	34.9 ±4.9	34.57 ±4.6
L_1 (cm)	19.67 ±1.2	19.80 ±1.1	19.29 ±1.09	19.62 ± 1.0
W_2 (g)	89.27 ± 3.7^a	96.67 ± 3.5^a	108.51 ± 3.8^b	110.93 ± 4.4^b
L_2 (cm)	27.34 ± 0.3^a	28.45 ± 0.4^a	29.64 ± 0.4^b	30.22 ± 0.3^b
WG (g)	55.06 ± 0.9^a	61.79 ± 1.2^b	73.69 ± 1.5^c	76.36 ± 1.0^c
LG (cm)	7.84 ± 0.16^a	8.64 ± 0.13^b	10.35 ± 0.34^c	10.60 ± 0.27^c
SGR (%)	$1.03^a \pm 0.00$	1.10 ± 0.02^b	1.22 ± 0.02^c	1.26 ± 0.01^c
CF	0.43 ± 0.01	0.41± 0.00	0.40 ±0.01	0.41± 0.00
FCR	1.70 ± 0.03^a	1.62 ± 0.03^a	1.50 ± 0.03^b	1.47 ± 0.01^b

Data are presented as mean ± SE. Different letters above the values indicate significant difference among groups ($p<0.05$). W_1, initial weight; L_1, initial length; W_2, final weight; L_2, final length; WG, weight gain; LG, length gain; SGR, specific growth rate; CF, condition factor; FCR, Feed conversion ratio.

Serum biochemical parameters

The results of this study showed an increasing trend of serum total protein in the groups supplemented with GLE, which significantly raised in 1 and 2 g/kg GLE compared to control group ($p<0.05$).

Also, the IgM level increased in GLE-supplemented groups. The lowest and highest IgM levels were observed in control group and 2 g/kg GLE-supplemented group, respectively. Meanwhile, the amount of albumin in different groups was not significantly different ($p>0.05$; Fig.1).

The amount of glucose in the groups fed with GLE showed a decreasing trend. However, there was no significant difference among the groups ($p>0.05$). The triglyceride level was reduced in GLE-supplemented groups and showed a significant difference in 1 and 2 g/kg GLE groups compared to 0.5 g/kg GLE and control group ($p<0.05$). The lowest

cholesterol level was observed in 2 g/kg GLE, which was significantly different compared to 0.5 g/kg GLE and the control group (p<0.05), however, it was not significantly different from 1 g/kg GLE (p>0.05; Fig. 2).

There were no significant differences in the amount of aspartate aminotransferase (AST), alanine aminotransferase (ALT), and alkaline phosphatase (ALP) in all groups (p>0.05; Table 3).

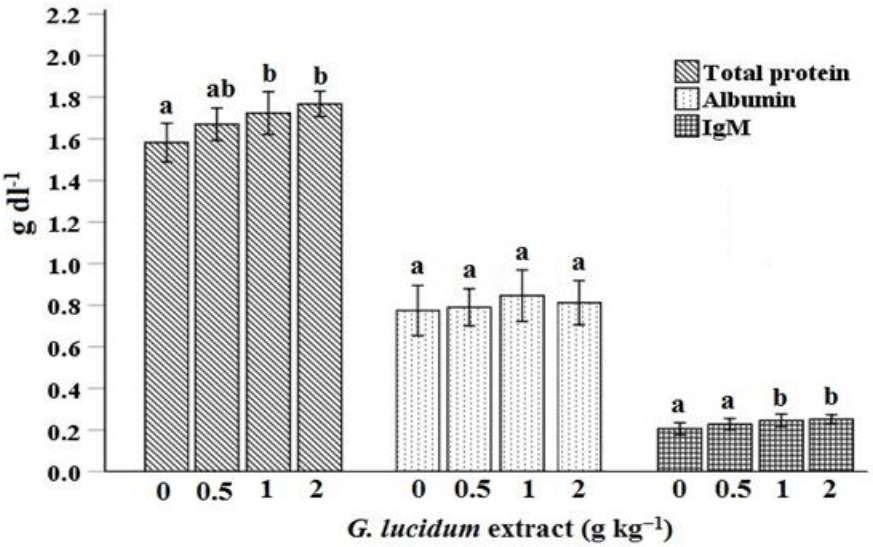

Figure 1: Serum biochemical parameters including total protein, immunoglobulin M (IgM), and albumin in *Huso huso* fed diet supplemented with *Ganoderma lucidum* extract for 6 weeks. Data are presented as mean±SE. Different letters above the bars indicate significant difference among groups (p<0.05).

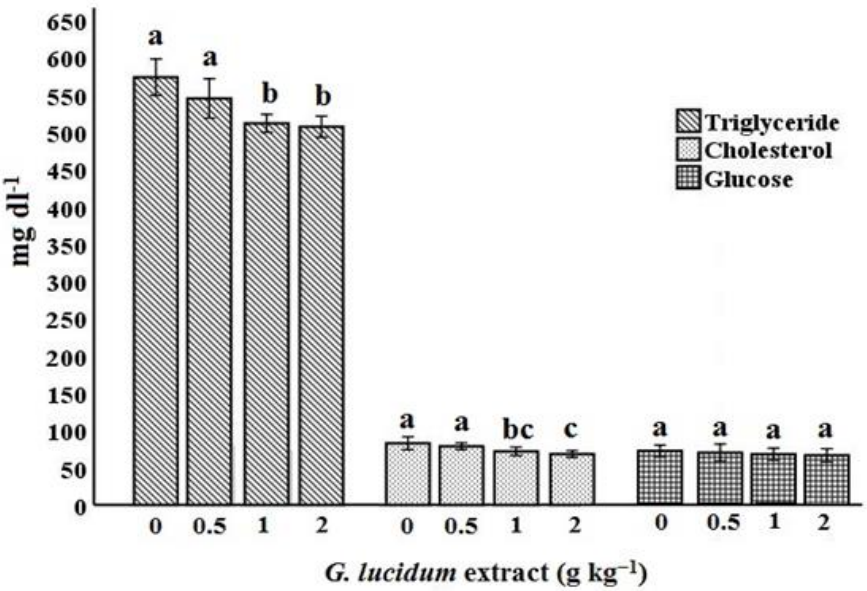

Figure 2: Serum biochemical parameters including glucose, triglycerides, and cholesterol in *Huso huso* fed diet supplemented with *Ganoderma lucidum* extract for 6 weeks. Data are presented as mean ± SE. Different letters above the bars indicate significant differences among groups (p<0.05).

Antioxidant and oxidative stress analysis

In the present study, serum TAC was affected by GLE. The highest TAC level was observed in 2 g/kg GLE, which was significantly different from 0.5 g/kg GLE and control group ($p< 0.05$). In contrast, serum MDA decreased in the groups with dietary supplementation, which was significantly lower in fish fed with 1 and 2 g/kg GLE compared to the other groups ($p< 0.05$; Table 3).

Table 3: Serum metabolic enzymes and antioxidant status in *Huso huso* fed diets supplemented with *Ganoderma lucidum* extract for 6 weeks.

Parameters	*G. lucidum* extract (g/kg)			
	0	0.5	1	2
AST (UL^{-1})	426.6±22.95	443.6±37.79	471.0± 32.48	431.6±23.91
ALT (UL^{-1})	12.6±1.07	11.2±1.24	11.6±1.02	12.0±0.70
ALP (UL^{-1})	265.4±16.86	250.4±8.68	255.0±14.36	245.0±0.05
TAC ($\mu M\ l^{-1}$)	116.70± 1.49^{a}	121.28± 1.27^{a}	138.66±1.51^{b}	143.57± 2.84^{b}
MDA ($\mu M\ l^{-1}$)	9.72±0.37^{a}	8.96±0.45^{a}	6.24±0.39^{b}	5.01±0.29^{c}

Data are presented as mean ± SE. Different letters above the values indicate significant difference among groups ($p<0.05$). AST, aspartate aminotransferase; ALT, alanine aminotransferase; ALP, alkaline phosphatase; TAC, total antioxidant capacity; MDA, malondialdehyde.

Discussion

Ganoderma lucidum contains beneficial biological compounds such as polysaccharides and triterpenoids. Recently, more attention has been paid to the therapeutic effects of *G. lucidum* (Wachtel-Galor *et al*., 2004; Paterson, 2006). This study showed an increase in the WG, LG, and SGR values as well as a decrease in the FCR in the groups fed diets supplemented with GLE. These results indicate the appropriate effect of GLE on the growth performance of fish during the experimental period. The ability to enhance the growth performance of GLE is due to the effect of immune stimulation caused by *G. lucidum*, which regulates immunity and prevents disease. In the study of Chithra *et al*. (2016) *G. lucidum* polysaccharides caused a significant increase of body weight and SGR in grass carp (*Ctenopharyngodon idella*) (Mohan *et al*., 2016).

Also, Mohan *et al*. (2016) reported an increase in the digestive enzymes including protease, amylase, and lipase in giant freshwater prawn (*M. rosenbergii*) fed with *G. lucidum* polysaccharides. The dietary supplementation with *G. lucidum* polysaccharides increased the secretion of digestive enzymes and enhanced the absorption of nutrients from the gastrointestinal tract and finally, improved the growth performance of *M. rosenbergi* (Mohan *et al*., 2016).

In the present study, the amounts of total protein and IgM increased with the increment of GLE in the diet. Total protein includes albumin and globulins. Globulins are the main constituents of serum protein that makeup immunoglobulins which are essential in the immune response. Serum

immunoglobulin level is a substantial indicator of immune status. B lymphocytes that originate from the anterior part of the kidney, spleen, and anterior part of the heart become the cells that secrete plasma cell antibodies and produce immunoglobulins (Yu *et al*., 2008; Yildiz *et al*., 2009). The increase of immunoglobulin in this study indicates an improving effect of GLE on the immune system.

This study showed hypoglycemia in the groups that supplemented with GLE, however, this reduction was not significantly different among the groups. *G. lucidum* facilitates the inflow of calcium to pancreatic cells by releasing insulin which leads to hypoglycemia (Zhang and Lin, 2004). In the present study, triglycerides and cholesterol were reduced in the GLE-supplemented groups, which significantly decreased in 1 and 2 g/kg GLE compared to 0.5 g/kg GLE and control group (p<0.05).

Triglycerides and cholesterol are important lipid metabolism biomarkers (Chen *et al*., 2014). Serum cholesterol reduction could be due to plant sterols (Fremont *et al*., 2000, Avci *et al.*, 2006), which are being considerably supplemented to the diet for preventing hypercholesterolemia and hyperlipidemia (Rubel *et al.*, 2011). The results of this study confirm former researches that reported hypolipidemia caused by *G. lucidum* (Kabir *et al*., 1988; Berger *et al*., 2004).

In this study, an increase in TAC was observed with a significantly different in 1 and 2 g/kg GLE compared to 0.5 g/kg GLE and control group. TAC protects biological molecules against oxidation (Yousefi *et al*., 2019). Antioxidants reduce oxidative stress by scavenging reactive oxygen (Lee *et al*., 2009). TAC indicates total antioxidant capacity, which illustrates antioxidant ability to resist oxidants (Taheri Mirghaed *et al*., 2018; Yousefi *et al*., 2019).

The result of this study indicated that GLE reduces the concentration of serum lipid peroxidation which showed its effect by decreasing serum MDA. Lipid peroxidation is an adverse event that leads to oxidation of unsaturated fatty acid, because of antioxidant system failure (Yilmaz, 2019). MDA which is produced by lipid peroxidation cause oxidative stress. Therefore, MDA is a biomarker used to evaluate lipid peroxidation and oxidative stress (Hwang *et al*., 2013;Taheri Mirghaed *et al*., 2018; Yousefi *et al*., 2019).

It can be concluded from this study that dietary GLE improved growth performance and antioxidant capacity in *H. huso*. Moreover, results revealed that GLE possesses hypoglycemic, hypolipidemic, and immunostimulatory properties.

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References

Adel, M., Nayak, S., Lazado, C.C. and Yeganeh, S., 2016. Effects of dietary prebiotic grobiotic®-a on growth performance, plasma thyroid hormones and mucosal immunity of great sturgeon, *Huso huso* (linnaeus, 1758). *Journal of Applied Ichthyology*, 32(**5**), 825-831. DOI: 10.1111/jai.13153

Amar, E. C., Kiron, V., Satoh, S. and Watanabe, T., 2004. Enhancement of innate immunity in rainbow trout (*Oncorhynchus mykiss* Walbaum) associated with dietary intake of carotenoids from natural products. *Fish and Shellfish Immunology*, 16(**4**), 527-537. DOI: 10.1016/j.fsi.2003.09.004

Avcı, G., Kupeli, E., Eryavuz, A., Yesilada, E. and Kucukkurt, I., 2006. Antihypercholesterolaemic and antioxidant activity assessment of some plants used as remedy in Turkish Folk Medicine. *Journal of Ethnopharmacology*, 107(**3**), 418-423. DOI: 10.1016/j.jep.2006.03.032

Berger, A., Rein, D., Kratky, E., Monnard, I., Hajjaj, H., Meirim, I. and Niederberger, P., 2004. Cholesterol-lowering properties of *Ganoderma lucidum* in vitro, ex vivo, and in hamsters and minipigs. *Lipids in Health and Disease*, 3(**1**), 1-12. DOI: 10.1186/1476-511X-3-2

Boh, B., Berovic, M., Zhang, J. and Zhi-Bin, L., 2007. *Ganoderma lucidum* and its pharmaceutically active compounds. *Biotechnology Annual Review*, 13, 265-301. DOI: 10.1016/S1387-2656(07)13010-6

Carmona, R., Domezain, A., García-Gallego, M., Hernando, J.A., Rodríguez, F. and Ruiz-Rejón, M. eds., 2009. Biology, conservation and sustainable development of sturgeons. Springer Netherlands. 486p.

Chen, K., Li, E., Gan, L., Wang, X., Xu, C., Lin, H., Qin, J.G. and Chen, L., 2014. Growth and lipid metabolism of the pacific white shrimp *Litopenaeus vannamei* at different salinities. *Journal of Shellfish Research*, 33(**3**), 825-832. DOI: 10.2983/035.033.0317

Chithra, E., Padmanaban, A. and Mohan, K., 2016. Potential use of *Ganoderma lucidum* polysaccharides as a feed supplement in diets on survival and growth performance of the grass carp, *Ctenopharyngodon idella*. *International Journal of Fisheries and Aquatic Studies*, 4, 328-333. DOI: 10.22271/fish

Fremont, L., Gozzelino, M.T. and Linard, A., 2000. Response of plasma lipids to dietary cholesterol and wine polyphenols in rats fed polyunsaturated fat diets. *Lipids*, 35(**9**), 991-999. DOI: 10.1007/s11745-000-0610-2

Galina, J., Yin, G., Ardo, L. and Jeney, Z., 2009. The use of immunostimulating herbs in fish. An overview of research. *Fish Physiology and Biochemistry*, 35(**4**), 669-676. DOI: 10.1007/s10695-009-9304-z

Hoseinifar, S.H., Mirvaghefi, A., Merrifield, D.L., Amiri, B.M., Yelghi, S. and Bastami, K. D., 2011.

The study of some haematological and serum biochemical parameters of juvenile beluga (*Huso huso*) fed oligofructose. *Fish Physiology and Biochemistry*, 37(**1**), 91-96. DOI: 10.1007/s10695-010-9420-9

Hoseinifard, S.M., Omidzahir, S., Hoseini, S.M. and Beikaee, H., 2018. Protective effect of garlic (*Allium sativum*) against zinc poisoning in the testicular tissue of goldfish (*Carassius auratus*). *Comparative Clinical Pathology*, 27(**2**), 357-361. DOI: 10.1007/s00580-017-2599-8

Hwang, D.F. and Lin, T.K., 2002. Effect of temperature on dietary vitamin C requirement and lipid in common carp. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 131(**1**), 1-7. DOI: 10.1016/S1096-4959(01)00449-3

Hwang, J.H., Lee, S.W., Rha, S.J., Yoon, H.S., Park, E.S., Han, K.H. and Kim, S.J., 2013. Dietary green tea extract improves growth performance, body composition, and stress recovery in the juvenile black rockfish, *Sebastes schlegeli*. *Aquaculture International*, 21(**3**), 525-538. DOI: 10.1007/s10499-012-9586-5

Kabir, Y., Kimura, S. and Tamura, T., 1988. Dietary effect of *Ganoderma lucidum* mushroom on blood pressure and lipid levels in spontaneously hypertensive rats (SHR). *Journal of Nutritional Science and Vitaminology*, 34(**4**), 433-438. DOI: 10.3177/jnsv.34.433

Lee, J.H., Felipe, P., Yang, Y.H., Kim, M.Y., Kwon, O.Y., Sok, D.E., Kim, H.C. and Kim, M.R., 2009. Effects of dietary supplementation with red-pigmented leafy lettuce (*Lactuca sativa*) on lipid profiles and antioxidant status in C57BL/6J mice fed a high-fat high-cholesterol diet. *British Journal of Nutrition*, 101(**8**), 1246-1254. DOI: 10.1017/S0007114508073650

Li, Y.B., Liu, R.M. and Zhong, J.J., 2013. A new ganoderic acid from *Ganoderma lucidum* mycelia and its stability. *Fitoterapia*, 84, 115-122. DOI: 10.1016/j.fitote.2012.11.008

Liu, Y.J., Du, J.L., Cao, L.P., Jia, R., Shen, Y.J., Zhao, C.Y., Xu, P. and Yin, G.J., 2015. Anti-inflammatory and hepatoprotective effects of *Ganoderma lucidum* polysaccharides on carbon tetrachloride-induced hepatocyte damage in common carp (*Cyprinus carpio* L.). *International Immunopharmacology*, 25(**1**), 112-120. DOI: 10.1016/j.intimp.2015.01.023

Liu, Z., Xing, J., Zheng, S., Bo, R., Luo, L., Huang, Y., Niu, Y., Li, Z., Wang, D., Hu, Y., Liu, J. and Wu, Y., 2016. G*anoderma lucidum* polysaccharides encapsulated in liposome as an adjuvant to promote Th1-bias immune response. *Carbohydrate polymers*, 142, 141-148. DOI: 10.1016/j.carbpol.2016.01.021

Martínez-Álvarez, R.M., Morales, A.E. and Sanz, A., 2005. Antioxidant defenses in fish: biotic and abiotic factors. *Reviews in Fish*

Biology and Fisheries, 15(**1**), 75-88. DOI: 10.1007/s11160-005-7846-4

Mohan, K., Padmanaban, A. M., Uthayakumar, V., Chandirasekar, R., Muralisankar, T. and Santhanam, P., 2016. Effect of dietary *Ganoderma lucidum* polysaccharides on biological and physiological responses of the giant freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture*, 464, 42-49. DOI: 10.1016/j.aquaculture.2016.05.046

Mohseni, M., Ozorio, R.O.A., Pourkazemi, M. and Bai, S.C., 2008. Effects of dietary l-carnitine supplements on growth and body composition in beluga sturgeon (*Huso huso*) juveniles. *Journal of Applied Ichthyology*, 24(**6**), 646-649. DOI: 10.1111/j.1439-0426.2008.01121.x

Paterson, R.R.M., 2006. Ganoderma–a therapeutic fungal biofactory. *Phytochemistry*, 67(**18**), 1985-2001. DOI: 10.1016/j.phytochem.2006.07.004

Rubel, R., Dalla Santa, H.S., Fernandes, L.C., Bonatto, S.J., Bello, S., Figueiredo, B.C., Lima, Filho, J.H., Santos, C.A. and Soccol, C.R., 2011. Hypolipidemic and antioxidant properties of *Ganoderma lucidum* (Leyss: Fr) Karst used as a dietary supplement. *World Journal of Microbiology and Biotechnology*, 27,1083-9. DOI: 10.1007/s11274-010-0554-9

Stojković, D.S., Barros, L., Calhelha, R.C., Glamočlija, J., Ćirić, A., Van Griensven, L.J., Soković, M. and Ferreira, I.C., 2014. A detailed comparative study between chemical and bioactive properties of *Ganoderma lucidum* from different origins. *International Journal of Food Sciences and Nutrition*, 65(**1**), 42-47. DOI: 10.3109/09637486.2013.832173

Taheri Mirghaed, A., Hoseini, S. M. and Ghelichpour, M., 2018. Effects of dietary 1, 8-cineole supplementation on physiological, immunological and antioxidant responses to crowding stress in rainbow trout (*Oncorhynchus mykiss*). *Fish and Shellfish Immunology*, 81, 182–188. https://doiorg/101016/jfsi201807027

Taleghani, M., Hoseini, S.M. and Omidzahir, S., 2019. The protective effect of Damask rose, Rosa damascena extract on the liver of *Cyprinus carpio* following zinc exposure. *International Journal of Aquatic Biology*, *7*(**5**), 315-321. DOI: 10.22034/ijab.v7i5.749

Taofiq, O., Heleno, S.A., Calhelha, R.C., Alves, M.J., Barros, L., González-Paramás, A.M., Barreiro, M.F. and Ferreira, I.C., 2017. The potential of *Ganoderma lucidum* extracts as bioactive ingredients in topical formulations, beyond its nutritional benefits. *Food and Chemical Toxicology*, 108, 139-147. DOI: 10.1016/j.fct.2017.07.051

Trichet, V.V., 2010. Nutrition and immunity: an update. *Aquaculture research*, 41(**3**), 356-372. DOI: 10.1111/j.1365-2109.2009.02374.x

Wachtel-Galor, S., Tomlinson, B. and Benzie, I.F., 2004. *Ganoderma lucidum* ('Lingzhi'), a Chinese medicinal mushroom: biomarker responses in a controlled human supplementation study. *British Journal of Nutrition*, 91(**2**), 263-269. DOI: 10.1079/BJN20041039

Wan, W.A.A.Q.I., Taufek, N.M., Thiran, J.P., Rahman, J.F.P., Yerima, G., Subramaniam, K. and Rowan, N., 2021. Investigations on the use of exopolysaccharide derived from mycelial extract of *Ganoderma lucidum* as functional feed ingredient for aquaculture-farmed red hybrid Tilapia (*Oreochromis* sp.). *Future Foods*, 3, 100018. DOI: 10.1016/j.fufo.2021.100018

Yadolahi M., Ahari H. and Anvar A., 2022. Influence of Ag/LDPE nanocomposite films on the microbial growth of Beluga (Huso huso) fillets during the refrigerated storage period. *Iranian Journal of Fisheries Sciences*, 21, 480-499. DOI:10.22092/ijfs.2021.124378

Yeganeh Kari A., Ershad Langroudi H., Valipour A. and Alinezhad S., 2022. Fingerling beluga sturgeon, *Huso huso* (Linnaeus, 1758) growth, hematological, biochemical parameters and opercular respiratory rate under hypoxia challenge with levels of dietary folic acid. *Iranian Journal of Fisheries Sciences*, 21, 1558-1572. DOI:10.22092/ijfs.2023.128564

Yıldız, M., Ciğerci, İ. H., Konuk, M., Fidan, A.F. and Terzi, H., 2009. Determination of genotoxic effects of copper sulphate and cobalt chloride in Allium cepa root cells by chromosome aberration and comet assays. *Chemosphere*, 75(**7**), 934-938. DOI: 10.1016/j.hemosphere.2009.01.023

Yilmaz, S., 2019. Effects of dietary caffeic acid supplement on antioxidant, immunological and liver gene expression responses, and resistance of Nile tilapia, *Oreochromis niloticus* to *Aeromonas veronii*. *Fish and Shellfish Immunology*, 86, 384-392. DOI: 10.1016/j.fsi.2018.11.068

Yin, G., Ardó, L.Á.S.Z.L.Ó., Thompson, K.D., Adams, A., Jeney, Z. and Jeney, G., 2009. Chinese herbs (*Astragalus radix* and *Ganoderma lucidum*) enhance immune response of carp, *Cyprinus carpio*, and protection against *Aeromonas hydrophila*. Fish & *Shellfish Immunology*, 26(**1**), 140-145. DOI: 10.1016/j.jep.2006.03.032

Yousefi, M., Vatnikov, Y.A., Kulikov, E.V. and Ghelichpour, M., 2019. Change in blood stress and antioxidant markers and hydromineral balance of common carp (*Cyprinus carpio*) anaesthetized with citronellal and linalool: Comparison with eugenol. *Aquaculture Research*, 50(**4**), 1313-1320. DOI: 10.1111/are.14007

Yu, Z.L., Zhang, J.G., Wang, X.C. and Chen, J., 2008. Excessive copper induces the production of reactive oxygen species, which is mediated by phospholipase D,

nicotinamide adenine dinucleotide phosphate oxidase and antioxidant systems. *Journal of Integrative Plant Biology*, 50**(2)**, 157-167. DOI: 10.1111/j.1744-7909.2007.00609.x

Zhang, H.N. and Lin, Z.B., 2004. Hypoglycemic effect of *Ganoderma lucidum* polysaccharides. *Acta Pharmacologica Sinica*, 25(**2**), 191-195.

Zhang, Y., Zhong, J., Huang, Y., Jian, J. and Cai, S., 2022. Effect of *Ganoderma lucidum* polysaccharides as immunostimulants against *Vibrio harveyi* in pearl gentian grouper (♀ *Epinephelus fuscoguttatus*×♂ *Epinephelus lanceolatus*). *Frontiers in Marine Science*, 9, 968838. DOI: 10.3389/fmars.2022.968838

Zhao, X.R., Zhang, B.J., Deng, S., Zhang, H.L., Huang, S.S., Huo, X.K., Wang, C., Liu, F. and Ma, X.C., 2016. Isolation and identification of oxygenated lanostane-type triterpenoids from the fungus *Ganoderma lucidum*. *Phytochemistry Letters*, 16, 87-91. DOI: 10.1016/j.phytol.2016.03.007

Zjawiony, J.K., 2004. Biologically active compounds from Aphyllophorales (polypore) fungi. *Journal of Natural Products*, 67(**2**), 300-310. DOI: 10.1021/np030372w