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Effects of Phospholipids in Diet on Growth of Sturgeon Fish (*Huso-huso*) Juveniles

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ABSTRACT

The aim of the study was to determine the influence of dietary phospholipids (PL) levels on growth and body composition of beluga (*Huso-huso*) juveniles. *Huso-huso* juveniles were fed with an isonitrogenous (45% crude protein (CP)) and isoenergetic (18.00 kJ g^{-1}) formulated diet with four levels of PL, 0, 2, 4 and 6%. The fish were then acclimated to laboratory conditions and fed with a commercial fish feed for 14 days. After acclimation, groups of 60 *Huso huso* fingerling (mean weight 4.5 g) were randomly stocked into the 12 circular fiberglass tanks. The results showed that during the feeding trials in (56 days), growth performance was high at 4% phospholipids groups. There were significant different ($p<0.05$) for Condition Factor (CF) fish fed diet D4 had a value of 0.38 followed by fish fed diet D1, D2 and D3 had CF value of 0.47, 0.43 and 0.42, respectively. Weight gain (%) and survival (%) had significant difference ($p<0.05$) but no significant differences were found for final weight, Feed Conversion Rate (FCR), Specific Growth Rate (SGR), Protein Efficiency Ratio (PER), Lipid Efficiency Ratio (LER), ($p>0.05$). Significant differences were showed in moisture and protein composition of treatments ($p<0.05$) but no significant effect ($p>0.05$) on the fat and ash composition in fish were observed.

Key words: Phospholipids, sturgeon fish, *Huso-huso,* juveniles, growth performance

INTRODUCTION

Fats were the main energy source for fish (Bell and Tocher, 1989) and have sensitive role in the larval growth of the fish (Rainuzzo *et al.*, 1997). Phospholipids have a great effect on the growth, deformity and resistance against stress in some fish and shellfish species (Cahu *et al.*, 2003; Koven *et al.*, 1998). Sterogeon are anadromous and potamodromous species live in the northern hemisphere. There are 28 species, six of which inhabit the Caspian basin and beluga (*Huso-huso*) is one of them (Bahmani *et al.*, 2001). Unfortunately, this fish has become an endangered species because of excessive fishing, decrease of input water from the rivers due to anthropogenic and agricultural consumptions and water pollution (Asadi *et al.*, 2006). In fact, all acipenserids are listed as threatened, vulnerable and endangered throughout their ranges (Baker *et al.*, 2005). Thus there has been an increased demand for information on all aspects of sturgeon biology and physiology (Billard and Lecointre, 2001; Baker *et al.*, 2005).

It is well known that lipids constitute a major energy source for fish (Bell and Tocher, 1989) and play a critical role in larval development (Rainuzzo *et al*., 1997; Sargent *et al*., 1999). Also phospholipids (PL) have been demonstrated to significantly affect survival, growth, deformities and/or resistance to stress in several fish and crustacea (Kanazawa *et al*., 1985; Geurden *et al*., 1998; Koven *et al*., 1998; Cahu *et al*., 2003; Gisbert *et al*., 2005). They play a major role in maintaining the structure and function of cellular membranes (Kanazawa *et al*., 1985; Tocher, 2003). They have been reported to act as emulsifiers in the gut (Koven *et al*., 1993) and to improve intestinal absorption of long chain fatty acids (Fontagne *et al*., 2000). Moreover, they stimulate lipoprotein synthesis in intestinal enterocytes (Fontagne *et al*., 1998; Geurden *et al*., 1998) and play an important role in the transport of dietary lipids (Kanazawa, 1991; Teshima *et al*., 1986). Few studies have demonstrated their effect on the maturation of digestive structures of fish larvae (Cahu *et al*., 2003; Gisbert *et al*., 2005; Morais *et al*., 2007).

In fish, dietary phospholipids are required for growth and development since de novo synthesis of phospholipids is not sufficient to meet metabolic needs (Gibbs *et al*., 2009). Generally, the levels of phospholipid requirement are around 2-4% of diet for juvenile fish and probably higher in larval fish (Tocher *et al*., 2008). A combination of the above mentioned factors may collectively contribute to the beneficial effects of dietary phospholipids on growth but the definitive mechanism remains unclear.

In this study the complex of phospholipid was used for survey of growth, survival and biochemical and Hematological parameter of beluga sturgeon.

MATERIALS AND METHODS

Fish diets were formulated by means of Lindo software (Lindo copyright, 1995, Releases 6.1) were as shown in Table 1. All diets are isonitrogenous (45% P) and isoenergetic (18 kJ g^{-1}). To

Table 1: Experimental diet formulation and proximate composition

	Dietary treatment			
Items	D1 (0% PL)	D2 (2% PL)	D3 (4% PL)	D4 (6% PL)
Diet ingredient				
Fish meal (%)	60.00	60.00	60.00	60.00
Wheat meal (%)	20.00	20.00	20.00	20.00
Fish oil (%)	5.00	5.00	5.00	5.00
Soybean oil (%)	6.00	4.00	2.00	0.00
Phospholipids (%)	0.00	2.00	4.00	6.00
Molasses (%)	2.30	2.30	2.30	2.30
Vitamin mixture (%)	2.00	2.00	2.00	2.00
Mineral mixture (%)	3.00	3.00	3.00	3.00
Anti oxidant (%)	0.20	0.20	0.20	0.20
Calcium phosphate (%)	1.50	1.50	1.50	1.50
Total	100.00	100.00	100.00	100.00
Proximate composition				
Dry mater (%)	90.30	90.10	90.90	90.90
Protein (N x6.25) (% DM)	44.94	45.94	45.21	45.10
Lipid (% DM)	14.70	15.10	15.30	15.50
Ash (% DM)	13.58	13.52	13.84	13.40
Digestible energy (kJ g^{-1} diet)	18.16	18.32	18.25	18.36
Gross energy (kJ g^{-1} diet)	21.01	21.18	21.10	21.23

D1 (control): 0% phospholipids, D2: 2%phospholipids, D3: 4%phospholipids, D4: 6%phospholipids maintain the isoenergetic nature of the diets, soybean oil was added. Phospholipids complex was obtained from Bergapor Co. Germany (Berg and Schmidt) in Iran. Mineral and vitamin complements were first mixed together before added to the base diet. Mixing preliminary materials like soybeans oil and fish oil to some wheat meal was done initially for 20 min and were mixed again for 20 min after adding the required quantity of water. Then the mixture was added to the other ingredients in the electrical mixer and was passed through a die (2.5 mm) to make the required size pellets. After making the pellet, they were placed on dry trays and were moved to the drier. Diets were kept at 4°C away from light, in special plastics, after they were prepared and used to feed fish. Feed was given at 4% of the body weight in five meals at 8:00, 11:00, 13:00, 15:00 and 18:00 h. Excretion and other waste materials were siphoned off the tanks daily. At first the initial weight and length of fish was taken and after every two weeks their weights and total lengths were measured again.

This experiment was conducted in spring 2009 (period 56 days) in Shahid Margani Reproduction and Farming Center of Fisheries General Department Golestan Iran. 720 Beluga juveniles with an average weight of 4.5 g were collected from Shahid Margani Reproduction and Farming Workshop of Gorgan after categorization process.

Growth factor measurement: Mean weight gain (WG, g) per fish was calculated from the sum of weight gains at the end of the experimental period. Other growth parameters such as Correction Factor (CF), Feed Conversion Ratio (FCR), Protein Efficiency Ratio (PER), Lipid Efficiency Ratio (LER), survival (%) and Specific Growth Rate (SGR) were calculated using the following formulas:

$$CF = [BW\ (g)/BL^3\ (cm)] \times 100,\ [CF = W_2/(L_2)^3 \times 100]$$

$$FCR = \text{Dry feed consumed (g)} \times \text{wet BW gain (g)-1}$$

$$\text{Weight gain} = \text{Final weight-initial weight } (WG = W_2\text{-}W_1)$$

$$\text{Protein efficiency ratio PER} = [\text{final BW (g)-initial BW (g)}] \times \text{weight of protein consumed (g)-1}$$

$$\text{Lipid efficiency ratio LER} = [\text{final BW (g)-initial BW (g)}] \times \text{weight of Lipid consumed (g)-1}$$

$$SGR = [(\text{Ln final BW (g)} - \text{Ln initial BW (g)}) \times 100] \times \text{(number of days)-1}$$

$$\text{Percentage of Weight gain (WG \%)} = ((\text{final weight-initial weight}) \times \text{initial weight (g)-1}) \times 100$$

where, BW indicates the total body weight (g) and BL the total body length (cm) of the *Huso-huso*.

RESULTS

The results of growth parameter of *Huso-huso* fed phospholipids after 56 days were shown in (Table 2). There were no significant differences in the initial weights of the fish at the beginning of the trial. The weight gain was significantly different ($p<0.05$) in fish fed the experimental diets (Table 2). Fish fed diet D3 had the highest weight gain with a value of 70.3 g followed by fish fed diets D1, D2 and D4 with values of 63.05, 56.42 and 47.94 g, respectively as showed in Fig. 1. Similarly, the percentage weight gain had a significant different ($p< 0.05$). With fish fed diet D3 had a value of 1389 followed by fish fed D1, D2 and D4 with values of 1264, 1136 and 993%

Table 2: Growth parameter of *Huso-huso* fed phospholipids in 8 weeks[1]

	Dietary treatment			
Performance parameters	D1 (0% PL)	D2 (2% PL)	D3 (4% PL)	D4 (6% PL)
Initial weight (g)	4.99±0.01[a]	4.97±0.03[a]	5.06±0.07[a]	4.92±0.03[a]
Final weight (g)	68.08±3.58[ab]	61.39±6.4[ab]	75.36±3.11[a]	52.76±9.45[b]
Weight gain (g)	63.05±3.59[ab]	56.42±6.42[ab]	70.30±3.05[a]	47.94±9.43[b]
Food consumption (g)	6036.67±297[a]	5376.67±454[ab]	6420.00±599[a]	4663.333±665[b]
Weight gain (%)	1264.47±75.32[ab]	1136.16±135.68[ab]	1389.07±44.18[a]	993.44±46.35[b]
FCR	2.52±0.33[a]	2.80±0.22[a]	1.98±0.10[a]	2.36±0.52[a]
SGR	4.66±0.10[a]	4.47±0.19[a]	4.82±0.05[a]	4.22±0.32[a]
CF	0.47±0.01[a]	0.43±0.01[b]	0.42±0.00[b]	0.38±0.01[c]
PER	0.92±0.13[a]	0.79±0.06[a]	1.12±0.06[a]	1.03±0.21[a]
LER	2.80±0.38[a]	2.39±0.18[a]	3.32±0.17[a]	2.99±0.60[a]
Survival (%)	65.00±5.10[ab]	57.80±4.85[b]	76.70±2.89[a]	73.33±3.84[a]

[1]D1 (control): 0% phospholipids, D2: 2% phospholipids, D3: 4% phospholipids, D4: 6% phospholipids, Values in each row with the same superscripts are not significantly different (Duncan significance level is defined as p>0.05)

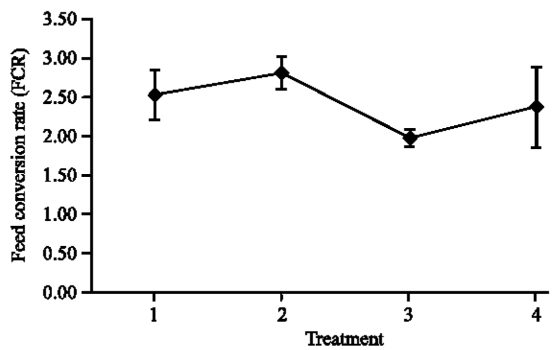

Fig. 1: Relationship between feed conversion rate (FCR with deferent level of phospholipids, No significant differences were found for FCR, the best value (1.98±0.01) of FCR was observed for fish fed diet D3 and the poorest was (2.80±0.22) again for fish fed diet D2

respectively. There were significant different ($p<0.05$) for CF (condition factor) fish fed diet D4 had a value of 0.38 followed by fish fed diet D1, D2 and D3 had CF value of 0.47, 0.43 and 0.42, respectively as showed in Fig. 2. Fish fed diet D3 also had the highest final weight with a value of 75.36 g followed by fish fed diet D1, D2 and D4 with value of 68.08, 61.39 and 52.76 g, respectively. No significant differences were found for FCR, SGR, PER, LER (Table 2, $p>0.05$). The best value (1.98±0.01) of FCR was observed for fish fed diet D3 and the poorest was (2.80±0.22) again for fish fed diet D2 as showed in Fig. 3. The highest and lowest Specific Growth Rate (SGR) was observed for fish fed diet D3 (4.82) and diet D4 (4.22) respectively as showed in Fig. 4. The highest and lowest protein efficiency ratio (PER g g^{-1}) was observed for fish fed diet D3 (1.12±0.06) and diet D2 (0.79±0.06), respectively as showed in Fig. 5. Lipid efficiency ratio (LER g g^{-1}) did not differ for any treatment but the highest and lowest was observed in fish fed diet D3 (3.32±0.17) and fish fed diet (2.39±0.18), respectively as showed in Fig. 6. There was significant difference in survival that highest (76.70) and lowest (57.80) was showed in fish fed diet D3 and fish fed diet D2, respectively.

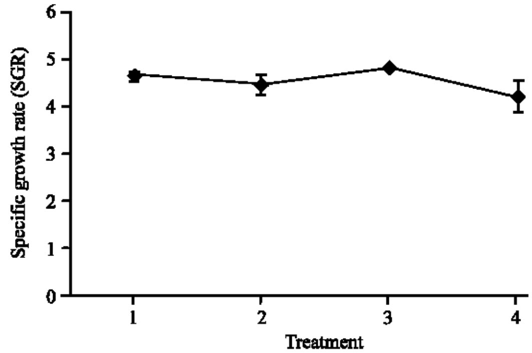

Fig. 2: Relationship between Specific Growth Rate (SGR), with deferent level of phospholipids, Specific growth rate (SGR, % day^{-1}) did not differ for any treatment but the highest and lowest was observed in fish fed diet D3 (4.82±0.05) and fish fed dietD4 (4.22±0.32), respectively

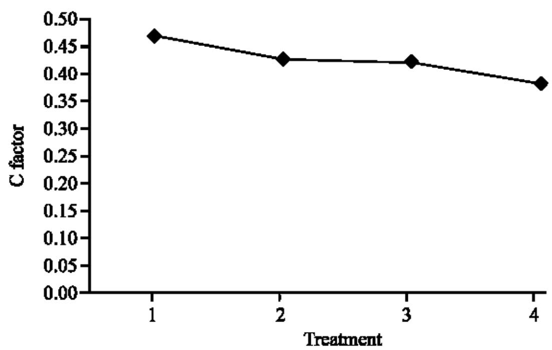

Fig. 3: Relationship between Condition Factors (CF) with deferent level of phospholipids, There were significant different ($p<0.05$) for CF (condition factor) fish fed diet D4 had a value of 0.38 followed by fish fed diet D1, D2 and D3 had CF value of 0.47, 0.43 and 0.42, respectively

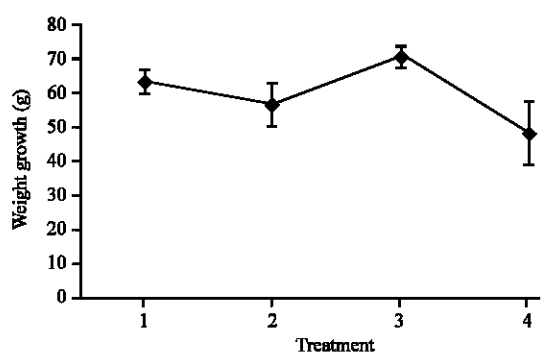

Fig. 4: Relationship between Weight Growths (WG) with deferent level of phospholipids, The weight gain was significantly different ($p<0.05$) in fish fed the experimental diets. Fish fed diet D3 had the highest weight gain with a value of 70.3 g followed by fish fed diets D1, D2 and D4 with values of 63.05, 56.42 and 47.94 g, respectively

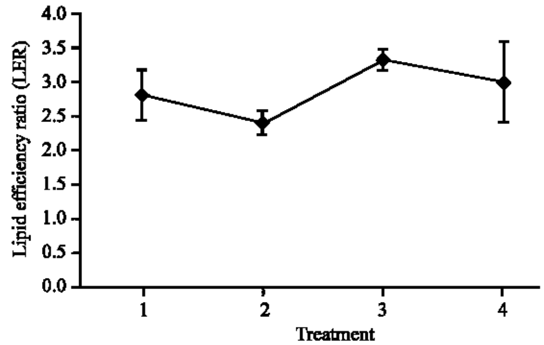

Fig. 5: Relationship between Lipid Efficiency Ratio (LER) with deferent level of phospholipids, Lipid efficiency ratio (LER g g^{-1}) did not differ for any treatment but the highest and lowest was observed in fish fed diet D3 (3.32±0.17) and fish fed diet (2.39±0.18), respectively

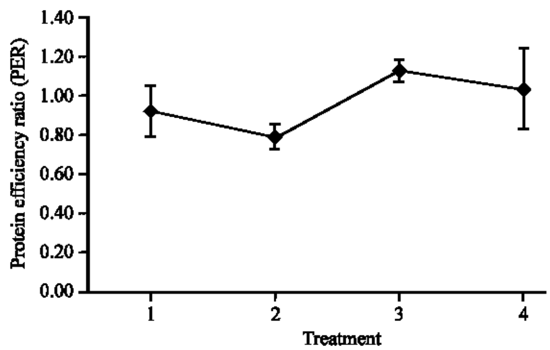

Fig. 6: Relationship between Protein Efficiency Ratio (PER) with deferent level of phospholipids, No significant differences were found for Protein Efficiency Ratio (PER). The highest and lowest protein efficiency ratio (PER g g^{-1}) was observed for fish fed diet D3 (1.12±0.06) and diet D2 (0.79±0.06), respectively

Table 3: Mean concentrations (% dry weight basis except for % moisture±SE) of the proximate constituents in the sturgeon fish (*Huso-huso),* reared on different levels of phospholipids[1]

	Dietary treatment			
Proximate constituent	D1 (0% PL)	D2 (2% PL)	D3 (4% PL)	D4 (6% PL)
Moisture	75.82±0.81^{bc}	78.08±0.33^{a}	74.77±0.32^{c}	77.69±0.82^{ab}
Protein	68.38±0.58^{a}	67.75±1.82^{a}	62.39±0.52^{b}	70.04±1.20^{a}
lipid	19.96±0.36^{a}	21.36±0.99^{a}	21.80±1.28^{a}	20.37±0.55^{a}
Ash	8.81±0.65^{a}	8.86±0.47^{a}	8.48±0.33^{a}	8.52±0.35^{a}

[1]D1 (control): 0% phospholipids, D2: 2% phospholipids, D3: 4% phospholipids, D4: 6% phospholipids, Values in each row with the same superscripts are not significantly different (Duncan significance level is defined as p>0.05)

Fish proximate: The proximate compositions of fish fed different diets are shown in Table 3. Slight change in the composition of the fish fed was observed for all measured components. Significant differences were shown in moisture and protein composition of treatments (p<0.05) but the phospholipids had no significant effect on the fat and ash composition (p>0.05). The highest moisture content was found in fish given diet D2 with value of 78.08% followed by fish fed diets D4, D1 and D3 with values of 77.69, 75.82 and 74.77%, respectively. There were significant deferent in protein content ($p<0.05$). Fish fed diet D4 had the highest percentage of protein with a value of 70.04% followed by fish fed diet D1, D2 and D3 with values of 68.38, 67.75 and 62.39%, respectively. There were no significant deferent lipid content ($p>0.05$). The highest lipid content was found in fish diet D3 with value 21.8% and the lowest was found in fish fed diet D1 with a value 19.96%. There were no significant deferent in ash content ($p>0.05$). Fish fed diet D2 had highest ash content with value of 8.86% and the lowest ash content was found in fish fed diet D3 with a value of 8.48%. The proximate composition of *Huso-huso* reared in all feeding trials was in accordance with the proximate composition data of aquatic animals (NRC, 1993).

DISCUSSION

In this study the 4% level of phospholipids improve the growth of beluga juveniles especially in early days with no significant effect ($p>0.05$). SGR and WG% in 4% level was better. Other researchers had presented seminar results (Fontagne *et al*., 1998; *Cyprinus carpio;* Gisbert *et al*., 2005; *Dicentrachus labrax;* Izquierdo *et al*., 2001, gilthead sea bream).

Complement of diet with phospholipid is improving the growth of fish with reducing energy consumption that require for synthesis of phospholipid (Craig and Gatlin, 1997). Although it discovered that biosynthesis of phospholipid in early days of fish a limited is done (Tocher *et al*., 2008) but the rate of this synthesis is very low (Kanazawa *et al*., 1985).

Generally, the levels of phospholipid requirement are around 2-4% of diet for juvenile fish and probably higher in larval fish (Tocher *et al*., 2008). Also positive impact of this kind of lipid may be because of emulsifier property that causes increase of digestion of neutral lipids (Kasper and Brown, 2003). On the other hand phospholipids have important role on transport of lipid particularly fatty acid (Fontagne *et al*., 1998). The effect of dietary PL appears to diminish with age and is generally not essential in adults (Sufang *et al*., 2008). Our results were showed that great sturgeon in juvenile stage requires less phospholipid complement.

In the present investigation, the moisture and protein composition were affected by diet treatment but the fat and ash were not affected by diet treatment. Although slight differences between the fat and ash were observed, these differences were not significant.

Xu *et al*. (1993) and Deng *et al*. (1998) on white sturgeon, McKenzie *et al*. (1999) on Adriatic sturgeon and Sener and Savas (2005) on Russian sturgeon found that except moisture, the proximate composition were not affected by diet treatment.

Present results showed that there is a relationship between lipid and protein composition of muscle in *Huso huso*. This relationship between muscle protein and lipid content has been observed in previous study with Russian sturgeon (Sener and Savas, 2005) and other fish, i.e., salmonids (Bell *et al*., 2001). It seems that in high level of phospholipid the retention of protein increased but the lipid consumed.

CONCLUSIONS

Fat (phospholipids) in sturgeon fish (*Huso-huso*) juvenile's diet can increase growth and improve nutritional indices. Adding phosphatidylcholine to (*Huso-huso*) juvenile's diet up to 4% leads to improvement in food digestion and absorption.

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REFERENCES

Asadi, F., M. Masoudifard, A. Vajhi, K. Lee, M. Pourkabir and P. Khazraeinia, 2006. Serum biochemical parameters of *Acipenser persicus*. Fish Physiol. Biochem., 32: 43-47.

Bahmani, M., R. Kazemi and P. Donskaya, 2001. A comparative study of some hematological features in young reared sturgeons *Acipenser persicus* and *Huso huso*. Fish Physiol. Biochem., 24: 135-140.

Baker, D.W., A.M. Wood, M.K. Litvak and J.D. Kieffer, 2005. Hematology of juvenile *Acipenser oxyrinchus* and *Acipenser brevirostrum* at rest following forced activity. J. Fish. Biol., 66: 208-221.

Bell, J.G., J. McEvoy, D.R. Tocher, F. McGhee, P.J. Campbell and J.R. Sargent, 2001. Replacement of fish oil with rapeseed oil in diets of Atlantic salmon (Salmo salar) affects tissue lipid compositions and hepatocyte fatty acid metabolism. J. Nutr., 131: 1535-1543.

Bell, M.V. and D.R. Tocher, 1989. Molecular species composition of the major phospholipids in brain and retina from rainbow trout (*Salmo gairdneri*). J. Biochem., 264: 909-915.

Billard, R. and G. Lecointre, 2001. Biology and conservation of sturgeon and paddlefish. Rev. Fish. Biol. Fish., 10: 355-392.

Cahu, C.L., J.L.Z. Infante and V. Barbosa, 2003. Effect of dietary phospholipids level and phospholipids: Neutral lipid value on the development of sea bass (*Dicentrarchus labrax*) larvae fed a compound diet. Br. J. Nutr., 90: 21-28.

Craig, S.R. and D.M. III. Gatlin, 1997. Growth and body composition of juvenile red drum (*Sciaenops ocellatus*) fed diets containing lecithin and supplemental choline. Aquaculture, 151: 259-267.

Deng, D.F., S.S.O. Hung and D.E. Conklin, 1998. White sturgeon (*Acipencer transmontanus*) require both n-3 and n-6 fatty acids. Aquacult. Abst. Lipids Fatty Acids, 161: 333-335.

Fontagne, S., I. Geurden, A.M. Escaffre and P. Bergot, 1998. Histological changes induced by dietary phospholipids in intestine and liver of common carp (*Cyprinus carpio* L.) larvae. Aquaculture, 161: 213-223.

Fontagne, S., L. Burtaire, G. Corraze and P. Bergot, 2000. Effects of mediumchain triacylglycérols (tricaprylin and tricaproin) and phospholipid supply on survival, growth and lipid metabolism in common carp (*Cyprinus carpio* L.) larvae. Aquaculture, 190: 289-303.

Geurden, I., D. Marion, N. Charlon, P. Coutteau and P. Bergot, 1998. Comparison of different soybean phospholipidic fractions as dietary supplements for common carp, *Cyprinus carpio*, larvae. Aquaculture, 161: 225-235.

Gibbs, V.K., S.A. Watts, A.L. Lawrence and J.M. Lawrence, 2009. Dietary phospholipids affect growth and production of juvenile sea urchin *Lytechinus variegates*. Aquaculture, 292: 95-103.

Gisbert, E., L. Villeneuve, J.L. Zambonino Infante, P. Quazuguel and C.L. Cahu, 2005. Dietary phospholipids are more efficient than neutral lipids for long-chain polyunsaturated fatty acid supply in European sea bass *Dicentrarchus labrax* larval development. Lipids, 40: 1-11.

Izquierdo, M.S., A. Tandler, M. Salhi and S. Kolkovski, 2001. Influence of dietary polar lipids quantity and quality on ingestion and assimilation of labelled fatty acids by larval gilthead seabream. Aquacult. Nutr., 6: 153-160.

Kanazawa, A., 1991. Essential Phospholipids of Fish and Crustaceans. In: Fish Nutrition in Practice, INRA (Ed.). Les Colloques n°61, Biarritz/France, Paris.

Kanazawa, A., S.I. Teshima and M. Sakamoto, 1985. Effects of dietary lipids, fatty acids and phospholipids on growth and survival of prawn (*Penaeus japonicus*) larvae. Aquaculture, 50: 39-49.

Kasper, E. and P. Brown, 2003. Growth improved in juvenile Nile tilapia fed phosphatidylcholine. North Am. J. Aquaculture, 65: 39-43.

Koven, W.M., S. Kolkovski, A. Tandler, G.W. Kissil and D. Sklan, 1993. The effect of dietary lecithin and lipase, as a function of age, on n-9 fatty acid incorporation in the tissue lipids of *Sparus aurata* larvae. Fish Physiol. Biochem., 10: 357-364.

Koven, W.M., G. Parra, S. Kolkovski and A. Tandler, 1998. The effect of dietary phosphatidylcholine and its constituent fatty acids on microdiet ingestion and fatty acid absorption rate in gilthead sea bream, *Sparus auratus*, larvae. Aquac. Nutr., 4: 39-45.

McKenzie, D.J., E. Cataldi, P. Di Marco, A. Mandlich and P. Romano *et al*., 1999. Some aspects of osmotic and ionic regulation in Adriatic sturgeon *Acipenser naccarii*. II: Morpho-physiological adjustments to hyperosmotic environments. J. Applied Ichthyol., 15: 61-66.

Morais, S., L.E.C. Conceicao, I. Ronnestad, W. Koven, C. Cahu, J.L. Zambonino Infante and M.T. Dinis, 2007. Dietary neutral lipid level and source in marine fish larvae: Effects on digestive physiology and food intake. Aquaculture, 268: 106-122.

NRC, 1993. Nutrient Requirements of Fish on Animal Nutrition Board on Agriculture. National Academy Press, Washington, DC., USA., pp: 114.

Rainuzzo, J.R., K.I. Reitan and Y. Olsen, 1997. The significance of lipids at early stages of marine fish: A review. Aquaculture, 155: 103-115.

Sargent, J., G. Bell, L. McEvoy, D. Tocher, A. Estevez, 1999. Recent developments in the essential fatty acid nutrition in fish. Aquaculture, 177: 191-199.

Sener, M.Y. and E. Savas, 2005. Effects of dietary lipids on growth and fatty acid composition in Russian sturgeon (*Acipenser gueldenstaedtii*) juveniles. Turk. J. Vet. Anim. Sci., 29: 1101-1107.

Sufang, L., Z. Na, Z. Ayong and H. Ruiguo, 2008. Effect of soybean phospholipid supplementation in formulated microdiets and live food on foregut and liver histological changes of *Pelteobagrus fulvidraco* larvae. Aquaculture, 278: 119-127.

Teshima, S.I., A. Kanazawa and Y. Kakuta, 1986. Effects of dietary phospholipids on growth and body composition of the juvenile prawn. Bull. Jap. Soc. Sci. Fish., 52: 159-163.

Tocher, D.R., 2003. Metabolism and functions of lipids and fatty acids in teleost fish. Rev. Fish. Sci., 11: 107-184.

Tocher, D.R., E.A. Bendiksen, P.J. Campbell and J.G. Bell, 2008. The role of phospholipids in nutrition and metabolism of teleost fish. Aquaculture, 280: 21-34.

Xu, R., S.S.O. Hung and J.B. German, 1993. White sturgeon tissue fatty acid compositions are affected by dietary lipids. J. Nutr., 123: 1685-1692.