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Research Article

Optimization of feeding rates for Persian sturgeon (*Acipenser persicus* Borodin, 1897)

Irani A.[1*]; Agh N.[1]

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Abstract

Determining the optimum feeding rate is one of the important feeding managerial activities in the aquaculture industry. The satiation rate of the sturgeons, especially during the early life stages, is hard to be determined. Thus, in this study we investigated the effects of different feeding rates on Persian sturgeon (*Acipenser persicus*) after initiation of the exogenous feeding. The study was conducted in eight trials, and allocated five feeding rate treatments (with three replicates) for each trial. The initial body weight in trials 1-8 were 0.039±0.005 to50.060±7.328 g, respectively, and the stocking densities were 12 to 0.25 individuals per liter, respectively. Results showed that in trial 1, food conversion ratio (FCR) was affected significantly, whereas the survival rate and growth performance were not affected by the feeding rates, except the dry weight. In trials2-8, the growth performance and FCR were affected significantly (p<0.05) by the feeding rates, whereas, there were no significant differences amongst the survival rates in trials 5-8. The analyses on the growth performance indicated that the optimum feeding rates of Persian sturgeon larvae and juveniles in trials 1 (0.039-0.097 g), 2 (0.107-0.193 g), 3 (0.211-0.334 g), 4 (0.417-1.944 g), 5 (2.335-6.219 g), 6 (6.950-13.275 g), 7 (14.720-37.350 g), and 8 (50.060-124.050 g) to be 20%, 15%, 9%, 7%, 6%, 3%, 3%, and 2.5% body weight day^{-1}, respectively.

Keywords: Persian sturgeon *(Acipenser persicus)*, Feeding rate, Growth performance, Survival rate

1- Artemia and Aquaculture Research Institute, Urmia University, Urmia, Iran.
*Corresponding author's Email: a.irani@urmia.ac.ir

Introduction

Feeding in aquaculture, accounting for the main portion of the total costs, is one of the operations that plays critical role in the success or failure of any intensive fish production activity (Okorie *et al.*, 2013). In intensive aquaculture systems, the feed cost can be ranged from 30% to 70% of the total production expenditure (Lovell, 1998; Webster *et al.*, 2001), thus economic success of these systems mainly depends on the feeding management. The growth performance, feed efficiency, survival rate, and production cost may be negatively affected by the overfeeding (i.e., feeding more than fish feed intake) and underfeeding (i.e., feeding lower than fish satiation rate) as well. Many studies on different fish species have indicated that rearing conditions, such as feeding strategy, feed quality and water quality could affect the adequate feeding rate (Hung, 1991; Li and Lovell, 1992a, 1992b; Hung *et al.*, 1995).

Because of their high quality meat and caviar, sturgeons are considered as highly valuable fish in the world (Kalbassi *et al.*, 2013). Persian sturgeon is the most prevalent sturgeon in the South coast of Caspian Sea. During the previous decades, Persian sturgeon has been propagated artificially and fingerlings were released into Caspian Sea for natural stocks restoration and support of commercial fisheries. Despite several great characteristics, such as artificial propagation and relatively high growth performance (Irani and Agh, 2019), some of the critical rearing and production biotechniques have not been revealed yet.

Larvae and fingerlings of the most sturgeon species have been reared on the live foods, such as oligochaetes (*Enchytraeus* sp. and *Tubifex* sp.) and zooplanktons (*Daphnia* sp. and *Artemia* sp.) (Gisbert and Williot, 2002). Moreover, several studies demonstrated that artificial larval diets could be used successfully for the intensive commercial culture of Siberian sturgeon (Dabrowski *et al.*, 1985) and white sturgeon (Deng *et al.*, 2003; Hung, 1991) from the onset of exogenous feeding.

According to findings of previous studies (Agh *et al.*, 2012; Agh *et al.*, 2013; Irani and Agh, 2019), the feeding strategy in the Persian sturgeon culture should be based on the percentage of the mean body weight instead of the satiation rate, as feed intake in this species is slower than in carnivorous fish like rainbow trout (*Oncorhynchus mykiss*). Consequently, satiation rate could hardly be distinguished in this species, especially during the early life stages.

Therefore, the present study was carried out to determine the optimum feeding rates during larval and juvenile stages of Persian sturgeon.

Materials and methods

Fish and rearing conditions

This study was conducted in the eight trials (eight time periods), which covered larval and juvenile stages of Persian sturgeon. Newly hatched larvae of Persian sturgeon were obtained from the Shahid Marjani Sturgeon Hatchery Center, Gorgan, Golestan, Iran, and transported to the Artemia and Aquaculture Research Institute of Urmia University, Urmia, West Azarbaijan, Iran. The larvae were stocked in a 1000-liter polyethylene adaptation tank. When the larvae absorbed more than half of their yolk sacs and about 10-20 percent of them could swim horizontally, were counted and distributed randomly amongst the fifteen rearing tanks to conduct trial 1. After the termination of each trial, fish of the entire treatments were transferred into a 1000-liter polyethylene tank and removed both too small and very big fish. Mean weight of thirty randomly sampled fish from the remainders was measured to determine the initial weight for the next trial and then the fish were distributed randomly amongst the rearing tanks. Rearing tanks were 45-liter polyethylene tanks (0.44×0.31×0.33 m) with the water capacity of 25 l in trials 1 (7 days), 2 (7 days), 3 (7 days), 4 (10 days), 5 (10 days), and 6 (14 days), and 90-liter polyethylene tanks (0.90×0.44×0.23 m) with the water capacity of 80 l in trials 7 (30 days) and 8 (60 days). In each trial, there were five experimental feeding rates (% body weight day^{-1}), with three replicates, thus, fifteen tanks were allocated to each trial (Table 1).

Temperature and dissolved oxygen were measured daily during the study period with a portable Multimeter (WTW, Multi 3630 IDS, Weilheim, Germany). Each tank was supplied with 0.7 l/min of the degassed groundwater and the values of water temperature and dissolved oxygen ranged from 18.8-19℃ and 7.4-8.6 mg/L, respectively, during trials 1, 2, and 3.The values were 0.8 l/min and ranged from 20.3-20.9℃ and 7.1-8.5 mg/L, respectively, during trials 4, 5, and 6. During trials 7 and 8, flow-through rate was 3.1 l/m and the temperature and dissolved oxygen ranged from 19.5-21 ℃ and 7.6-8.5 mg/L, respectively.

The initial body weights were 0.039, 0.107, 0.211, 0.417, 2.335, 6.950, 14.720, and 50.060 g in trials 1, 2, 3, 4, 5, 6, 7, and 8, respectively. The stocking densities were 12, 8, 6, 4, 2, 1, 0.31, and 0.25 individual per liter in trials 1-8, respectively. The experimental duration lasted 7 days in trials 1, 2, and 3; 10 days in trials 4 and 5; and 14, 30, and 60 days in trials 6, 7, and 8, respectively (Table 1).

Feeding

Feeding with newly hatched Artemia nauplii started one day after the distribution of the larvae amongst the rearing tanks in trial 1. The larvae in all treatments were fed Artemia nauplii during the first five days followed by the gradual replacement with a commercial trout starter diet (Faradaneh co., Iran) in 10 days, daily 10% increasing of the formulated diet and decreasing the same amount of Artemia nauplii simultaneously, as all fish groups weaned to formulate-diet 15 days after initiation of exogenous feeding. Thus, fish groups were fed Artemia nauplii in the first five days of trial 1, and co-feeding of Artemia nauplii and SFT00 was carried out in the days 6 and 7 in trial 1. The co-feeding of Artemia nauplii and SFT00 lasted to the end of trial 2.The fish were fed SFT0, SFT1, SFT2, SFT2 and SFT3, and FFT and GFT1 (Faradaneh CO., Iran) in trials 3,4, 5, 6, 7, and 8, respectively (Table 1).The fish were fed at 20%, 25%, 30%, 35%, and 40% body weight per day (BW/day) in trial 1 (Agh *et al*., 2013); 12%, 15%, 18%, 21%, and 24% BW/day in trial 2; 6%, 9%, 12%, 15%, and 18% BW/day in trial 3; 5%, 7%, 9%, 11%, and 13% BW/day in trial 4; 2%, 4%, 6%, 8%, and 10% BW/day in trial 5; 1.5%, 3%, 4.5%, 6%, and 7.5% BW/day in trial 6; 2.5%, 3%, 3.5%, 4%, and 4.5% BW/day in trial 7; and 1.5%, 2%, 2.5%, 3%, and 3.5% BW/day in trial 8.

Table 1: Feeding rates, initial body weight, feed, and duration of trials.

Trial	Feeding rate (% Body weight day^{-1})	Initial body weight (g)*	Stocking density (individual/l)	Feed**	Duration (day)
Trial 1	20, 25, 30, 35, 40	0.039 ± 0.005	12	Artemia	5
				Artemia&*SFT00	2
Trial 2	12, 15, 18, 21, 24	0.107 ± 0.009	8	Artemia& SFT00	7
Trial 3	6, 9,12, 15, 18	0.211± 0.017	6	SFT0	7
Trial 4	5, 7, 9, 11, 13	0.417 ± 0.052	4	SFT0	10
Trial 5	2, 4, 6, 8, 10	2.335 ± 0.311	2	SFT1	10
Trial 6	1.5, 3, 4.5, 6, 7.5	6.950 ± 0.574	1	SFT2	14
Trial 7	2.5, 3, 3.5, 4, 4.5	14.720 ± 1.925	0.31	SFT2	15
				SFT3	15
Trial 8	1.5, 2, 2.5, 3, 3.5	50.060 ± 7.328	0.25	FFT	30
				GFT1	30

* The values represent mean ± S.E., ** SFT: Starter Food for Trout, FFT: Fingerling Food for Trout, GFT: Grower Food for Trout.

Crude protein of the pre starter (SFT00 and SFT0), starter (SFT1, SFT2, and SFT3), pre grower (FFT), and grower (GFT1) feed were 50-54%, 46-50%, 40-44%, and 38-42%, respectively. Their crude fats were 11-15%, 11-15%, 12-16%, and 13-17%, respectively (Table 2). During the study period, 10 fish from each tank were sampled randomly and weighed at three-day (trials 1 and 2) or five-day intervals (rest of the trials) for adjusting the feeding rate.

Table 2: Proximate composition of trout diet used for feeding of Persian sturgeon.

Proximate composition (%)	SFT00	SFT0	SFT1	SFT2	SFT3	FFT	GFT1
Crude protein	50-54	50-54	46-50	46-50	46-50	40-44	38-42
Crude fat	11-15	11-15	11-15	11-15	11-15	12-16	13-17
Crude fiber	1.5-3	1.5-3	1.5-3	1.5-3	1.5-3	2-4	2-4
Ash	9-13	9-13	9-13	9-13	9-13	7-11	7-11
Moisture	5-11	5-11	5-11	5-11	5-11	5-11	5-11

Growth and feeding parameters

At the end of each trial, 20 fish from each tank were sampled randomly, and the total length and weight of them were measured. Weight gain was calculated using weight gain = final weight – Initial weight. Specific growth rate (SGR) was calculated using SGR ($\%day^{-1}$) = $100\times(\ln W_t-\ln W_0)/t$, where W_t and W_o represent the final and initial weights, respectively, and t is the growing period in days (Gisbert and Williot, 1997). Dry weight was calculated via drying the samples for 16 h at 105 °C in the oven (AOAC, 2005). Food conversion ratio (FCR) was measured by FCR=total feed (kg)/weight gain (kg). The values of FCR were measured based on the total delivered feed. The daily feeding amounts and FCR calculations were based on the wet weight of Artemia nauplii.

Statistics

The results were reported as the mean of replicates (n=3) and standard error of mean (Mean ± SEM). Statistical analyses were carried out using SPSS 22. Homogeneity of variances and normality of distribution were tested using the Levene's test and Shapiro-Wilk test, respectively. The values of parameters were analyzed by one-way ANOVA and Duncan's *post-hoc* Test. All analyses were performed at α=0.05 (Irani and Agh, 2020).

Results

Trial 1: First week after initiation of feeding

Fish offered the 40% BW/day showed the highest dry weight (0.014±0.0035 g), the value was significant compared to fish offered the 20% BW/day (0.010±0.0005 g). In terms of final length, total weight, weight gain, SGR, and condition factor there were no significant differences amongst the experimental groups (p>0.05). All groups showed high values of the survival rates, 97.67-98.80%, during the first week after initiation of exogenous feeding. The values of FCR ranged from 1.17-1.81 in the experimental groups, and the significant differences were observed between the 20% and 40% BW/day fish groups (Table 3).

Trial 2: Second week after initiation of feeding

The growth parameters (i.e., total weight, dry weight, weight gain, and SGR) of the 12% BW/day fish group were significantly lower than in the other groups, whereas there were not significant differences amongst the rest of the groups. The survival rates ranged from 91.33-96.33% in the experimental groups, and the values of the 15-24% BW/day fish groups were significantly higher than of the 12% BW/day fish group. The highest FCR (2.44±0.37) was observed in the fish group fed 24% BW/day, being significantly more than in the other groups, whereas no significant differences were observed amongst the rest of the groups (Table 4).

Table 3: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon larvae at different feeding rates in trial 1 (during the first week after initiation of feeding).

Feeding rates (%BW day^{-1})	20	25	30	35	40
Total length (mm)	25.47 ± 0.21*	25.53 ± 0.32	26.27 ± 1.30	27.07 ± 0.45	27.03 ± 1.64
Total weight (g)	0.097± 0.005	0.097± 0.002	0.104± 0.015	0.114 ± 0.011	0.118 ± 0.026
Dry weight (g)	0.010± 0.0005^{a}	0.011 ± 0.0001^{ab}	0.011 ± 0.0017^{ab}	0.013 ± 0.001^{ab}	0.014 ± 0.0035^{b}
Weight gain (g)	0.058 ± 0.005	0.059 ±0.002	0.065 ± 0.015	0.075 ± 0.011	0.079 ± 0.016
SGR (% day^{-1})	12.97 ± 0.81	13.09 ± 0.36	13.97 ± 2.0	15.28 ± 1.43	15.58 ± 2.95
FCR	1.17 ± 0.11^{a}	1.44 ± 0.06^{ab}	1.60 ± 0.35^{ab}	1.58 ± 0.25^{ab}	1.81 ± 0.49^{b}
Survival rate (%)	97.8 ± 1.15	97.67 ± 0.91	98.23 ± 0.68	98.00 ± 1.73	98.80 ± 0.17

* The values represent mean±S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, $p<0.05$).

Table 4: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon fry at different feeding rates in trial 2 (during the second week after initiation of feeding).

Feeding rate (%BW day^{-1})	12	15	18	21	24
Total length (mm)	30.80±1.41^{a}*	33.13±0.68^{b}	32.30± 0.60^{ab}	33.50± 0.79^{b}	33.60± 0.17^{b}
Total weight (g)	0.148± 0.018^{a}	0.193± 0.021^{b}	0.183± 0.003^{b}	0.207± 0.006^{b}	0.195± 0.013^{b}
Dry weight (g)	0.0150± 0.0013^{a}	0.0200± 0.0026^{b}	0.0190± 0.0035^{b}	0.0210± 0.0004^{b}	0.0210± 0.0004^{b}
Weight gain (g)	0.041± 0.009^{a}	0.087± 0.014^{b}	0.076± 0.003^{b}	0.100± 0.006^{b}	0.088± 0.013^{b}
SGR (% day^{-1})	4.58±1.76^{a}	8.43±1.53^{b}	7.69±0.22^{b}	9.46±0.42^{b}	8.55±0.96^{b}
FCR	1.87± 0.21^{a}	1.62± 0.23^{a}	1.92± 0.07^{a}	1.75± 0.11^{a}	2.44± 0.37^{b}
Survival rate (%)	91.33± 1.44^{a}	94.00±1.00^{b}	94.67±1.04^{b}	95.67± 1.15^{b}	96.33±1.53^{b}

* The values represent mean ± S.E., n=3. Different superscripts in each row represent significant differences (One-way ANOVA, $p<0.05$).

Trial 3: Third week after initiation of feeding

Growth parameters in the groups offered 9-18% BW/day (except the total length of the 12% BW/day group) were significantly higher than in the group offered 6% BW/day, whereas there were no significant differences amongst the 9-18% BW/day fish groups. The lowest FCR value (0.94±0.11) was observed in the 9% BW/day fish group. This parameter in the 6%, 15%, and 18%BW/day groups were significantly more than in the 9% and 12% BW/day groups (Table 5).

Trial 4: 22-32 days after initiation of feeding

In this trial, the total length, total weight, dry weight, weight gain, and SGR of the fish group fed 5% BW/day were significantly lower than of the other groups, whereas no significant differences were detected amongst the 7-13% BW/day groups. The lowest value of FCR (0.31±0.06) was observed in the group fed 5% BW/day. There were no significant differences between the 5% and 7% BW/day groups in terms of FCR. The fish group of 9% BW/day showed the highest survival rate (93.80%±2.30) that was significantly different compared to the 5% and 7% BW/day fish groups (Table 6).

Table 5: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon fry at the different feeding rates in trial 3 (during the third week after initiation of feeding).

Feeding rate (%BW day^{-1})	6	9	12	15	18
Total length (mm)	35.40± 0.78^{a1}	39.90±2.60^{b}	38.30± 0.51^{ab}	39.40± 2.35^{b}	39.30± 0.61^{b}
Total weight (g)	0.233± 0.012^{a}	0.334± 0.045^{b}	0.309± 0.011^{b}	0.321± 0.065^{b}	0.309± 0.014^{b}
Dry weight (g)	0.023± 0.006^{a}	0.032± 0.001^{b}	0.032± 0.001^{b}	0.032± 0.005^{b}	0.031± 0.008^{b}
Weight gain (g)	0.022± 0.006^{a}	0.123± 0.025^{b}	0.098± 0.011^{b}	0.110± 0.035^{b}	0.098± 0.014^{b}
SGR (% day^{-1})	1.41± 0.36^{a}	6.46±1.13^{b}	5.45±0.51^{b}	5.82± 1.23^{b}	5.46±0.66^{b}
FCR	2.14± 0.24^{c}	0.94± 0.11^{a}	1.37± 0.15^{b}	1.85± 0.22^{c}	1.98± 0.14^{c}
Survival rate (%)	74.00±2.64^{a}	78.00±1.73^{b}	77.67±2.52^{b}	78.33± 1.15^{b}	78.67±1.53^{b}

[*] The values represent mean ± S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, p<0.05).

Table 6: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon fingerlings at the different feeding rates in trial 4 (during the 22-32 days after initiation of feeding).

Feeding rate (%BW day^{-1})	5	7	9	11	13
Total length (mm)	69.50±3.30^{a*}	74.90±0.40^{b}	76.90± 1.20^{b}	78.20± 0.40^{b}	77.80± 3.20^{b}
Total weight (g)	1.503± 0.196^{a}	1.944± 0.094^{b}	2.009± 0.119^{b}	2.153± 0.117^{b}	2.091± 0.213^{b}
Dry weight (g)	0.197± 0.025^{a}	0.258± 0.013^{b}	0.287± 0.021^{bc}	0.308± 0.007^{c}	0.295± 0.032^{bc}
Weight gain (g)	1.086± 0.196^{a}	1.527± 0.094^{b}	1.592± 0.119^{b}	1.736± 0.017^{b}	1.674± 0.213^{b}
SGR (% day^{-1})	12.70±1.30^{a}	15.40±0.50^{b}	15.70± 0.60^{b}	16.40±0.10^{b}	16.10±1.00^{b}
FCR	0.31± 0.06^{a}	0.33± 0.02^{a}	0.43± 0.03^{b}	0.49± 0.01^{b}	0.66± 0.09^{c}
Survival rate (%)	87.30±1.80^{a}	84.70±2.40^{a}	93.80± 2.30^{b}	92.00±2.40^{b}	93.50±3.40^{b}

[*]The values represent mean±S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, p<0.05).

Trial 5: 33-43 days after initiation of feeding

The fish groups offered the 6%, 8%, and 10% BW/day exhibited significantly higher total length, total weight, dry weight, weight gain, and SGR than of the fish groups offered the2% and 4% BW/day. The survival rates were 100% in the all groups.

In terms of FCR, there were significant differences amongst the experimental groups, with an exception between the 2% and 6% BW/day groups. The lowest values of FCR (0.39±0.02) were detected in the fish group offered 4% BW/day group (Table 7).

Table 7: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon fingerlings at the different feeding rates in trial 5 (during the 33-43 days after initiation of feeding)

Feeding rate (% BW day^{-1})	2	4	6	8	10
Total length (mm)	94.50±2.10^{a*}	108.00±0.90^{b}	113.00± 1.30^{c}	114.10± 0.40^{c}	115.00± 0.70^{c}
Total weight (g)	3.424± 0.133^{a}	5.208± 0.117^{b}	6.219± 0.272^{c}	6.458± 0.113^{c}	6.451± 0.132^{c}
Dry weight (g)	0.425± 0.035^{a}	0.738± 0.017^{b}	0.930± 0.083^{c}	0.988± 0.006^{c}	1.007± 0.012^{c}
Weight gain (g)	1.089± 0.042^{a}	2.872± 0.065^{b}	3.884± 0.232^{c}	4.122± 0.083	4.115± 0.084^{c}
SGR (% day^{-1})	3.82±0.38^{a}	8.02± 0.22^{b}	9.78± 0.59^{c}	10.17± 0.02^{c}	10.16±0.21^{c}
FCR	0.46± 0.05^{b}	0.39± 0.02^{a}	0.49± 0.04^{b}	0.63± 0.01^{c}	0.77± 0.03^{d}
Survival rate (%)	100	100	100	100	100

[*] The values represent mean±S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, p<0.05).

Trial 6: 44-58 days after initiation of feeding

The total length and dry weight of the fish groups fed the 4.5%, 6%, and 7.5%BW/day were significantly higher than of the fish groups fed the 1.5% and 3% BW/day, whereas there were no significant differences amongst the 4.5%, 6%, and 7.5% BW/day fish groups. The performance of the 1.5% BW/day fish group were significantly lower than of the other groups in terms of the total weight, weight gain, and SGR.

The lowest FCR (0.56±0.04) was observed in the fish group fed the 3% BW/day, showed significant differences compared to the fish group fed the 6% and 7.5% BW/day. The survival rates ranged from 97.3%-100% amongst the experimental groups in this trial (Table 8).

Table 8: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon juveniles at the different feeding rates in trial 6 (during the 44-58 days after initiation of feeding).

Feeding rate (%BW day^{-1})	1.5	3	4.5	6	7.5
Total length (mm)	146.20±2.40[a*]	158.70±1.40[b]	167.90± 2.60[c]	167.60± 3.90[c]	165.60± 4.90[c]
Total weight (g)	9.405± 0.526[a]	13.275± 0.459[b]	14.622± 0.198[b]	15.295± 0.290[b]	14.777± 1.354[b]
Dry weight (g)	1.495± 0.162[a]	2.274± 0.138[b]	2.886± 0.204[c]	2.910± 0.023[c]	2.628± 0.267[c]
Weight gain (g)	2.455± 0.133[a]	6.425± 0.221[b]	7.672± 0.919[b]	8.345± 0.158[b]	7.827± 0.717[b]
SGR (% day^{-1})	2.15±0.40[a]	4.67± 0.24[b]	5.27± 0.95[b]	5.63± 0.14[b]	5.37±0.67[b]
FCR	0.64± 0.13[ab]	0.56± 0.04[a]	0.77± 0.16[ab]	0.88± 0.03[b]	1.19± 0.23[c]
Survival rate (%)	98.70±2.30	98.70 ± 2.30	97.30 ±4.60	100.00 ±0.00	98.70 ±2.30

[*] The values represent mean ± S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, p<0.05).

Trial 7: 60-90 days after initiation of feeding

The 2.5% BW/day fish group showed significant differences compared to the other groups in terms of the total length, total weight, weight gain, and SGR.

The FCR values of the fish groups offered 2.5% and 3% BW/day were significantly lower than of the fish groups offered4% and 4.5% BW/day. Survival rates were 100% in the all groups (Table 9).

Table 9: Biometric parameters, growth, FCR, and survival rate of Persian sturgeon juveniles at the different feeding rates in trial 7 (during the 60-90 days after initiation of feeding).

Feeding rate (%BW day^{-1})	2.5	3	3.5	4	4.5
Total length (mm)	210.70±3.20[a*]	221.00±3.00[b]	223.60± 7.30[b]	225.20± 4.60[b]	226.30± 6.30[b]
Total weight (g)	32.670± 0.880[a]	37.350± 1.510[b]	40.660± 1.910[b]	40.840± 3.270[b]	39.470± 2.030[b]
Weight gain (g)	17.890± 0.810[a]	22.620±1.440[b]	26.030±2.050[b]	26.060±3.310[b]	24.760±2.130[b]
SGR (% day^{-1})	2.64±0.74[a]	3.10± 0.13[b]	3.40 ± 0.19[b]	3.38± 0.28[b]	3.29±0.20[b]
FCR	0.87± 0.02[a]	0.89± 0.02[a]	0.97± 0.05[ab]	1.05± 0.11[b]	1.24± 0.11[c]
Survival rate (%)	100	100	100	100	100

[*] The values represent mean±S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, p<0.05).

Trial 8: 91-150 days after initiation of feeding

The total length of the fish group offered 1.5%BW/day was significantly lower than of the other groups. This parameter in the group offered 2% BW/day was significantly lower than in the groups offered 2.5%, 3%, and 3.5% BW/day. Fish fed at2.5, 3, and 3.5% BW/day feeding rates showed significantly higher growth performance than those fed at 1.5 and 2% feeding rates. There were no significant differences amongst the 1.5%, 2%, and 2.5% BW/day groups, and between the 3% and 3.5% BW/day groups in terms of the FCR, whereas fish groups offered3% and 3.5% BW/day showed the significant differences compared to the other groups. Like previous trial, the survival rates were 100% in the all groups (Table 10).

Table 10: Biometric parameters, growth, FCR and survival rate of Persian sturgeon juveniles at different feeding rates in trial 8 (91-150 days after initiation of feeding).

Feeding rate (%BW day^{-1})	1.5	2	2.5	3	3.5
Total length (mm)	298.10±7.30^{a*}	318.60±6.40^{b}	331.30± 3.90^{c}	328.50± 2.60^{c}	336.20± 7.20^{c}
Total weight (g)	89.900± 2.530^{a}	106.490± 4.110^{b}	124.050± 2.960^{c}	120.590± 3.570^{c}	123.410± 4.780^{c}
Weight gain (g)	40.000 ± 3.010^{a}	56.290 ±4.030^{b}	74.050 ±3.960^{c}	70.490 ±4.330^{c}	73.310 ±5.580^{c}
SGR (% day^{-1})	0.98± 0.07^{a}	1.25± 0.07^{b}	1.51± 0.07^{c}	1.46± 0.08^{c}	1.50± 0.09^{c}
FCR	1.41± 0.10^{a}	1.45± 0.09^{a}	1.45± 0.09^{a}	1.80± 0.15^{b}	1.98± 0.09^{b}
Survival rate (%)	100	100	100	100	100

[*] The values represent mean±S.E. n=3. Different superscripts in each row represent significant differences (One-way ANOVA, *p*<0.05).

Discussion

Current study was carried out during the early life stages of Persian sturgeon; from the beginning of the exogenous feeding to approximately 120 g body weight. The satiation feeding rate of this species, especially during the early life stages, is hard to be distinguished. Thus, determination of the optimum feeding rates is one the important steps of the Persian sturgeon culture practice.

The growth parameters of Persian sturgeon larvae and juveniles were influenced significantly by the feeding rates, with the exception of the total length, total weight, weight gain, and SGR in trial 1, and survival rate in trials 1, 5, 6, 7, and 8. The analysis on the growth performance indicated that the optimum feeding rates of Persian sturgeon were 20%, 15%, 9%, and 7% BW day^{-1}in the first, second, third, and forth weeks after initiation of exogenous feeding (trials 1-4), respectively. The optimum feeding rates of white sturgeon (*A. transmontanus*) based on SGR, were reported to be 26%, 13%, 11%, and 6% body weight day^{-1}in the first, second, third, and forth weeks after initiation of feeding, respectively (Deng *et al.*, 2003). The differences of these values in compare with the results of the present study might be a consequence of specific species, feed types and rearing conditions. In the above-mentioned study, fish fed commercial diets from initiation of exogenous feeding, whereas, in the present study, the larvae of the all groups were fed Artemia nauplii during the first five days followed by gradual replacement with a commercial trout starter diet in 10 days.

The optimum feeding rates of Persian sturgeon were 6% and 3%, BW day^{-1} in 5-6 and 7-8 weeks after initiation of feeding (trials 5 and 6), respectively. The optimum feeding rates of White sturgeon reported by De Riu *et al.* (2012) were 6.5%, 4.8%, 4.2%, and 3.8% BW day^{-1}in 6-9 weeks after initiation of exogenous feeding, respectively. Zheng *et al.* (2015) reported that the optimum feeding rates of Green sturgeon (*A. medirostris*)to be 5.7% and 5.3% BW day^{-1} in 6 and 7weeks after initiation of exogenous feeding. These values almost agree our findings in trial 5, whereas the optimum feeding rates of Persian sturgeon in 7-8 weeks after initiation of feeding were lower than of above-mentioned species.

The optimum feeding rate of white sturgeon juveniles, growing period: from 30-100 g body weight, reported by Hung *et al.* (1995) were 2% BW day^{-1},which was a little lower than the optimum feeding rate of Persian sturgeon, growing period: 50-120 g body weight, in this study (i.e., 2.5% BW day^{-1}). According to the findings of above mentioned authors and previous studies carried out on the various species and sizes of cultured fishes (Andrews and Page, 1975; Minton, 1978; Hung, 1991; Li and Lovell, 1992a, 1992b), rearing conditions such as feeding strategies, feed quality, and physicochemical factors of rearing water could affect the adequate feeding rate.

The SGR values of Persian sturgeon larvae fed at or above the optimum feeding rates, ranged from 7.69-15.58% day^{-1}, were high during trial 1 and 2.These values were comparable to those of White sturgeon, 9.6-13% day^{-1} (Deng *et al.*, 2003), Russian sturgeon, *A. gueldenstaedtii*, 6.83-12.45 % day^{-1} (Memis*et al.*, 2009), Green sturgeon,10.5 % day^{-1}(Deng, 2000), Siberian sturgeon, *A. baerii*, 12.2-15.3% day^{-1} (Gisbert *et al.*, 2000), and Persian sturgeon, about 11-14 % day^{-1} (Agh *et al.*, 2013).

Deng *et al.*, 2003reported that the gain per food fed values of white sturgeon were low during the first week after initiation of feeding. They interpreted that the low values may have resulted from the lack of acclimation to the feed prior to the first week, poor ability of the larvae to acquire feed, and/or age-related physiological conditions such as a higher metabolism for metamorphosis and poorly developed digestive apparatus (Deng *et al.*, 2003). However, our findings are different from results of above-mentioned authors, as growth performance and feed efficiency were high during the first two weeks after initiation of feeding, while these parameters were affected adversely in the third week, and the values increased in the fourth week again. This might be a consequence of the weaning strategy used in the present study and the acclimation process of the fish to the commercial feed. After trial 4, the values of SGR decreased, more likely because of the increased body weight of the growing fish and decreased body moisture (Memis *et al.*, 2009).

There was an initial decrease, followed by an increase on the FCR values at the optimum feeding rates; in trials 1 and 2, the values were relatively high (1.17 and 1.62, respectively), followed by the decreasing FCR values during the trials 3 and 4 (0.94 and 0.33, respectively). This might be a consequence of the feeding live food, having a higher water contents (>80% in Artemia vs <10% in dry feed.), poor ability of larvae to acquire feed, and poorly developed digestive system (Deng *et al.*, 2003). Artemia can be considered of similar water contents as the fish larvae. In this respect, the values observed in the trial 1 were lower than the expected FCR. It suggests that apart from the feed loss, the fish would have utilized the feed components with a little loss attributed to metabolism. Live food, Artemia nauplii in this study, contains digestive enzymes that play an auto-digestion role in the digestive system of larvae, contributing them to extract nutrients more efficiently.

The FCR increased progressively during trials 5-8 (0.49, 0.56, 0.89, and 1.45, respectively). However, these values were slightly higher than the results reported by Memis *et al.* (2009) for Russian sturgeon (*A. gueldenstaedtii*) and Agh *et al.* (2013) for Persian sturgeon that might be a consequence of different feeding strategies. Overall survival rates were high in this study. However, the values decreased in trial 3, the third week after initiation of feeding (74.0-78.67%). Unlikely, Deng *et al.* (2003) reported the increasing values of the survival rate for white sturgeon larvae fed commercial diet from the initiation of feeding. Predation and starvation are the main factors of larval mortality during the early life stages of Siberian sturgeon (Gisbert, 1999). Predation was rarely observed in this study, thus, starvation linked tothe weaning time, which more likely was a consequence of poorly developed larval digestive system, may have been main reason of mortality in trial 3.

Considering the slow feeding habit of Persian sturgeon, the feeding strategy applied for the farming of this species (as a candidate species for the aquaculture industry) should be based on the percentage of mean body weight instead of the satiation rate. In addition, good growth and survival rate of Persian sturgeon were observed with gradual weaning process, in which the larvae have been fed on the newly hatched Artemia nauplii for five days after initiation of exogenous feeding, and then weaned slowly to formulated diet; at 10% daily weaning substitution level of Artemia nauplii with artificial diet. In conclusion, the optimum feeding rates determined in this study: 20%, 15%, 9%, 7%, 6%, 3%, 3% and 2.5% body weight day^{-1} for the larvae and juveniles in trials 1 (0.039-0.097 g), 2 (0.107-0.193 g), 3 (0.211-0.334 g), 4 (0.417-1.944 g), 5 (2.335-6.219 g), 6 (6.950-13.275 g), 7 (14.720-37.350 g), and 8 (50.060-

124.050 g), respectively, can be helpful guidelines for Persian sturgeon culture.

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