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Growth and Survival of *Penaeus monodon* (Fabricius, 1798) in Monosex and Mixed-sex Cultures

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Abstract

Sexual dimorphism is apparent in black tiger shrimp *Penaeus monodon* (Fabricius, 1798) with females achieving larger size than males. An experiment was conducted to compare rearing of all female and all male *P. monodon* with a mixed-sex population using juveniles segregated by hand-sexing. External sex differentiation of postlarvae started after 55 – 60 days of rearing when they reached 2.5 g and 7.0 cm size. Healthy juveniles (4.46 ± 0.54 g; 8.55 ± 0.30 cm for males and 4.35 ± 0.38 g; 8.54 ± 0.20 cm for females) were stocked in 250 l circular cement tanks with water of salinity 18 ± 2 g l^{-1} at a density of 8 individuals per tank (equivalent to a density of 12.5 m^{-2}). The treatments were all male, all female, and mixed-sex juveniles at a ratio of 1:1, with five replicates in each one. The animals were fed with a commercial shrimp starter feed for 50 days. All female shrimps attained significantly higher growth of 40% and 43% compared to all male and mixed-sex treatments, respectively, with greater specific growth rate and protein efficiency ratio, and lower feed conversion ratio ($p<0.05$). Survival rates were not significantly different among treatments. The male growth in the all male and mixed sex treatments was similar, while the female growth was significantly higher in the all female treatment compared to that in the mixed sex treatment. Results of this study demonstrate the benefit of all female culture of *P. monodon* over the conventional mixed-sex culture although more trials are recommended to establish its commercial attributes.

Keywords: Monosex culture, mixed-sex culture, *Penaeus monodon*, sex differentiation, sexual dimorphism, survival rate

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Introduction

Sexual dimorphism, which may be attributed to behavioural and/or physiological differences between the sexes, is characterized by the presence of different male and female body forms. In a cultured species, it can make one sex more commercially valuable than the other, since in most species of fish one of the sexes grows faster than the other (Hansford, 1991). Monosex culture, which exploits the sex-dependent size difference, is a proven practice in commercial aquaculture of finfish and shellfish (Mires, 1977; Curtis & Jones, 1995; Beardmore et al., 2001). In channel catfish, males grow faster than females and this growth difference in two sexes is exploited in its commercial farming (Goudie et al., 1993). In mixed-sex culture, males of tilapia *Oreochromis niloticus* (Linnaeus, 1758) typically grow faster than females (Tave, 1995), and monosex culture is successfully adopted to prevent breeding that diverts energy for growth (Mires, 1977; Little & Edwards, 2004). The benefit of culturing monosex populations has been clearly demonstrated in the case of several crustaceans, particularly crabs, crayfishes and freshwater prawns in which the males grow significantly larger than females (Cohen et al., 1981; Sagi et al., 1986; Curtis & Jones, 1995; Triño et al., 1999; Rodgers et al., 2006).

In the giant freshwater prawn *Macrobrachium rosenbergii* (De Man), males grow faster than the females (Cohen et al., 1988; Hulata et al., 1988) and its all male culture was found to be 63% and 60% more profitable than mixed and all female cultures respectively (Nair et al., 2006). In case of mud crab farming, all male culture was more economical than mixed-sex or monosex culture of females (Cholik & Hanafi, 1992; Triño et al., 1999; Khatun et al., 2009). The all male population of crayfish (*Cherax albidus*) grows 68% and 53% faster than all female and mixed-sex populations, respectively (Cortes-Jacinto et al. 2004). Contrary to the faster growth of males

in case of channel catfish, tilapia, giant freshwater prawn, mud crabs and crayfish, in penaeids female shrimps grow faster than males.

Black tiger shrimp, *Penaeus monodon* (Fabricius, 1798) is one of the most important cultured penaeid shrimps because of its fast growth, high survival and good market demand (Cheng & Chen, 1990). Hansford (1991) reported that females of *P. monodon* reached harvestable size in ponds up to a month earlier than males, which could enable in decreasing grow-out period and or increasing pond yield. Reports on several other penaeid species also suggest the advantages of sexual size dimorphism for shrimp farming, as reviewed by Campos-Ramos et al. (2006). Sexual dimorphism with females larger than males was observed in *P. monodon* and Pacific white shrimp *Litopenaeus vannamei* (Boone) in wild populations (Motoh, 1981; Garcia, 1985; Somers et al., 1987) and in shrimp aquaculture (Gopal et al., 2010). Size-dependent sexual dimorphism as evidenced in the growth of *Fenneropenaeus chinensis* and *L. vannamei* females which diverged from males at about 10 g and 20 g, respectively has been reported (Moss & Hennig, 2002). Large and uniform-sized shrimp in female monosex culture might assist in marketing the product, as the price structure depends on size classes.

While most of the trials on all female culture of *P. monodon* were carried out in temperate or subtropical regions, such reports from the tropics are rare. In the present study a comparative assessment of growth performance of *P. monodon* was done under three stocking strategies *viz.*, all male, all female and mixed-sex, with a view to evaluate the possible advantages of an all female monosex culture in this important shrimp species.

Materials and Methods

The present study was performed in the brackish water farm at the College of Fisheries, Cochin, Kerala, India for a period of 100 days. Two thousand post larvae (PL-20) of mean size 41 ± 0.9 mg and 18 ± 0.02 mm from the State Shrimp Hatchery, Varkala, Kerala were stocked in an earthen pond (80 m^2) and reared for about 50 days before starting the experiment to obtain sex differentiated male and female shrimps for the growth experiment. The PL were fed twice daily with a commercial shrimp feed (40% protein content) (Godrej Gold Coin Feeds, Chennai, India) of 1.5 mm pellet size, at a rate of 10% of the shrimp biomass in the pond. Optimum water quality parameters were maintained by regular water exchange. Weekly sampling was done to check the minimum shrimp size at which sex differentiation was possible.

The growth experiments were carried out in 250-l outdoor circular cement cisterns for 50 days, using the pond-grown *P. monodon* juveniles segregated into males and females by hand-sexing. The test animals were adapted to tank conditions by holding them in 1000-l circular fibreglass tanks, provided with continuous aeration for 2 days. For the growth trial, 8 healthy, uniform-sized male (4.46 ± 0.54 g and 8.55 ± 0.30 cm) and female (4.35 ± 0.38 g and 8.54 ± 0.20 cm) juveniles were stocked (equivalent to a density of 12.5 m^{-2}) in each cistern. The treatments were: all male (T_1), all female (T_2) and mixed-sex at 1:1 ratio (T_3), with five replicates in each treatment.

The experimental tanks were filled with water of salinity 18 ± 2 g l^{-1} sourced from the adjacent creek, provided with continuous aeration and shelters for juveniles in the form of two or three 10 cm long PVC pipes, in each tank. Water quality was maintained by exchanging 50% of water on alternate days. Physico-chemical parameters in the tank water *viz.*, temperature – by using mercury thermometer; pH – by using universal indicator solution; dissolved oxygen – by Winkler's method following Strickland & Parsons (1972); salinity – by using salinity refractometer (Atago, Japan); alkalinity, and ammonia (NH_3-N) (by test kits – Merck, Darmstadt, Germany) were monitored every week throughout the experiment.

Two grades (Starter 2 and 3 of 1.5 and 2.0 mm pellet sizes, respectively) of a commercial shrimp feed (Godrej Gold Coin Feeds, Chennai, India) containing fish meal, shrimp meal, soya flour, squid liver powder, wheat flour, minerals and vitamins as the major ingredients (crude protein 40%; fat 6%; crude fibre 3%; ash 12% and moisture 11%) were fed to the juveniles during the experiment. Starter 2 was fed twice daily at a rate of 5% of the shrimp biomass up to 25 days of rearing, after which the juveniles were fed with Starter 3 at 4% of the biomass based on sampling, until the end of the experiment. Left over feed and faecal matter were collected daily by siphoning out using a plastic tube of 3 mm diameter before providing the next day's feeding.

Upon completion of the experiment, all test animals were sampled, and performance under each treatment was analysed with regard to their average

gain in weight (AGW), specific growth rate (SGR), percentage survival, feed conversion ratio (FCR), and protein efficiency ratio (PER) using the following formulae.

$$\text{Survival (\%)} = \frac{\text{Initial number - final number}}{\text{Initial number}} \times 100$$

AGW (g) = Average final weight (g) – Average initial weight (g);

$$\text{SGR (\%)} = \frac{\ln (W2) - (W1)}{\text{Time interval in days}} \times 100,$$

where, W_1 is the initial weight of animal (g) and W_2 is the final weight of animal (g);

$$\text{FCR} = \frac{\text{Average weight of food consumed in dry weight}}{\text{Average live weight gain}};$$

$$\text{PER} = \frac{\text{Wet weight gain of shrimp (g)}}{\text{Crude protein consumed (g)}}.$$

The experiment was set up using a completely randomized design. Biological parameters *viz*., AGW, SGR, percentage survival, FCR and PER for the treatments T_1, T_2 and T_3 were compared using One-Way ANOVA making arcsine transformations wherever necessary. Multiple comparisons of mean values were carried out using Tukey's HSD test. Means of all male and mixed-sex male, and all female and mixed-sex female were compared using two sample Student's *t*-test. Significant differences were determined among treatments at 5% levels (Rangaswamy, 2002).

Results and Discussion

In *P. monodon* postlarvae (PL), external sex differentiation appeared after a period of 35 – 40 days of rearing in ponds (55 – 60 days as PL) when they reached 2.5 g of body weight and 7.0 cm of body length. From day 35 of juvenile rearing in ponds, the beginning of the development of endopodites on the first pair of pleopods into a tubular structure in males, and the appearance of a triangular structure at the base of the last two pairs of pereiopods in females revealed the first external sex differentiation signs. Research on sex differentiation and adoption of female monosex culture in shrimp farming would require determining the gender at early juvenile stages. Sex differentiation in many penaeid species occurs during the second month as PL, as observed in *L. vannamei* in which sex differentiation began when the shrimp reached around 10 g of body weight after 50-90 days of rearing (Campos-Ramos et al., 2006). Development of the endopodite observed in the present study after 55 days as PL agrees with previous finding in *L. vannamei*. The size and weight of *P. monodon* in the present study were lower than those in *L. vannamei* around the same age during the beginning of external sex differentiation (Campos-Ramos et al., 2006).

Survival rates of juveniles, which ranged from 95 - 98% (Fig. 1), showed no significant difference among treatments, allowing yields to be affected more by animal size than number. Uniform water quality was maintained in treatment ponds throughout the experiment (Table 1).

Average gain in weight (AGW), specific growth rate (SGR), food conversion ratio (FCR) and protein efficiency ratio (PER) of all male, all female and

Table 1. Water quality parameters in rearing tanks of juvenile *Penaeus monodon*

Parameters	Weeks						
	1	2	3	4	5	6	7
Water temperature (°C)	28.6 ± 0.00	30.3 ± 0.15	30.4 ± 0.17	30.6 ± 0.48	28.4 ± 0.42	28.4 ± 0.41	28.4 ± 0.53
pH	7.7 ± 0.31	7.7 ± 0.32	7.8 ± 0.32	7.8 ± 0.26	7.8 ± 0.32	7.6 ± 0.30	7.9 ± 0.23
Dissolved oxygen (mg l^{-1})	7.3 ± 0.30	7.2 ± 0.30	7.4 ± 0.31	6.8 ± 0.70	7.3 ± 0.33	7.0 ± 0.70	7.0 ± 0.70
Salinity (g l^{-1})	20.0 ± 0.00	18.0 ± 0.00	18.0 ± 0.00	18.0 ± 0.00	16.0 ± 0.00	16.0 ± 0.00	18.0 ± 0.00
Alkalinity (mg l^{-1})	92.67 ±11.00	98.00 ± 8.62	102.67 ± 7.04	82.00 ± 3.69	104.0 ± 7.37	88.67 ± 2.29	92.00 ± 4.14
Ammonia (mg l^{-1})	0.00 ± 0.000	0.05 ± 0.006	0.00 ± 0.000	0.06 ± 0.006	0.07 ± 0.005	0.06 ± 0.017	0.05 ± 0.006

mixed-sex are shown in Fig. 2. Analysis of variance of the data showed significant difference in gain in weight among the three treatments. Multiple comparisons by Tukey's HSD test revealed that weight gain was higher ($p<0.05$) in all female followed by all male and mixed-sex. Comparison of average gain in weight using Student's t-test showed no significant growth difference between males cultured in the all male (5.91 ± 1.23 g) and those in the mixed-sex treatments (5.78 ± 0.98 g). However, the average weight gain was significantly higher ($p<0.05$) for females in the all female culture (8.24 ±1.39 g) in which they grew 43% faster than those in the mixed-sex. Females grew only 1.1% better than the males in mixed-sex culture while the females grown separately in all female monosex culture, grew approximately 40% faster than the males grown in all male monosex culture.

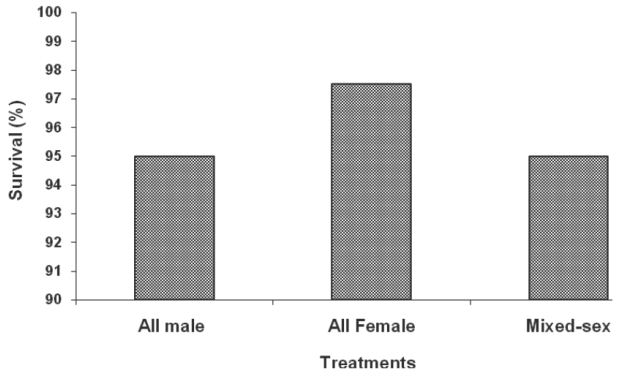

Fig. 1. Percentage survival of *Penaeus monodon* juveniles during rearing period

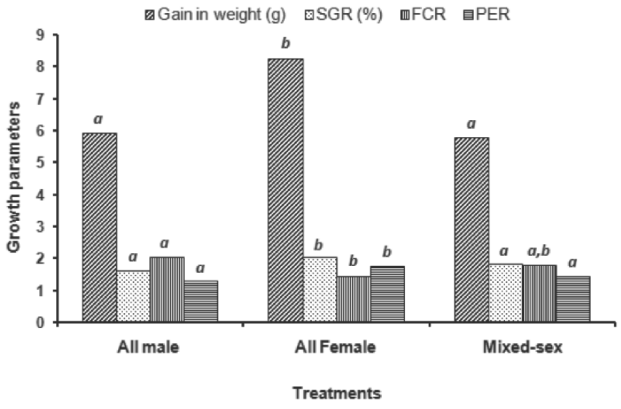

Fig. 2. Gain in weight, Specific growth rate (SGR), Feed conversion ratio (FCR) and Protein efficiency ratio (PER) of *Penaeus monodon* juvaniles. (Superscripts on the bars indicate significant differences)

Mean SGR of all female (2.04 ± 0.21%) was significantly higher than mixed-sex (1.80 ± 0.21%) and all male (1.62 ± 0.21%) ($p<0.05$). Likewise the best FCR and the highest PER were obtained in all female treatment (1.43 ± 0.29 and 1.75 ± 0.25, respectively), followed by mixed sex (1.79 ± 0.29 and 1.41 ± 0.25, respectively), while all male treatment yielded the highest FCR and the lowest PER (2.01 ± 0.29 and 1.27 ± 0.25, respectively).

The advantage of having only females of *P. monodon* in culture ponds is clearly evident from the present study. While there was no difference in growth of males between all male and mixed-sex cultures, the differences in growth of females in all female culture were significantly higher than females in mixed-sex culture and males in monosex culture over a period of 100 days. It is interesting to see that given the same conditions, when females and males were grown together in mixed-sex culture, the females were unable to grow as fast as they could in all female culture. We must then assume that *P. monodon* males might exert some kind of growth inhibition among co-habiting females, possibly a reproductive interaction, resulting in comparatively reduced female growth. Perhaps this may not be similar to the male-female or male-male interactions limiting growth of females reported in case of crayfish (Rodgers et al., 2006) and *M. rosenbergii* (Nair et al., 2006; Pillai et al., 2007), but needs further behavioural studies. Hansford & Hewitt (1994) reported that females of *P. monodon* grew 16% faster when grown in isolation compared to those in mixed-sex culture. Sexually dimorphic growth in pond-grown *P. monodon* was not observed below a mean weight of 28 g in Taiwan (Liao, 1977; Cheng & Chen, 1990), while in Australia Hansford (1991) reported a significant difference in the size of male and female shrimps at a mean size around 13 g wet weight. In commercial culture ponds in India, *P. monodon* males and females were of same size (22 g) 70 days of stocking, but beyond this period the size superiority of females in the pond was very evident, ranging from 6 – 10 g (Gopal et al., 2010). Other studies on this species concurred that at the end of culture period, females grew faster than males (Chow & Sandifer, 1991; Moss & Hennig, 2002), which agreed with the present study in *P. monodon*.

Mechanisms underlying growth dimorphism in *P. monodon* due to behavioural, physiological and/or environmental differences is still not clearly understood. Weight of shrimp might be more important

than age in determining the onset of sexual dimorphism for growth in *P. monodon* (Gopal et al., 2010). The faster growth of females in monosex culture might be due to the more efficient utilization of feed by females. Similar observation has also been reported for another crustacean, the fairy shrimp *Branchinecta gigas* (Lynch) that is sexually dimorphic in growth (Daborn, 1973). However, in *L. vannamei* it was observed that the female superiority in growth over males was not modulated by behavioural interactions or feed competition (Moss & Hennig, 2002). Efficient feed utilization by females in all female culture in the present study might have been reflected in the lowest FCR obtained in all female culture. FCR values obtained in the present study were lower than those reported by Hansford & Hewitt (1994) where FCR of *P. monodon* males tended to be lower than for females. Efficient use of food by female shrimps would make monosex culture highly attractive, as feed costs account for up to 40-50% of the overall production costs (Hardman et al., 1991).

Results of this study provide further support for all female culture of *P. monodon*. In addition, results indicate that females may have some physiological advantages with respect to growth, which would confer positive benefits during grow-out. This indicates that farming of monosex females of *P. monodon* could be more economical than the present practice of mixed sex culture. However, further studies, especially on the economic aspects are recommended before all female culture could be adopted as a standard practice in commercial shrimp farming.

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