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Effect of different food items on the survival and growth of *Farfantepenaeus paulensis* (Pérez-Farfante 1967) postlarvae

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Abstract

The effect of different food items on growth and survival was assessed in four feeding experiments conducted consecutively using distinct *Farfantepenaeus paulensis* (Pérez-Farfante) postlarval growing stages: (1) PL_1–PL_4 (i.e. from postlarvae 1-day old to postlarvae 4 days old); and (2) PL_4–PL_{10}; (3) PL_{10}–PL_{18} and (4) PL_{18}–PL_{30}. For each trial, 10 feeding treatments were tested in triplicate: Unf, unfed shrimp; Tt, *Tetraselmis chuii*; Ch, *Chaetoceros calcitrans*; C, commercial diet; AC, decapsulated *Artemia* cysts; C+Ph, commercial diet and phytoplankton combination; FA, frozen *Artemia* nauplii; A, live *Artemia* nauplii; A+Ph, *Artemia* nauplii and phytoplankton combination and Mix, mixture of phytoplankton, live *Artemia* nauplii and commercial diet. Postlarvae feed phytoplankton (i.e. Tt or Ch) exclusively exhibited low growth and survival. The best results for growth and survival were observed in the A, A+Ph and Mix treatments. Frozen *Artemia* nauplii was found to be suitable for younger postlarvae (PL_{1-10}), whereas AC may be offered from PL_4 to PL_{30}. In general, the present findings indicated that even at an early postlarval stage, *F. paulensis* presents a high degree of carnivory, and a diet containing *Artemia* is recommended.

Keywords: diet, *Farfantepenaeus paulensis*, postlarvae, growth, survival

Introduction

The pink shrimp *Farfantepenaeus paulensis* has been found to be very suitable to culture conditions in southern Brazil (Peixoto, Wasielesky & Louzada 2003) and is the species of choice for pen culture in the Patos Lagoon estuary (Wasielesky, Cavalli, Santos & Peixoto 2003). Although controlled reproduction of *F. paulensis* has been successfully achieved for wild-caught and pond-reared broodstock (Cavalli, Scardua & Wasielesky 1997; Peixoto, Cavalli, Wasielesky, D'Incao, Krummenauer & Milach 2004), little information is available on its nutritional requirements during the postlarval phase. To make seedstock production more reliable, recent efforts have focused on identifying key limitations in feed management to improve growth and survival during culture of *F. paulensis* larvae.

The natural diet of penaeids is known to change with age or size. The reasons why this occurs have been attributed to changes of habitat and improvements in carnivore behaviour as shrimp grow (Dall, Hill, Rothlisberg & Staples 1990). When shrimp attain the postlarval phase, they progressively switch from a planktonic to a benthic behaviour, which is accompanied by alterations in their digestive system and enzyme activity that facilitate digestion and assimilation of different food items (Lovett & Felder 1989, 1990; Jones, Yule & Holland 1997; Lemos, Hernandez-Cortés, Navarrete, Garcia-Carreño & Phan 1999).

Identifying the ideal diet for penaeid larviculture is a primary problem and various aspects must be considered to attain a feeding protocol that supplies the needs of the larvae and culturists. From the practical viewpoint of culturists, a good diet would be readily available, cost-effective and versatile in application, whereas for the larvae, the diet must have adequate physical, i.e. purity, availability, acceptability, and

nutritional, i.e. digestibility, energetic and nutrient requirements, characteristics for the target species (Léger & Sorgeloos 1992). While feeding studies have provided information on the contribution of various food resources to postlarvae (PL) growth and survival (Lovett & Felder 1990; Moss 1994; Rodriguez, Le Vay & Jones 1994; Dittel, Epifanio, Cifuentes & Kirchman 1997; Jones *et al*. 1997), a specific feeding protocol would be valuable for reducing massive mortalities and disparities in size during *F. paulensis* larviculture.

This study investigated the effects of distinct food items on the growth and survival of *F. paulensis* PL at four developmental stages.

Materials and methods

The experiments were carried out at the Laboratory of Mariculture, University of Rio Grande, Southern Brazil. *Farfantepenaeus paulensis* PL were produced in the laboratory from wild broodstock captured off shore in Southern Brazil (27°S) at depths of 35–40 m. These larvae (i.e. from nauplii to PL) were cultured in 10 tonne tanks at densities of 100–200 larvae m^{-2} for 12 days. Seawater (29–33 g L^{-1}) was exchanged daily (50–90%), and the temperature ranged from 25 to 28 °C. According to the ontogenetic phase, larvae were fed using microalgae (*Chaetoceros calcitrans* and *Tetraselmis chuii*), *Artemia franciscana* (PRIME, Great Salt Lake, Midvale, UT, USA) nauplii and commercial diet (LANSY, Inve Aquaculture, Ogden, UT, USA).

Four feeding trials were conducted consecutively using PL with different ages: (1) PL_1–PL_4 (i.e. 1-day-old PL to 4-day-old PL), (2) PL_4–PL_{10}, (3) PL_{10}–PL_{18} and (4) PL_{18}–PL_{30}. The mean body weight (± SE) of PL_1, PL_4, PL_{10} and PL_{18} at the beginning of each trial was 0.44 mg (± 0.02), 0.90 mg (± 0.09), 1.47 mg (± 0.41) and 5.12 mg (± 0.32) respectively. For each trial, 10 treatments were tested in three replicates (Table 1).

At the beginning of each trial, 50 PL were randomly sampled, individually weighed and used as a reference. Each treatment consisted of 150 individuals randomly divided into three groups with 50 PL each. Postlarvae were acclimated and starved for 8 h before each trial. Groups of PL were reared in 5-L plastic containers filled with 4.5 L of filtered seawater (28 g L^{-1} salinity) and with a constant air supply. A 130 cm long × 115 cm wide × 10 cm high water bath accommodated all 30 containers (three replicates × 10 treatments) used in each trial. Two heaters with thermostats were placed inside the bath to keep the water temperature constant (25–26 °C). Additionally, a small water pump was used to circulate the warmed water around the containers to homogenize the temperature. Artificial illumination was used, simulating a 12L:12D photoperiod. Daily, faeces and uneaten feed were recovered by siphoning and water was renewed (90%). In order to avoid water deterioration, food items were offered slightly in excess and divided into two daily meals (08:00 and 17:00 hours).

Statistical analysis

At the end of each trial, all shrimp were counted and weighed. Weight and survival differences among treatments were analysed using one-way ANOVA performed on data corrected for heteroscedasticity by

Table 1 Description of the feeding treatments tested in postlarvae of *Farfantepenaeus paulensis* of different ages

Treatment	Description
Unf	Unfed
Ch	Monoculture of the diatom *Chaetoceros calcitrans* (20×10^4 cells mL^{-1})
Tt	Monoculture of the green algae *Tetraselmis chuii* (20×10^4 cells mL^{-1})
C	Commercial diet Lansy PL (15% of the shrimp body weight)
C+Ph	Combination of commercial diet Lansy PL (15% of the shrimp body weight) and phytoplankton (*C. calcitrans*+*T. chuii*; 10×10^4 cells mL^{-1} of each algae)
AC	Decapsulated *Artemia* cysts (12 cysts mL^{-1})
A	Live *Artemia* nauplii (12 nauplii mL^{-1})
FA	Frozen *Artemia* nauplii (12 nauplii mL^{-1})
A+Ph	Combination of live *Artemia* nauplii (12 nauplii mL^{-1}) and phytoplankton (*C. calcitrans*+*T. chuii*; 10×10^4 cells mL^{-1} of each algae)
Mix	Combination of live *Artemia* nauplii (12 nauplii mL^{-1}), phytoplankton (*C. calcitrans*+*T. chuii*; 10×10^4 cells mL^{-1} of each algae) and commercial diet Lansy PL (15% of the shrimp body weight)

the transformations: weight (log (x)) and survival (arcsin $x^{0.5}$). Tukey' s range test was used to assess the relationship between the diets.

Results

At the end of the PL_{1-4} trial, survival was above 70% in all treatments, but values above 90% were observed in the Tt, A, A+Ph and Mix treatments (Fig. 1a). During this short rearing period, 72.7% of the PL survived even without food addition. The weight gain at the end of this trial was significantly different ($P < 0.05$) among treatments, with the highest final weights recorded for A+Ph and Mix treatments (Fig. 1a).

The superior growth and survival in the treatments containing live *Artemia* (i.e. A, A+Ph, Mix) became more evident in the PL_{4-10} trial (Fig. 1b). Intermediary values of weight and survival were observed in the C, AC and FA treatments. Besides the poor growth performance in the phytoplankton treatments, which were not significantly different ($P > 0.05$) from the Unfed treatment, feeding Tt resulted in a mean survival rate of 56%.

As observed in the previous trial (i.e. PL_{4-10}), PL_{10-18} had significantly higher weight and survival in the A, A+Ph and Mix treatments (Fig. 1c). Although the growth of PL-fed *Artemia* cysts (AC) increased in comparison with the previous trial, an opposite trend was observed for FA treatment (Fig. 1b and c).

In the last trial (PL_{18-30}), the survival rate was above 80% in most of the treatments, except for Unf, Tt and Ch (Fig. 1d). However, the highest final weight was recorded in the treatments containing live *Artemia*, followed by the AC treatment.

Overall, *F. paulensis* PL feeding exclusively on phytoplankton (i.e. Tt or Ch) exhibited survival and growth similar to those of the unfed treatment. However, *T. chuii* tended to be more efficient in supporting survival than *C. calcitrans*. The best results for growth

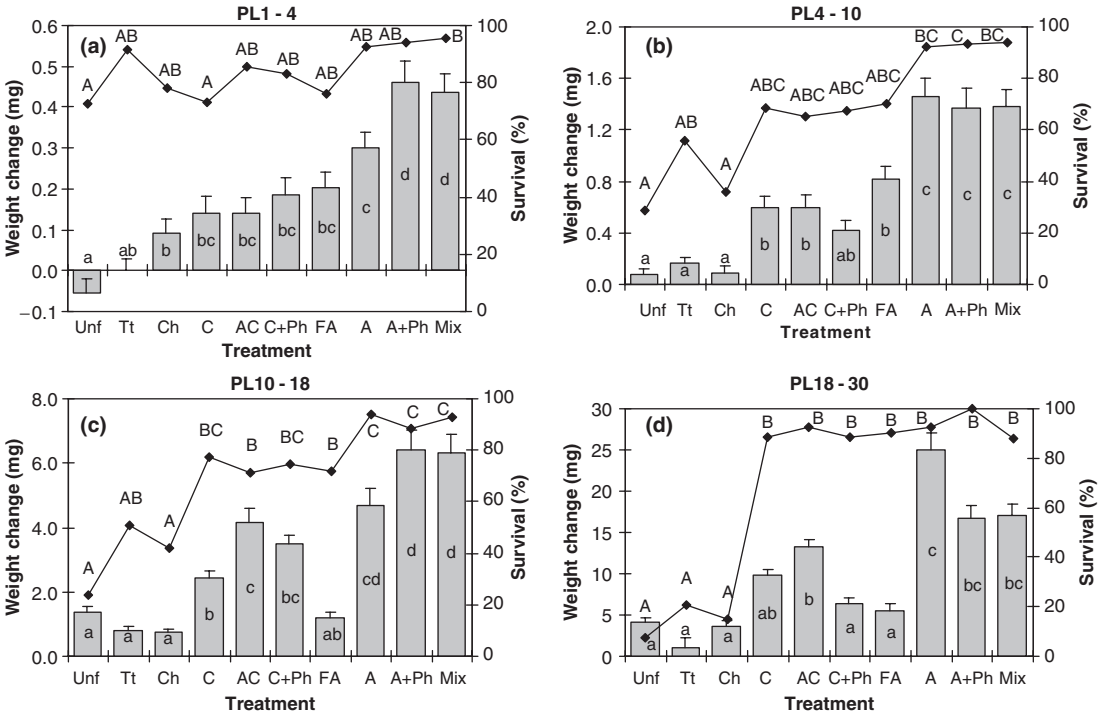

Figure 1 Changes in body weight (final − initial weight) (bars) (+SE) and per cent survival (lines) of *Farfantepenaeus paulensis* postlarvae (PL) submitted to different feeding treatments in four sets of experiments: (a) from PL_1 to PL_4; (b) from PL_4 to PL_{10}; (c) from PL_{10} to PL_{18} and (d) from PL_{18} to PL_{30}. Common lowercase letters (comparisons of weight change among treatments) and uppercase letters (comparisons of survival among treatments) denote no significant difference at the $\alpha = 0.05$ level by Tukey's multiple range test. Unf, unfed shrimp; Tt, *Tetraselmis chuii*; Ch, *Chaetoceros calcitrans*; C, commercial diet; AC, decapsulated *Artemia* cysts; C+Ph, commercial diet and phytoplankton combination; FA, frozen *Artemia* nauplii; A, live *Artemia* nauplii; A+Ph, *Artemia* nauplii and phytoplankton combination; Mix, mixture of phytoplankton, live *Artemia* nauplii and commercial diet.

and survival were observed in the A, A+Ph and Mix treatments. The growth performance of *F. paulensis* submitted to FA was reduced in older individuals (PL_{10-18} and PL_{18-30}). In contrast, body weight increased with PL age in the AC treatment. Providing phytoplankton together with the commercial diet had no significant impact on growth and survival when compared with individuals fed the commercial diet exclusively.

Farfantepenaeus paulensis PL were observed to exhibit a planktonic behaviour from PL_1 to PL_8. After this period, they started to shift to a benthic habit, spending more time on the walls and at the bottom of the containers.

Discussion

Experience from penaeid larviculture has shown that the first weeks of postmetamorphic life (postlarval phase) represent a critical period during which high rates of mortality are encountered (Lovett & Felder 1990). This critical period has been related to changes in digestive enzyme activity that accompany the change in habit (i.e. planktonic to benthic), so that shrimp can efficiently digest and assimilate a new diet (Lovett & Felder 1990; Dall 1992; O'Brien 1994; Rodriguez *et al.* 1994). Therefore, successful larviculture of penaeids is dependent on the addition of known quantities of live feeds (i.e. microalgae and *Artemia*) to the PL-rearing tanks (Smith, Biedenbach & Lawrence 1992). The selection of natural prey species for larviculture is generally based upon ease of culture in laboratory, nutritional quality and preferences of the target species (Jones *et al.* 1997).

Penaeid shrimp has been proven to have variable ability to utilize different species of microalgae, which can have different forms, sizes and nutritional composition (Gleason & Zimmerman 1984; Gleason 1986; McTigue & Zimmerman 1991; Moss 1994). In the present work, *F. paulensis* PL feeding exclusively on phytoplankton (i.e. *T. chuii* or *C. calcitrans*) had a growth performance similar to unfed individuals. Similar results were observed by Aseredo, Mello, Aquini, Kanthack and Vinatea (1998) for *F. paulensis* PL (from PL_1 to PL_5), which presented low consumption of microalgae (*C. calcitrans*) and higher growth on animal diet (live *Artemia*). These authors argued that there is no need for microalgae addition for the PL diet in intensive culture systems. Although the importance of microalgae addition to the maintenance of water quality is well known, this was not evaluated in the present work due to the high daily water exchange (90%).

In comparison with the unfed treatment, *F. paulensis* fed phytoplankton, especially *T. chuii*, had higher survival rates. According to Gleason and Zimmerman (1984), even though the growth rates of postlarval *F. aztecus* fed plant diets were not comparable to those obtained for shrimp fed animal protein-based diets, plant materials may provide a maintenance diet during periods in which the appropriate food items are not available. However, the capacity of *F. paulensis* PL to survive when feeding exclusively the microalgae species tested here is limited to a few days.

The provision of phytoplankton, together with the artificial feed, did not improve PL growth and survival compared with those fed exclusively on the commercial diet. Likewise, *Fenneropenaeus indicus* had poor growth performance feeding on artificial diet during the first two weeks of postlarval development (Ribeiro & Jones 2000). These authors suggested that this may be related to the low digestive capacity of PL after metamorphosis, as digestive enzymes were present in low levels. Conversely, Le Vay, Rodríguez, Kamarudin and Jones (1993) observed superior growth responses when *Marsupenaeus japonicus* larvae (until PL_1) was fed with *C. gracilis* in addition to artificial diet. According to these authors, the algae may provide a source of readily digestible protein or might supply some factor that improves the ability of larvae to meet their nutritional requirements from artificial diet. Further investigations on the efficiency of artificial diets are required for penaeid larviculture, as they represent a supplementary feed when little or no natural food is available.

There are alternative ways to offer *Artemia* during shrimp larviculture as decapsulated cysts or frozen nauplii (Smith *et al.* 1992). Decapsulated cysts are the most concentrated energy form of *Artemia*, containing up to 50% more energy than the first instar nauplii (Léger & Sorgeloos 1992). Frozen *Artemia* is generally used on an emergency basis, but its continued use not only deteriorates water quality but also larvae may become accustomed to feeding on dead *Artemia* and may not go back to capturing live prey (Smith *et al.* 1992). The present study showed that *F. paulensis* PL are able to survive and grow when fed only frozen *Artemia* or decapsulated cysts. Therefore, either forms can be used as an alternative food item. Nevertheless, the present results indicate that frozen *Artemia* is recommended only for younger individuals (PL_{1-10}), whereas decapsulated cysts may be offered from PL_4 to PL_{30}.

The current study found evidence that *F. paulensis* PL fed diets containing live *Artemia* alone or combined with phytoplankton and artificial feed showed higher growth. In accordance, *Artemia* nauplii also promoted consistently higher growth and survival than artificial diet during the first 2 weeks of postlarval development of *F. indicus* (Ribeiro & Jones 2000). Rodriguez *et al.* (1994) suggested that *C. gracilis* may improve the digestion of *Artemia* by elevating the trypsin activity levels in *M. japonicus* (from mysis to PL). The growth performance of *Litopenaeus setiferus* and *F. aztecus* PL was higher when fed a mixed animal and plant diet (*Artemia*+*Skeletonema* sp.) when compared with the same diets offered alone (McTigue & Zimmerman 1991). Similarly, the youngest *F. paulensis* PL (PL_{1-4}) in the present study showed higher growth when fed *Artemia* combinations (Ph+A and C) in comparison with *Artemia* alone. However, older individuals ($>PL_4$) had similar growth between treatments with *Artemia* alone and *Artemia* combinations. This is likely due to a more pronounced carnivorous habit of older *F. paulensis* PL and a higher predatory ability to utilize animal material in their diet.

In general, the present findings indicated that even at an early postlarval stage, *F. paulensis* show a high degree of carnivory and therefore the provision of food items of animal origin is recommended as a way to improve growth and survival rates during the postlarval phase. Although the direct use of microalgae as a nutrition source seems to be limited, the addition of phytoplankton in *F. paulensis* larviculture must be further investigated focusing on its contribution to the digestibility and water quality.

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