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Growth performance of the white shrimp *Litopenaeus vannamei* reared under time- and rate-restriction feeding regimes in a controlled culture system

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Abstract

When shrimp prices are low there can be economic pressure to restrict or cease feeding temporarily. Nevertheless, there is little or no information available on the effects of moderate or severe feed restriction on growth performance of *Litopenaeus vannamei*. The present study aimed at evaluating the effect of time- (TR) and rate-restricted feeding (RR) on the growth performance of *L. vannamei* raised in controlled conditions. Three separate experiments were carried out in a clear water rearing system, composed of 500-l tanks. In experiment 1, 2.8 ± 1.20 g shrimp were stocked in 20 tanks at 46 shrimp/m^2. Animals were randomly submitted to four experimental treatments (2, 3, 4, 5 h/day of feed availability) and one control (6 h/day) for 96 days. In experiment 2, 9.1 ± 1.44 g shrimp were stocked in 16 tanks at 36 animals/m^2 and reared for 28 days. Shrimp in the control group were fed to satiation, while in RR treatments feeding rates were reduced to 25%, 50% and 75%. In experiment 3, 9.1 ± 1.95 g shrimp were stocked in eight tanks at 40 shrimp/m^2. The experiment consisted of collecting feed remains at consecutive 1-h intervals, starting 1 h after first feed delivery up to 8 h. Treatments were composed of 9 replicates, each with an uninterrupted observation period of 9 days. In all trials, shrimp were fed a 39.6% crude protein diet delivered in PVC feeding trays. Shrimp performed better in treatments under longer TR periods. Although survival was not affected by TR, yield and weekly growth were significantly higher for shrimp fed longer than 3 h/day. There were no statistical differences in BW when shrimp were fed to apparent satiation versus under a 25% and 50% RR ($P > 0.05$). On the other hand, final BW of shrimp fed at 75% restriction was significantly lower ($P < 0.05$) than that of shrimp fed to apparent satiation and with 25% restriction. In contrast, under the maximum RR (75%) shrimp showed the poorest feed efficiency and development index ($P < 0.05$). Shrimp feed intake was proportional to feed exposure and BW, not ration size. Feed intake occurred in a continuous and uniform fashion over the 8-h feed exposure period. On average, hourly feed intake reached 4.09% BW. The present study has shown that longer and continuous feed exposure periods enhanced shrimp growth performance and feed intake. Also, this study has indicated it is possible to moderately reduce daily feeding rates without detrimental effects in *L. vannamei* survival, growth and feed efficiency.

Keywords: Shrimp; Feeding; Performance; Litopenaeus; Feed restriction

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1. Introduction

Feed is a major expense in farm-raised shrimp production. In shrimp grow-out, farm managers usually adopt feeding tables that provide feed near to apparent satiation and that is available during all day to the animals. However, when shrimp prices are low, there can be economic pressure to restrict or cease feeding temporarily. In shrimp farming, restricted feeding tables target desired FCRs, but may also lead to detrimental growth under adverse culture conditions (Nunes, 2003, 2004). Nevertheless, there is little or no information available on the effects of moderate or severe feed restraint on the growth performance of the white shrimp *Litopenaeus vannamei*.

In manipulative feeding experiments, feed available to the animals can be restricted in two different ways: (1) by decreasing daily feed allotment or (2) by decreasing the time for feeding (Pirhonen and Forsman, 1998). In the first approach, short-term, severe feed restrictions have reduced growth and fillet yield of Atlantic salmon (Einen et al., 1998, 1999), brown trout (Regost et al., 2001), and channel catfish (Bosworth and Wolters, 2005; Weber and Bosworth, 2005).

In the other case, trials on time-restricted feeding are scarce or rare. Alanärä (1992) working with cage-reared rainbow trout concluded that two feeding periods per day, each of about 2 h, are sufficient for optimal growth. In whitefish, Koskela et al. (1997) found that growth among the fish and the length of the feeding period had no significant effect upon feed conversion.

However, these studies have not tested feed-restricted levels in relation to animal apparent satiation, but only continuous or intermittent feed deprivation periods. Also, there is no published work on time- and rate-restricted feeding with penaeid shrimp. In this study, we have hypothesized that it is possible to restrict to some extent *L. vannamei* period of feed exposure and feeding rates without hampering shrimp growth. The present work aimed at evaluating the effects of time- and rate-restricted feeding on the growth performance of *L. vannamei* raised under controlled conditions.

2. Material and methods

2.1. Culture system, shrimp and experimental design

Three experiments were carried out at the indoor shrimp tank facilities of the Laboratório de Ração e Nutrição de Camarão Marinho (LRNCM) located at Instituto de Ciências do Mar (Labomar/UFC), State of Ceará, Brazil. Experiments 1 and 2 investigated the effects of time- and rate-restricted feeding on the growth performance of *L. vannamei*, respectively. Experiment 3 evaluated shrimp feed intake in relation to an excess meal and period of feed exposure.

The clear water rearing system is composed of 71 polypropylene tanks of 500 l in volume (bottom area of 0.57 m^2) arranged in individual cells of four or five tanks. Tanks in each cell were interconnected by a sand filter and an electrical pump which recirculated water at a capacity of 2700 l/h. Constant aeration was supplied by three 2.0-hp blowers. Animals were submitted to a 12 h light cycle, which began at 0630 h and ended at 1830 h.

In experiment 1, shrimp with a mean body weight of 2.8±1.20 g (mean±standard deviation; n=30) were stocked in 20 tanks at 46 shrimp/m^2. Animals were randomly submitted to four experimental treatments (2, 3, 4 or 5 h/day of feed exposure) and one control (6 h/day of feed exposure) for 96 days. Shrimp were obtained from a commercial shrimp farm (Artemisa Aqüicultura S.A, Acaraú, Ceará, Brazil) 245 km from the laboratory. Four replicates were assigned to each treatment or control group.

In experiment 2, shrimp of 9.1±1.44 g (n=160) from the laboratory's own supply were stocked in 16 tanks at 36 animals/m^2 and reared for 28 days. The experiment was composed of three treatments and one control, each with four replicate tanks. Shrimp from the control group were fed to apparent satiation following adjusted feeding rates based on the maximum meal (MM) determined for *Farfantepenaeus subtilis* (Nunes and Parsons, 2000). The MM is given by the power function $MM=0.0931BW^{0.6200}$, where BW is the shrimp wet body weight. In the experimental treatments, the control group feeding rates were reduced to 25%, 50% and 75% (Table 1).

In experiment 3, shrimp of 9.1±1.95 g (n=194) were stocked in 8 tanks at 40 shrimp/m^2. Animals were obtained from the laboratory's own stock. Prior to stocking, all shrimp were individually weighed. The experiment consisted of collecting feed remains at consecutive 1-h intervals, starting 1 h after first feed delivery up to 8 h. Treatments were composed of nine replicates, each with an uninterrupted observation period of 9 days. The time of feed exposure was shifted daily for each tank.

2.2. Feed and feeding

In all experiments, animals were fed a pelleted shrimp feed (Camaronina 35 hp, Purina do Brasil, São

Table 1
Feeding rates (% shrimp body weight) adopted in the rate-restricted feeding experiment with *L. vannamei*

Shrimp wet body weight (g)		Feeding rates (% of shrimp body weight)			
Initial	Final	0 [a]	25	50	75
8.0	8.9	4.5	3.4	2.3	1.1
9.0	9.9	4.0	3.0	2.0	1.0
10.0	10.9	3.5	2.6	1.8	0.9
11.0	11.9	3.0	2.3	1.5	0.8
12.0	12.9	2.5	1.9	1.3	0.6
13.0	13.9	2.0	1.5	1.0	0.5

Ration size was adjusted weekly based on shrimp growth. Values of 25, 50 and 75 indicate the percentage reduction in ration size using the control as the baseline.

[a] Feeding rates to allow shrimp to reach apparent satiation (Nunes and Parsons, 2000).

Lourenço da Mata, Pernambuco, Brazil), with 39.6±0.6% crude protein and 9.3±0.9% lipid. Feed was delivered in PVC feeding trays with 14.3 cm of diameter and 3.5 cm of rim height. After this period, trays were recovered and all feed remains collected for weighing. In experiments 1 and 2, trays were recovered after 1 h and all uneaten feed collected, weighed and discarded. For these experiments, shrimp were fed 6 days a week.

To evaluate the effects of a time-restricted feeding regime (experiment 1), feed was delivered for 2 h/day (at 0700 and 1700 h), 3 h/day (at 0700, 1100 and 1500 h), 4 h/day (at 0700, 1000, 1300 and 1500 h), 5 h/day (at 0700, 0900, 1200, 1500 and 1700 h) and 6 h/day (at 0700, 0900, 1100, 1300, 1500 and 1700 h). In the rate-restricted study (experiment 2), feeding for all groups were scheduled to 0700, 1000, 1300 and 1600 h.

In experiment 3, shrimp were fed ad libitum, following a fixed feeding rate of 4.8% in relation to the stocked biomass. All feed was delivered in feeding trays, once a day at 0700 h. Feed intake was calculated relative to ration size (CRS) and shrimp body weight (CBW), given by the equations: CRS=(Cs/Fd)100 and CBW=(Cs/SB)100, where Cs is the apparent feed intake in a dry weight basis (Carvalho and Nunes, in press), Fd is the amount of feed delivered and SB is the stocked shrimp biomass.

2.3. Sample collection and performance indicators

In experiments 1 and 2, shrimp were counted and sampled fortnightly or weekly, respectively, to adjust feeding rates and to determine their growth performance. A total of 25% of the population of each tank was collected, weighed individually and returned to their respective tank. At harvest, all remainder animals were weighed individually and counted. Based on these evaluations, shrimp survival, yield (final biomass/m^2), weekly weight gain (final weight − initial weight / weeks of rearing), final biomass (average shrimp final weight × number of remaining of shrimp), feed conversion ratio (FCR, apparent feed intake/biomass gained), feed efficiency (biomass gained / apparent feed intake × 100) and development index (growth rate × survival) were determined.

Apparent feed intake (Cs) was calculated based on feed remains from feeding trays. Apparent feed intake (Cs) was determined for each feeding treatment by the equation: $Cs=\sum[(Fd\times DM_i)-(Fc_i\times WA_i)]$, where: Cs= apparent feed intake; Fd=amount of feed delivered, and; Fc_i=amount of feed remains in feeding trays at

Table 2
Biweekly growth of *L. vannamei* reared in a clear water tank system

Day	Period of feed exposure (h/day)				Control	ANOVA *P*
	2	3	4	5		
7	4.0±1.22[a,b]	3.7±0.95[a,b]	3.3±1.04[a]	4.3±0.95[b]	3.8±0.92[a,b]	<0.05
22	5.1±1.19	5.19±1.17	5.4±1.11	5.8±1.03	5.5±1.03	>0.05
36	5.4±1.28	6.4±1.46[a]	6.8±1.16[a]	7.2±1.25[a]	7.3±1.06[a]	<0.05
50	7.0±1.44[a]	7.8±1.30[a,b]	9.3±1.68[c]	8.9±1.38[b,c]	9.0±1.22[c]	<0.05
64	8.1±1.37[a]	9.4±1.53[a,b]	10.6±2.08[b,c]	10.9±1.54[c]	10.7±1.54[b,c]	<0.05
78	9.4±1.82	11.2±2.08[a]	11.6±1.79[a]	12.4±2.41[a]	11.9±1.44[a]	<0.05
82	10.7±1.78	13.7±1.83[a]	12.9±2.24[a]	13.7±2.05[a]	13.7±2.16[a]	<0.05
96	11.7±2.44[a]	13.8±2.96[b]	13.1±2.55[a,b]	14.2±2.51[b]	15.0±2.00[b]	<0.05
CV	20.8%	21.4%	19.5%	17.6%	13.4%	–

Animals were fed under four time-restricted feeding regimes and one control (6 h/day of feed exposure). Each value represents the mean body weight (g)±standard deviation of 24 shrimp sampled from four tanks. Lines with common letters denote non-significant differences between treatments at the α=0.05 level by Scheffé's Multiple Range Test. Coefficient of variation (CV) refers to the mean body weight and standard deviation of shrimp at harvest.

Table 3
Effect of time-restricted feeding on the growth performance of *L. vannamei* raised in 500-l tanks for 96 days (mean±S.D.; $n=4$; initial weight: 2.8±1.20 g)

Feed exposure (h/day)	Survival (%)	Yield (kg/m^2)	Growth (g/week)	Final biomass (kg/tank)	FCR
2	95.20±0.04	0.14±0.01[b]	0.51±0.06[b]	0.168±0.02[c]	3.20±0.36[b,c]
3	94.90±0.05	0.14±0.03[b]	0.52±0.03[b]	0.176±0.02[b,c]	3.30±0.37[b]
4	92.30±0.08	0.43±0.20[a]	0.65±0.07[a]	0.209±0.03[a,b,c]	2.72±0.33[a,b]
5	92.30±0.05	0.60±0.06[a]	0.68±0.02[a]	0.225±0.02[a,b]	2.61±0.05[a,c]
Control[a]	98.00±0.04	0.64±0.04[a]	0.71±0.01[a]	0.254±0.06[a]	2.46±0.06[a]
ANOVA *P*	>0.05	<0.05	<0.05	<0.05	<0.05

Water quality parameters were kept at 28.9±0.7 °C ($n=2438$), 39±1.7‰ salinity ($n=3300$) and 7.6±0.24 pH ($n=3278$). Columns with common non-superscript letters denote non-significant differences between treatments at the α=0.05 level by Scheffé's Multiple Range Test.
[a] 6 h/day of feed exposure.

time *i*. Feed dry matter leaching (DM_i) and feed water absorption (WA_i) were evaluated in 500-l tanks without stocked shrimp following the methodology described by Carvalho and Nunes (in press). Water temperature, salinity (ATAGO hand refractometer, Japan) and pH (YSI pH 100, Yellow Springs, USA) from all tanks were measured and recorded daily.

2.4. Statistical analysis

Data from each treatment were subjected to one-way analysis of variance performed with the Statistical Package for Social Sciences Windows version, release 7.5.1 (SPSS Inc., Chicago, Illinois, USA). When overall differences were significant ($P<0.05$), Scheffé's Multiple Range Test was used to compare the means between individual treatments (Zar, 1984). All percentage data were arcsine-transformed before analysis. Broken-line model (Robbins et al., 1979) was used to estimate the maximum feed restriction which does not hamper shrimp growth. The equation used in the model was as follows: $y=L-U(R-x)$, where y is the value of the parameter, L is the maximum value of the parameter, U is the slope, x is the level of feed restriction and R is the optimum value.

3. Results

3.1. Shrimp performance under a time-restricted feeding regime

L. vannamei body weight (BW) was significantly affected by the period of feed exposure. Differences in shrimp BW were more evident starting on the 36th day of rearing, when animals fed 2 and 3 h/day showed a significantly lower BW ($P<0.05$, Table 2). The coefficient of variation (CV) of shrimp final BW progressively increased when the period of feed exposure was reduced from 6 (13.35%) to 2 h/day (20.82%).

After 96 days of rearing, shrimp achieved a final survival of over 92%. Statistical differences in shrimp survival could not be observed among feeding regimes (Table 3). On the other hand, shrimp yield (kg of shrimp/m^2) and weekly growth were significantly higher when shrimp were fed longer than 3 h/day ($P<0.05$). Shrimp yield increased more than four times when the period of feed exposure was raised from 2 or 3 h/day to 6 h/day. A statistically higher final shrimp biomass was also achieved when shrimp had 4 or more hours of daily feed exposure. In general, shrimp performed better in treatments under longer feed exposure periods as opposed to shorter periods (Table 2). The broken-line analysis showed that the minimum period of daily feed exposure that does not hamper shrimp weight gain is 4.91 h/day (Fig. 1).

3.2. Shrimp performance under a rate-restricted feeding regime

After 28 days, shrimp survival was high (>90%) and similar within all treatments ($P>0.05$). Final shrimp BW fed to apparent satiation (control) and in treatments under a 25% and 50% restriction showed no significant

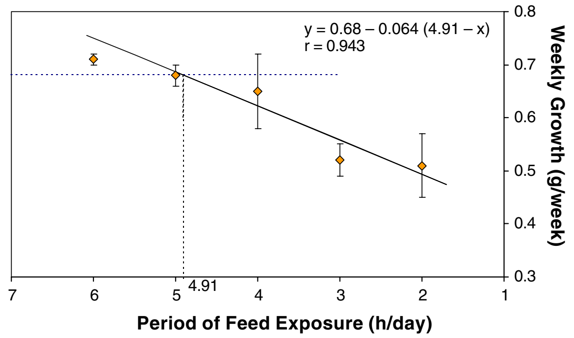

Fig. 1. *L. vannamei* weekly growth relative to time-restricted feeding in 500-l tanks for 96 days. The breakpoint of the broken-line is 4.92 h/day of feed exposure.

Table 4
Effect of rate-restricted feeding on the growth performance of *L. vannamei* juveniles raised in 500-l tanks for 28 days (mean ± S.D.; $n=4$)

Rate restriction (%)	Initial weight (g/shrimp)	Final weight (g/weight)	Survival (%)	Development index (mg/day)	Feed efficiency (%)
0 [a]	8.6 ± 0.44	11.3 ± 0.75^{a}	96.7 ± 2.89	91.9 ± 26.63^{a}	35.8 ± 12.76^{a}
25	9.4 ± 1.50	11.2 ± 0.13^{a}	93.7 ± 7.50	86.9 ± 16.76^{a}	32.6 ± 6.02^{a}
50	9.2 ± 1.45	10.7 ± 0.94^{a,b}	95.0 ± 4.08	53.4 ± 20.98^{a}	29.1 ± 5.58^{a}
75	9.3 ± 1.08	8.0 ± 0.09^{b}	95.0 ± 5.77	−30.7 ± 7.49^{b}	−42.2 ± 13.19^{b}
ANOVA *P*	>0.05	<0.05	>0.05	<0.05	<0.05

Water quality parameters were kept at 29.1 ± 0.43 °C ($n=95$), 39 ± 1.5‰ salinity ($n=95$) and 7.4 ± 0.18 pH ($n=95$). Columns with common non-superscript letters denote non-significant differences between treatments at the $\alpha=0.05$ level by Scheffé's Multiple Range Test.
[a] Shrimp subjected to feeding (control) to allow apparent satiation (Nunes and Parsons, 2000).

differences (Table 4). On the other hand, final BW of shrimp fed at 75% restriction was significantly lower ($P<0.05$) than that of shrimp fed to apparent satiation and with 25% restriction.

A similar statistical response was observed for the development index and feed efficiency. There were no significant differences for these indicators between the control group (apparent satiation) and the feed-restricted groups at 25% and 50%. In contrast, shrimp fed under the maximum feed rate restriction (75%) showed the poorest feed efficiency and development index ($P<0.05$). The broken-line analysis showed that the maximum feed restriction level that does not hamper shrimp weight gain is 28.8% (Fig. 2).

3.3. Shrimp feed intake fed ad libitum

Feed intake of *L. vannamei* increased progressively with longer feed exposure periods (Fig. 3). Feed intake relative to ration size (CRS) increased significantly over the 8-h exposure period ($P<0.05$). CRS reached 68.6% in the first 2 h of feed exposure, reaching a peak of 97.5% after 7 h. Conversely, feed intake relative to shrimp body weight (CRB) was uniform throughout the 8-h exposure period. CRB varied from a minimum of 4.00% to a maximum of 4.18%.

4. Discussion

Longer feed exposure periods favored more uniform body weights (BW) of *L. vannamei* at harvest. Shrimp fed for only 2 and 3 h/day showed a high coefficient of variation in BW. The differences in shrimp growth became more noticeable at 36 days of rearing or when animals reached 6.6 g in BW. Prior to this stage, observations suggest that shrimp started to display a dominant feeding behavior, remaining longer on feeding trays during feeding activity. Such condition could have caused underfeeding in the 2 and 3 h/day treatments. Feed competition or time-restricted feeding may have imposed a limited or an uneven feed access to the stocked population. These results indicate that longer feed exposure periods lead to better growth performance and more uniform body weights in *L. vannamei*. Smith et al. (2002) working with *Penaeus monodon* suggested that shrimp exhibited a better growth performance when feed remained in water for longer periods of time.

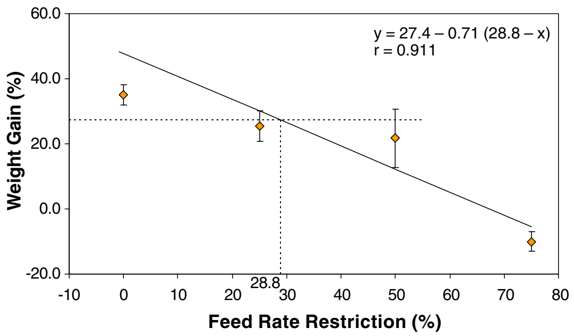

Fig. 2. *L. vannamei* weight gain relative to rate-restricted feeding in 500-l tanks for 28 days. No feed rate-restriction allowed shrimp to reach apparent satiation according to Nunes and Parsons (2000). The breakpoint of the broken-line is 28.8% of feeding rate restriction.

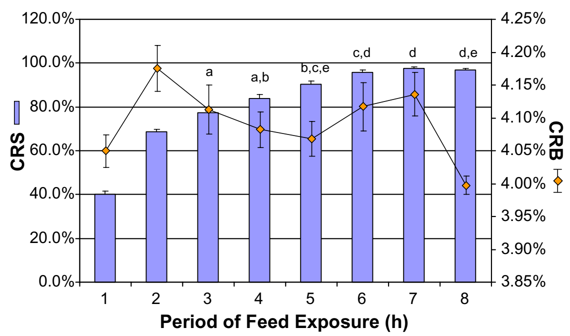

Fig. 3. *L. vannamei* mean feed intake relative to ration size (CRS) and body weight (CRB) ± standard error over an 8-h exposure period. Common letters denote non-significant differences between periods of feed exposure at the $\alpha=0.05$ level by Scheffé's Multiple Range Test.

These results are also corroborated by the continuous feeding periodicity *L. vannamei* exhibited when fed ad libitum. During the present study, the species feed intake occurred in a continuous and uniform fashion over the 8-h feed exposure period. On average, hourly feed intake reached 4.09% BW. Nunes and Parsons (2000) indicated that *F. subtilis* is able to resume feed intake soon after an initial meal is given (i.e., 1 h after the first ration was provided). The authors suggested that the species were fed while digesting an earlier meal.

In the present study, shrimp feed intake was proportional to feed exposure and BW, not ration size. This occurred despite a probable loss of feed attractability and physical stability with increasing water immersion periods. Even when fed in excess, shrimp feed intake lied within a threshold, which is probably a reflection of the species maximum stomach volume or its satiation level.

The minimum period of daily feed exposure that supports good growth performance of *L. vannamei* was 4 h 55 min. This suggests that the on-going time allowances used in clear water laboratory rearing systems can be substantially reduced with no significant impact on shrimp growth or FCR. Results are in agreement with those obtained by Alanärä (1992) and Koskela et al. (1997). The authors concluded that after an adaptation period it would be feasible to apply time-restricted feeding in rainbow trout and whitefish, respectively, without detriment in growth performance.

In the present study, only the 75% feed rate-restricted treatment resulted in a significantly poor growth performance of *L. vannamei*. While in this treatment, shrimp survival was not negatively affected by a reduction in feeding rates, weight gain and feed efficiency were negative. This result is corroborated by Bosworth and Wolters (2005) who submitted channel catfish to three different feeding regimes: (1) fed daily to satiation, (2) fed once weekly to satiation and (3) not fed. After 4 weeks, those authors observed that there were no differences in survival between the feeding regimes tested.

Survival is a biological priority of the organism. Consequently, the absorbed nutrients are allocated first to ensure life and all other biological processes are supplied only afterwards (Sá et al., 2004). Thus, a feed reduction of 75% over the animal's apparent satiation was very severe. Under such level, meal size was not able to meet *L. vannamei* nutritional requirements for growth. Therefore, future studies with this species should consider maximum feed restriction levels lower than 75% of apparent satiation.

Shrimp final weight, development index and feed efficiency were not statistically different between shrimp fed to apparent satiation and to the 25% and 50% feed rate-restricted groups. However, if the study had continued for a longer period, significant differences may have been observed in shrimp performance, particularly on the 50% rate-restricted group. Nevertheless, these results suggest that shrimp fed to apparent satiation were overfed and, accordingly, some feed restriction would be possible. This could be confirmed by daily observations of feed remains in feeding trays. On the other hand, it is important to point out that a moderate short-term feed restriction of 28 days would already have a positive outcome on reducing feed costs in shrimp farms.

As feed is the major operational cost in intensive aquaculture systems, a concern of farmers is not to overfeed the animals (Tan and Dominy, 1997). Any reduction in the amounts of feed allocated to farm-raised shrimp could bring important economic savings in commercial farms. Besides, there are always doubts on what level of reduction of feeding rates can be undertaken without compromising shrimp performance. These issues become more critical at times of product's price depreciation (Tacon and Akiyama, 1997).

In the present study, if shrimp had continuous access to feed (i.e., over 24-h periods), as it is actually done in commercial operations (Nunes, 2003, 2004), feed remains could have reached minimum levels in the apparent satiation group. As such, longer feed exposure periods would allow an even greater restriction in feeding rates. This question remains to be verified.

In the present work, there was no hampering of *L. vannamei* growth performance up to a 28.8% feed rate-restriction, as determined by broken-line analysis. Hence, in controlled conditions and for a short-term, it is possible to moderately reduce daily feeding rates without detrimental effects in *L. vannamei* survival, growth or feed efficiency. On the other hand, results imply that one-time feed delivery on Sundays is more beneficial than no feeding at all.

However, it is important to be considerate to the methodological constraints of the present work. Firstly, as already mentioned, it was a short-term feed restriction study. Thus, our results could not be valid for longer periods of feed restriction. Under environmental or disease-challenging rearing conditions results could have also differed. Besides, if feed restrictions had been carried out at earlier phases of shrimp growth, performance could be severely compromised. Therefore, we suggest that a further and extensive study of feed restriction with *L. vannamei* be performed for a longer rearing period starting with 1-g juveniles. Moreover, feed restriction studies at the farm level or (and) under disease-challenging conditions are also encouraged.

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