Studies on Energy and Protein Requirements to Improve Feed Management of the Pacific White Shrimp, *Litopenaeus vannamei*

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Abstract

Daily requirements for energy and protein were determined in growing *Litopenaeus vannamei* as the sum of requirements for maintenance and growth. The requirement of digestible energy for maintenance was calculated to be DE_{maint} = 345 J per g body mass and for digestible protein DP_{maint} = 7.5mg per g shrimp per day. The partial efficiencies of utilization for growth above maintenance were 0.31 and 0.44 for digestible energy and digestible protein respectively. The daily weight gain (g) as a function of body weight (g) could be described at a temperature of 28^0C by the following equation: $y = 0.05 \times BW (g)^{0.582}$. The composition of the gain was determined by analyzing whole shrimp ranging from 1 to 35g. The energy and protein contents were independent upon shrimp weight and were on average 4.844 kJ g^{-1} and 172 mg g^{-1} body mass respectively.

Based on those results, feeds can be formulated for growing *Litopenaeus vannamei* with optimal energy to protein ratio during the entire grow-out period to increase retention efficiency and reduce excretion of nutrients.

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Introduction

With the increase in shrimp aquaculture worldwide there has been a shift from extensive systems, where the shrimp are largely part of the natural ecosystem to highly intensive systems with an increase in feed inputs, giving rise to environmental problems. The challenge nutritionists are facing is to continually reduce feed costs, improve conversion efficiency and at the same time minimize environmental impact. Thus it is essential to develop feeds with the proper balance between protein and energy in combination with optimal feeding regimes for most efficient feed utilization. Growth means deposition of new body components, which in shrimp consist mainly of protein and lipid besides water. The feed has to supply the material for building new tissue, but also the energy needed to deposit the new growth. In addition to these, energy and protein for maintenance requirement have to be supplied as well.

The following outlines the principles of the factorial approach for evaluating the energy and protein demands for optimal growth of *Litopenaeus vannamei*.

Material and Methods

Shrimps and holding facilities

Pacific white shrimp (*L. vannamei)* spawned and subsequently reared at the Centre for Sustainable Aquaculture (CSAR) were used for the growth trials in this study. Those shrimp were offspring of a brood-stock acquired from Bonaire in the Caribbean. Various sized tanks as part of a recirculation system were supplied with flow-through seawater with optimal water quality parameters, a temperature of 28^{0}C and salinity of 32ppt. Feeds were manufactured by a local supplier.

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Methodology

A novel approach, which had been successfully applied to determining requirements in fish is described here by quantifying the requirements for energy and protein as the sum for maintenance and growth (Lupatsch *et al.*, 2001, 2003a, 2003b and 2005). The energy and protein requirement for maintenance at a constant temperature is primarily dependent on body size. It is proportional to the metabolic body weight in the form of the equation, $a \times BW (kg)^b$, where a is a constant, characteristic of a certain species at a set temperature and b is the exponent of the metabolic weight (Lupatsch *et al.*, 2003a). The requirement for growth is dependent on the amount and the composition of the weight gain.

Daily requirements can therefore be expressed as:

$$\text{Requirements} = a \times \text{body weight (kg)}^b + c \times \text{gain}$$

Where c = cost of production in units of dietary energy to deposit energy as growth.

The significance of this approach is that protein and energy needs are expressed primarily in terms of absolute demand per shrimp body mass and anticipated weight gain and only secondarily as a percentage of the feed.

The following demonstrates the derivation of those parameters for growing white shrimp.

Growth prediction and feed intake

To test the growth potential of Pacific white shrimp over the whole growing cycle until market size, a data set was established derived from growth trials with shrimps ranging from 0.5 to 35g. Depending on size, shrimps were fed twice or three times daily to apparent satiation. Feed was formulated to contain 400mg crude protein and 100mg lipid per g feed. In these growth trials shrimps were weighed every 14 days, and absolute weight gain as well as feed intake per day was calculated for the period between two successive sample weighings. The corresponding body weight was the geometric weight of the shrimps during this period. Thus two sets of 40 data were

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obtained referring daily weight gain as well as feed intake to increasing shrimp weights at a water temperature of 28^{0}C.

Composition of weight gain and loss at starvation

During those growth trials, shrimps were sampled frequently to determine changes in their body composition along the growing cycle. Twenty-three groups of 10 -15 equal sized shrimps were selected over a range of 1 to 35 g. Half of the shrimp in each group were sacrificed immediately and frozen. The other half were individually stocked in tanks and not fed for 10 - 14 days. After the fasting period, shrimps were sacrificed and stored at -20^{0}C until analyzed.

Requirement for maintenance and efficiency of utilization

To determine the maintenance requirement and efficiency for growth two trials of each 42 days were performed using shrimps of 1.5g and 7.5g initially. *L. vannamei* were fed a diet containing 400 mg protein and 18.8 kJ g^{-1} at increasing levels, starting at zero and going up to maximum voluntary feed intake, but making sure all feed was consumed. Digestibility of energy and protein was determined beforehand. Total energy and protein gain in the shrimps was then determined by comparative body analysis and the relationships between digestible energy (DE) intake and energy gain as well as digestible protein (DP) intake and protein gain established.

Results

Loss on starvation and metabolic body weight

In calculating the loss of protein and energy of the fasting shrimps it was assumed that the initial body composition of the non-fed shrimps equalled the average value of each group sacrificed at the beginning of the starvation trials. Energy and protein losses were calculated on a per shrimp

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per day basis and plotted against the mean weight, being the geometric mean of the shrimp during the 14 day fasting period.

The relationships between energy and protein loss and shrimp weight were almost linear with exponents of b = 0.95 and b = 0.96 for energy and protein respectively as described below

$$\text{Energy loss per shrimp day}^{-1} = -134\ \text{J} \times \text{BW(g)}^{0.95}$$

The daily loss of protein per shrimp can be described as:

$$\text{Protein loss per shrimp day}^{-1} = -5.5\ \text{mg} \times \text{BW(g)}^{0.96}$$

Those exponents are not significantly different from 1.0 which means that the metabolic rate is increasing linearly with size and is contrary to what one finds in fish where the exponent of the metabolic body weight is b = 0.80 (Lupatsch *et al.*, 2003a).

Requirement for maintenance and efficiency for growth

The results of the trials where *L. vannamei* were fed increasing amounts of feed are presented in Table 1.

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Table 1: Performance of Pacific white shrimp fed increasing levels of feed

Feeding level	Initial BW (g)	Final BW (g)	Weight gain (g shp^{-1} day^{-1})	FCR	% feed intake	Days of trial
Trial 1						
100%	1.51	5.69	0.099	1.89	6.84	42
60%	1.80	4.94	0.075	1.73	4.61	42
30%	1.48	2.55	0.025	1.94	2.55	42
zero	1.76	1.67	-0.005	-1.58	0.29	19
Trial 2						
100%	7.66	18.14	0.249	2.58	5.46	42
60%	7.44	12.98	0.132	2.69	3.58	42
30%	8.40	10.58	0.052	3.41	1.87	42
zero	6.50	5.86	-0.034	-	-	19

The comparative slaughter technique was used to determine energy and protein gain of the shrimps at each feeding level. Feeding shrimps graded levels of digestible energy (DE) resulted in a linear response as depicted in Fig. 1 and the relationship between daily DE intake (x) and energy gain (y) per unit of g body mass can be described by the following equation:

$$y = -107 + 0.31\,x \qquad r^2 = 0.94 \qquad (1)$$

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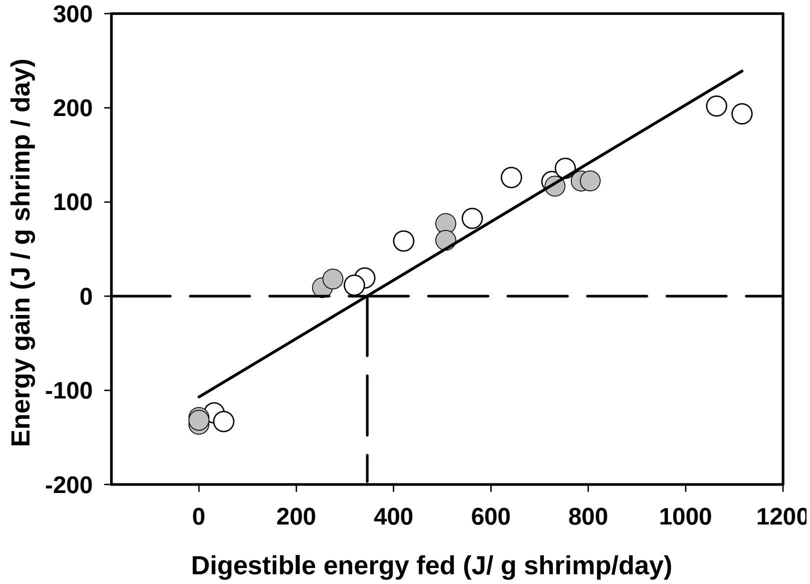

Figure 1: Daily energy retention per g body weight in shrimps fed increasing levels of digestible energy (DE).

The efficiency of DE for growth is defined by the slope of the line and the reciprocal 1/0.31 = 3.23 describes the cost of DE (kJ) per unit of energy deposited (kJ). In addition the maintenance requirement - DE_{maint} - where energy gain $y = 0$ can be determined as 345 J g^{-1} shrimp day^{-1}.

The same data set can also be used to establish the relationship between protein intake (x) and protein gain (y) per g body mass (Fig 2).

$$y = -3.3 + 0.44\,x \qquad r^2 = 0.93 \qquad (2)$$

This defines the requirement of dietary protein for maintenance as 7.5mg g^{-1} shrimp and the efficiency coefficient of 0.44 (or 1/0.44 = 2.27) to deposit protein as growth.

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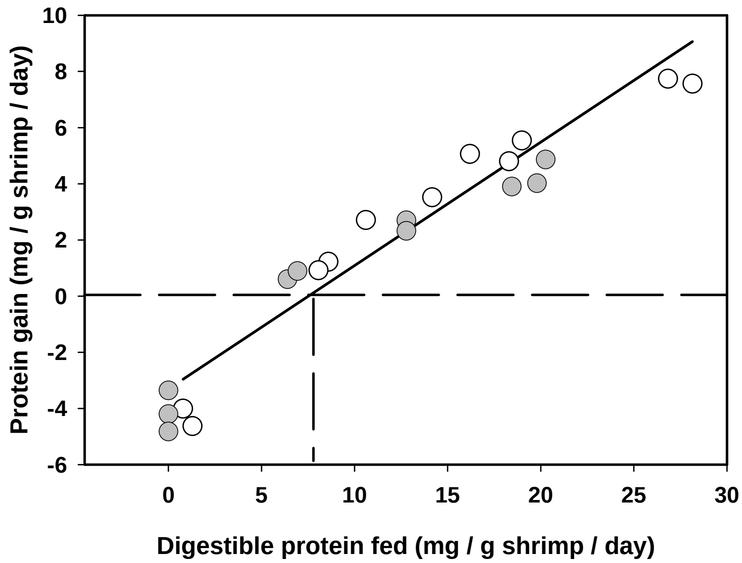

Figure 2. Daily protein retention per g body weight in shrimps fed increasing levels of digestible protein (DP).

Growth prediction and voluntary feed intake

A necessity for estimating the feed requirement is a prediction of the growth potential of a certain species. Therefore one of the first steps was, to establish a workable growth model for shrimps grown under optimal conditions and fed to satiation. Another prerequisite is a prediction of this maximum feed intake, i.e. the amount that the shrimp is physically able to consume. This is needed to adjust the energy and nutrient density of a potential feed.

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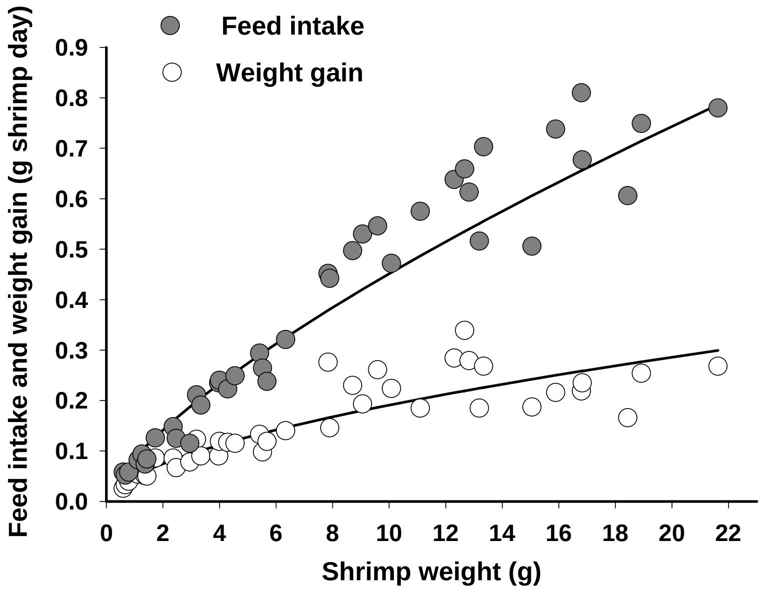

Figure 3: Daily feed intake and weight gain of *L. vannamei* (at 28^0C)

Fig. 3 describes daily feed intake and the resulting weight gain of shrimps at a water temperature of 28^0C. The equation defining the relationship between daily weight gain, shrimp size appears below:

$$\text{Weight gain (g)} = 0.050 \times \text{BW(g)}^{0.582} \quad (3)$$

where BW = Weight (g) of shrimp between 1 and 35 g.

By rearranging this equation one can also predict the weight of shrimp after t days (BW_t) starting from an initial weight BW_0 at t_0.

$$BW_t = [BW_0^{\,0.418} + 0.0209 \times \text{days}]^{2.39} \quad (4)$$

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The daily voluntary feed intake depending upon shrimp size can be described by the same general equation:

$$\text{Feed intake (g)} = 0.086 \times \text{BW (g)}^{0.720} \qquad (5)$$

Composition of weight gain

Because a large proportion of the energy and protein consumed by shrimp is retained as growth, the composition of the gain is a major factor determining the subsequent energy and protein requirement. Thus an additional goal was to determine changes in body composition of shrimps relative to their weight or age. As it is obvious from Fig. 4 whole body energy and protein content do not change considerably relative to shrimp size. The average energy and protein contents could thus determined to be 4.844 kJ g^{-1} and 172 mg g^{-1} body mass respectively.

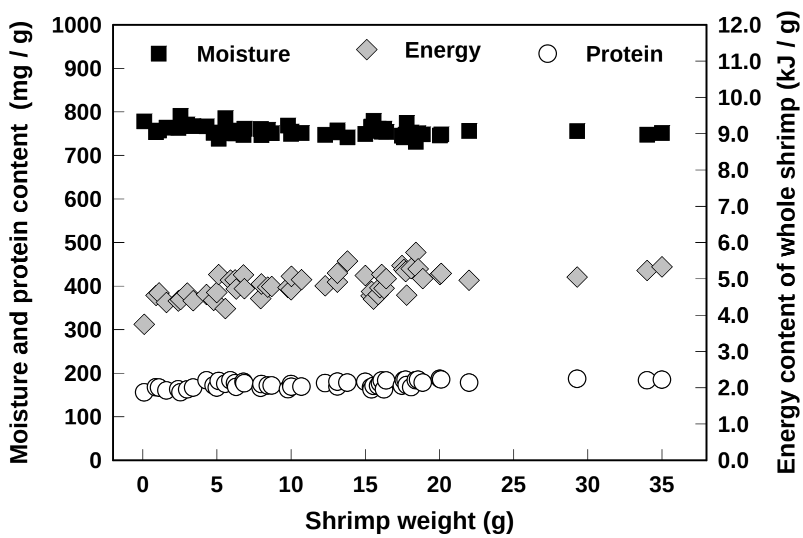

Figure 4: Body composition of shrimps at increasing sizes

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Practical application

The results of the above allow calculation of the daily recommended intake for growing *L. vannamei*. By defining the demands for maintenance and growth a comprehensive energy and protein budget can be derived that essentially quantifies the daily amount of energy and protein the shrimp would need to consume to achieve its anticipated growth.

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Table 2: Calculations of daily energy and protein requirements of growing *L. vannamei*

Body weight, per shrimp	**2g**	**10g**
Weight gain[1], g day^{-1}	0.075	0.191
Voluntary feed intake, g day^{-1}	0.142	0.451
Energy requirement, kJ $shrimp^{-1}$ day^{-1}		
DE_{maint}[2],	0.690	3.450
Energy gain[3]	0.363	0.925
DE_{growth}[4],	1.171	2.988
$DE_{maint+growth}$[5]	1.861	6.438
% Maintenance of total DE	37.1	53.6
Protein requirement, g $shrimp^{-1}$ day^{-1}		
DP_{maint}[6],	0.015	0.075
Protein gain[7]	0.013	0.033
DP_{growth}[8],	0.029	0.075
$DP_{maint+growth}$[9],	0.044	0.150
Feed formulation		
DE content of feed, kJ g^{-1}	*14*	*14*
Feed intake,[10] g $shrimp^{-1}$ day^{-1}	0.133	0.460
DP content of feed,[11] mg g^{-1}	333	325
FCR , feed $gain^{-1}$	1.78	2.41
DP DE^{-1} ratio, mg kJ^{-1}	23.8	23.2

[1] Predicted weight gain for *Litopenaeus vannamei* at 28°C (equation 1)

[2] Digestible energy required for maintenance - 345 kJ g^{-1} BW day^{-1}

[3] Expected energy gain = weight gain × energy content of gain (4.844 kJ g^{-1})

[4] Digestible energy required for growth = expected energy gain × 3.23 (cost in units of DE to deposit one unit of energy as growth)

[5] Total DE required for maintenance and growth

[6] Digestible protein required for maintenance = 7.5mg g^{-1} BW day^{-1}

[7] Expected protein gain = weight gain × protein content of gain (172 mg g^{-1})

[8] Digestible protein required for growth = expected protein gain × 2.27 (cost in units of DP to deposit one unit of protein as growth).

[9] Total DP required for maintenance and growth

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[10] Required feed intake to meet daily requirements when formulating feeds with 14 DE kJ g^{-1}.

[11] Required dietary DP content to meet daily protein requirements

Table 3 describes two potential feeds that could be formulated from commercially available ingredients. The feeds include a low nutrient dense diet (LND) and a high nutrient dense (HND) feed.

Table 3: Proposed feed formulations for two sets of commercial feeds with 'high' and 'low' nutrient density (for ease of presentation vitamins and other supplements are considered under 'others').

	Low nutrient dense diet LND	*High nutrient dense diet HND*
Ingredients (g kg^{-1})		
Fish meal	200	400
Soybean meal	310	320
Wheat meal	260	100
Starch	70	90
Fish oil	20	40
Others, Filler	140	50
Estimated composition (per kg as fed)		
Dry matter (DM), g	920	920
Crude protein, g	296	405
Gross energy, MJ	16.2	18.8
Crude lipid, g	49	97
Ash, g	145	99
Carbohydrates, g	430	319
Digestible energy (DE), MJ	12.0	14.8
Digestible protein (DP), g	250	344
DP DE^{-1} ratio, g kg^{-1}	20.8	23.2

As the absolute requirements (Table 2) do not change, the feed amount fed has to be higher when offering the low nutrient diet (Table 4). Furthermore, the low nutrient feed does not conform to the ideal DP / DE of 23.5 as derived from Table 2. In this case the protein would be the limiting factor and shrimp have to consume even more feed to satisfy their daily protein needs. Due to limitations

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of its stomach capacity the 2g shrimp for example would not be able to reach its anticipated growth potential.

Table 4: Proposed feeding table and expected FCR when feeding a high (HND) and low nutrient dense (LND) feed.

Weight	**2g**		**10g**	
Weight gain, g shrimp^{-1} day^{-1}	0.075		0.191	
Voluntary feed intake, g shrimp^{-1} day^{-1}	0.142		0.451	
DE requirements, kJ shrimp^{-1} day^{-1}	1.86		6.44	
DP requirements, g shrimp^{-1} day^{-1}	0.044		0.150	
Feed selection	*LND*	*HND*	*LND*	*HND*
Required feed intake , g shrimp^{-1} day^{-1}	0.177	0.129	0.598	0.435
Required feed intake, % biomass day^{-1}	8.84	6.43	5.98	4.35
FCR	2.36	1.72	3.13	2.28

The amount of energy and protein consumed by shrimp is a function of the amount of feed and the energy and protein content of that feed. Thus it is necessary to formulate a specific feed in combination with a suitable feeding regime. Using this approach to quantifying energy and protein demands in shrimp, it is possible to estimate the biological and economical efficiency of different feeds and culture systems.

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