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Replacement of Poultry By-product Meal in Production Diets for the Pacific White Shrimp, *Litopenaeus vannamei*

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Abstract

In recent years there has been increasing interest in the replacement of animal proteins with plant proteins in commercial feeds for the Pacific white shrimp, *Litopenaeus vannamei*. Both pond- and tank-based experiments were conducted to evaluate the potential of replacing poultry by-product meal (PBM) with a combination of soybean meal, corn gluten meal, and a low level of squid meal. For pond-based research, juvenile shrimp were stocked at 34 shrimp/m^2 and were cultured in 0.1 ha ponds under standardized production conditions. These four diets and a commercial reference diet were evaluated in an outdoor tank system stocked with 30 juvenile *L. vannamei* per tank. Culture water was pumped from a production pond to these tanks to mimic production pond conditions with a more uniform environment. Feed rates were predetermined by using a feed conversion ratio (FCR) of 1:1.2 and an average weekly growth of 1.5 g/wk. Final yields in the pond study averaged between 6093 and 6943 kg/ha. Average final weights varied between 22 and 24 g, survival varied between 78.9 and 82.2%, and the FCR was 0.94–1.09. The 79-d tank culture produced average final weights between 19.9 and 20.5 g, survival varied between 94.2 and 96.7%, and the FCR was 1.10–1.18. There were no significant differences found between any of the PBM replacement diets in either the pond or tank study.

Global farm-raised shrimp production is increasing at an average annual rate of 12%, totaling 2 million metric tons in 2005 and nearly 2.3 million metric tons in 2006 (Hedlund 2007). Farmers prefer raising the Pacific white shrimp, *Litopenaeus vannamei*, because the species is easier, quicker, and more profitable to grow than other commonly farm-raised shrimp (Hedlund 2007). Expansion of world production in combination with other economic factors has led to a reduction of shrimp prices. Market experts predict these trends to continue. Consequently, the less efficient producers will not be able to compete with more efficient producers or producers that are able to sell their product to premium markets (FAO 2006).

The need to become more competitive has sparked interest to develop better feed management practices and improve the economics of feeds. If diets can be formulated with high quality but lower cost ingredients, preferably from renewable resources, feed prices can be reduced (Amaya et al. 2007a). Feed contributes 40–60% of the production cost of intensely reared shrimp (Tan and Dominy 1997; Tan et al. 2005). Therefore, reducing the investment in feeds without compromising production outputs can decrease production costs. The first step in reducing feed costs is identifying the most expensive components, typically protein (Akiyama 1992; Forster and Dominy 2006).

One possible venue to reduce feed expenditures is reducing the cost of protein sources. In recent years, the replacement of fish meal in the diets has been gaining momentum because of increased demand and limited supply, which is driving up the cost of feed (Forster and Dominy 2006). The idea of replacing fish meal with animal by-product meals, such as meat and bone meal, blood meal, feather meal, and poultry by-product meal (PBM) in practical diets for *L. vannamei*, has been widely investigated (Davis and Arnold 2000; Mendoza et al. 2001;

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Forster et al. 2003; Samocha et al. 2004; Tan et al. 2005).

Significant reduction of ingredients from animal sources is expected in the near future because of availability limitations, renewability, as well as environmental and safety constraints. Increasing demand and decreasing availability will cause the prices for these animal-based meals to continue to increase and will restrict the use of animal-based meals as the main protein source in commercial shrimp feeds (Amaya et al. 2007b). Fish meal produced from wild fish stocks has been and will continue to be an overexploited resource, causing environmental concern in regard to fish meal production. The disease management spectrum of animal feeds has also become of great concern when formulating diets. After incidents such as bovine spongiform encephalopathy, feeding animals' animal proteins have become a more speculated issue with some countries restricting use in animal feeds (Amaya et al. 2006; Caparella 2006).

The use of primarily plant-based meals has been suggested as one possible solution to these issues. Using plant-based meals may also offer an economic opportunity for shrimp producers, as some markets would pay a higher price for shrimp fed and raised under environmentally sound conditions (Samocha et al. 2004; Davis et al. 2006; Amaya 2007a; Josupeit 2007). Increasing the use of plant proteins could broaden the spectrum of available feedstuffs and may even be a cheaper resource depending on local market value. Plant protein sources are also a more renewable resource than marine animal protein and animal by-product protein sources. Soybean meal is much more cost efficient than animal by-product meals and is a source of highly digestible protein and moderate energy (United States Department of Agriculture 2007). Solvent-extracted de-hulled soybean meal (soybean meal) is highly digestible by shrimp and is effective in diets for many aquatic species (Divakaran et al. 2000; Forster and Dominy 2006). Typical analysis of soybean meal would yield 48% protein, 89% dry matter, 7% crude fiber, 0.5% fat, and 0.65% phosphorus. (National Grain and Feed Association 2007).

Replacing animal protein meals with plant proteins in well-formulated diets may reduce the dependence on the animal protein industry and provides alternative choices when formulating feeds. Amaya et al. (2007a) demonstrated that in a practical diet the complete replacement of fish meal could be obtained using PBM as the replacement protein source. The next logical step is to remove poultry meal from the diets and move toward a plant-based formulation. Hence, the primary objective of this study was to demonstrate the replacement of PBM using a combination of plant protein sources and low levels of squid meal in feeds formulated for *L. vannamei*.

Materials and Methods

The study was conducted at the Claude Peteet Mariculture Center in Gulf Shores, AL, USA, and consisted of two parallel growth trials utilizing production ponds and outdoor tanks. Four diets (Table 1) were formulated to contain 35% protein and 8% lipid and varying levels of PBM (15, 10, 5, and 0%) replaced by a combination of solvent-extracted soybean meal, distiller grain solubles, and a low level of squid meal. The diets were steam-extruded sinking

TABLE 1. *Composition (g/100g as is) of practical diets for* Litopenaeus vannamei *used to evaluate the replacement of animal proteins with plant protein sources. The diets were produced under commercial conditions by Rangen Inc.*

Ingredient	15% PBM[a]	10% PBM	5% PBM	0% PBM
Soybean meal	40.85	46.54	52.32	58.02
Sorghum	29.83	25.18	19.99	14.85
PBM	15.01	10.01	5.00	—
Corn gluten	4.84	4.84	4.83	4.83
CFS corn distill	—	3.34	6.66	10.00
Menhaden fish oil	4.72	5.09	5.47	5.82
CaP-diebasic	2.65	2.90	3.13	3.38
Bentonite	1.50	1.50	1.50	1.50
Squid liver	—	—	0.50	1.00
Mold inhibitor	0.15	0.15	0.15	0.15
Vitamin premix	0.33	0.33	0.33	0.33
Mineral premix	0.09	0.09	0.09	0.09
Stay-C 35%	0.02	0.02	0.02	0.02
Copper sulfate	0.01	0.01	0.01	0.01

PBM = poultry by-product meal.
[a]Percent PBM in the diet.

pellets produced by Rangen™ Inc. (Angleton, TX, USA) under commercial feed manufacturing conditions. A commercial reference diet (Rangen Shrimp Grower, 35% protein, 8% lipid) was utilized as a commercial reference in the outdoor tank system.

Experimental Shrimp

L. vannamei postlarvae were obtained from Ocean Boy Hatcheries, Clearwater, Florida, USA. Eight-day-old postlarvae (PL_8) were received with an initial mean weight of 0.003 ± 0.001 g. All PL were cultured in a nursery for 21 d in a semi-closed recirculating system containing six culture tanks (3600 L), biological filter (3600 L), sand filter, and a 1 hp circulation pump (Aquatic Eco-systems, Apopka, FL, USA). At the conclusion of the nursery phase, juveniles were pooled and stocked into 16 grow-out ponds at a density of 34 shrimp/m^2. Shrimp were stocked in the research ponds on June 4 and harvested the last week of September.

Pond Grow-out

Each pond was 0.1 ha in surface area, with an average depth of 1 m. Ponds were equipped with a 20-cm diameter standpipe, a concrete catch basin (3.0 × 2.0 × 0.5 m), and lined with 1.52-mm thick high-density polyethylene lining covered with a 25-cm deep layer of sandy-loam soil. Prior to filling, pond soils were dried and tilled to allow for oxidation and mineralization of organic matter. Three weeks prior to stocking, the ponds were filled with brackish water (15–20 ppt) from the intracoastal canal between Mobile and Perdido Bay. Intake water was filtered through a 250-μm mesh nylon filter sock to prevent the introduction of large predators and minimize the introduction of larval fish, shrimp, and crabs, while allowing the introduction of small planktonic organisms. All ponds were fertilized with a combination of inorganic liquid fertilizers (10-34-0/32-0-0) applied at a ratio of 1:2 (N : P_2O_5) to provide 4 kg/ha nitrogen. No water exchanges occurred within 1 wk prior to stocking.

In each pond, temperature, dissolved oxygen (DO), salinity, and pH was measured three times a day, at sunrise, noon, and at night using an YSI 556MPS meter (Yellow Spring Instruments Co., Yellow Springs, OH, USA). Secchi disc readings were taken on a weekly basis. Water samples for total ammonia nitrogen (TAN) readings were taken at 40 cm from the pond surface and measured with a spectrophotometer (Spectronic Instrument Inc., Rochester, NY, USA) by the Nesslerization method (APHA 1989). A zero-water exchange was applied except in cases of severe drought. In order to maintain a minimum DO level of 3 mg/L, each pond was provided with a base aeration capacity of 10 hp/ha (1 hp/pond) and 10–20 additional hp/ha for emergency aeration throughout the grow-out phase.

Shrimp were fed twice daily, in the morning and late afternoon, following a predetermined feeding protocol. During the first 4 wk of pond culture, the shrimp were fed at fixed rates of 10, 15, 30, and 60 kg of feed/ha/d. Thereafter, feed amounts were calculated based on an expected weight gain of 1.5 g/wk, a feed conversion of 1.2:1, and a expected mortality of 1.8% per week from stocking to harvest (ca. 70% survival).

During the initial 2 wk of pond culture, a commercial shrimp diet (Rangen Shrimp Grower, 35% protein, 8% lipid) was provided, and the experimental diets were fed starting the third week of the grow-out phase when shrimp had reached an average weight of 2.3 g. Maximum feeding rates were set at 71.0 kg of feed/ha/d during the fifth week. Four test diets (Table 1) were formulated to provide equal protein (35%) and lipid (8%) levels while maintaining required levels of lysine and total sulfur amino acids. Lipid levels were adjusted by adding menhaden fish oil. Soybean meal was used in combination with distiller grain solubles to replace PBM. Calcium phosphate was added to ensure an adequate supply of phosphorus. These four diets were fed among the 16 grow-out ponds, allowing four replicates per diet. The objective of the four test diets was to reduce or eliminate the inclusion of PBM in the basal formulation. As soybean meal levels were increased in the diet, additional squid liver was used to serve as an attractant and ensure palatability of the diets without significant levels of animal protein sources. The diets were steam-extruded sinking pellets produced by Rangen Inc. (Angleton) under commercial feed manufacturing conditions.

Feeding ceased 36 h prior to harvest. Harvest took place after 115–117 d of pond culture. The pond culture water was drained, and shrimp were pumped from the catch basin using a hydraulic fish pump (Aqualife-Life pump, Magic Valley Heli-arc and Mfg, Twin Falls, ID, USA), dewatered, and collected into a transport truck. Following harvest, the shrimp were cleaned and weighed. During weighing, a random sample of 150 shrimp from each pond was collected to measure individual weights. These individual weights were used to further calculate mean individual weights, yields, survivals, and size distributions of the shrimp.

Tank Trial

Juvenile *L. vannamei* were obtained from 16 shrimp production ponds located at the Claude Peteet Mariculture Center. Shrimp with a mean weight of 2.32 g $\pm$ 0.02 g were stocked at a density of 37.5 shrimp/m^2 (30 shrimp/tank) in an outdoor green water recirculating system. This system contained a series of circular polyethylene tanks (0.85 m height $\times$ 1.22 m upper diameter, 1.04 m lower diameter) designed to hold 800 L of water, as well as an 800 L reservoir tank, biological filter, circulation pump, and supplemental aeration.

Before stocking, the system was filled with brackish green water (14–16 ppt) to mimic production pond settings. The system's make up water was exchanged daily between 0400 and 1200 h. Water from one of the shrimp production ponds was pumped into the central filter at a rate of 8 L/min. This exchange rate allowed a 100% water exchange of the system's make-up water every 6 d. Aeration was provided in the filter and in each tank by two air stones connected to a common air supply from a 1 hp regenerative blower.

During the experimental period, DO, temperature, salinity, and pH values were measured every morning and afternoon in the biological filter. Each week, water samples were taken from the biological filter and two randomly selected tanks for TAN readings measured as previously described.

Four test diets (Table 1) and one commercial diet (Rangen Shrimp Grower, 35% protein, 8% lipid) were offered to shrimp maintained in four replicate tanks per treatment throughout the 79-d culture period. Nutrient composition for these diets is presented in Table 2. Feed amount was calculated using an expected growth of 1.5 g/wk and expected feed conversion ratio (FCR) of 1.2.

Data Analysis

All statistical analyses were performed using SAS (V9.1., SAS Institute, Cary, NC, USA). One-way ANOVA was utilized to determine significant differences ($P < 0.05$) in survival, final weight, yields, and FCR. In separate analyses of the complete data set (four test diets and reference diet), Dunnett's t-test (Steel and Torrie 1980) was used to compare the experimental treatments to the reference diet.

Results

Pond Grow-out

Daily feed inputs (Fig. 1) changed on a weekly basis to meet the feed requirements necessary for optimum growth. On some days,

TABLE 2. *Nutritional composition of practical diets and commercial reference formulated to contain 35% protein for* Litopenaeus vannamei *used to evaluate the replacement of animal proteins with plant protein sources.*[a]

Ingredient	15% PBM[b]	10% PBM	5% PBM	0% PBM	Reference[c]
Moisture	7.91	9.15	10.08	9.73	9.65
Protein	36.6	35.5	35.6	36.8	36.9
Fat	8.39	8.66	8.04	8.12	7.65
Fiber	1.50	1.52	1.68	1.86	2.42
Ash	8.74	8.98	8.65	8.69	9.29

PBM = poultry by-product meal.
[a]Analyzed values from New Jersey Feed Laboratory Inc., Trenton, NJ, USA (2006).
[b]Percent PBM in the diet.
[c]Rangen Shrimp Grower, 35% protein, 8% lipid.

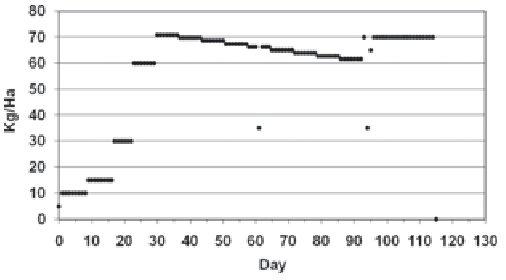

FIGURE 1. *Daily feed inputs (kg/ha/d) for* Litopenaeus vannamei *reared in ponds at a density of 34 shrimp/m*^{2} *over a 17-wk growing period and fed four practical diets with varying levels of poultry by-product meal and plant protein sources.*

ponds were fed half or none of the planned feeding because of severe thunderstorms, high winds, or heavy rain conditions. Water quality parameters observed throughout the 17-wk grow-out phase were suitable for growth and survival of the shrimp (Table 3). Low DO readings (<2.5) were occasionally observed throughout the study. DO and TAN levels were associated with plankton bloom and die-offs. As a plankton die-off occurred, oxygen demand increased, which decreased the amount of available oxygen, and TAN increased. Prior to stocking juvenile shrimp into the grow-out ponds, Secchi disc readings varied between 40 and 110 cm. By the fourth week after stocking, plankton blooms were evident in every pond, and the mean Secchi disc reading was 40 cm.

At the conclusion of the 17-wk culture period, there were no significant differences in the production parameters measured related to diet treatment (final weight, yield, weekly growth, FCR, and survival; Table 4). Mean final weight of all treatments ranged between 21.9 and 24.2 g, with Treatment 4 (0% PBM) having the numerically largest mean final weight and Treatment 3 (5% PBM) with the lowest. Final yield of all treatments ranged between 6093 and 6943 kg/ha (Table 4). FCR of all treatments ranged between 0.9 and 1.1. Survival of all treatments ranged between 78.9 and 82.2%. Treatment 1 (15% PBM) had the lowest survival of the four dietary treatments and Treatment 2 (10% PBM) had the highest.

Percent distribution of shrimp by count size of head-on shrimp per pound for all treatments is also shown in Figure 2. In all treatments, about 50% of the population was 16–20 count and about 30% of the population was 21–25 count.

Tank Trial

Water quality parameters of the 79-d trial were suitable for growth and survival of shrimp and are summarized in Table 5. There were no significant differences in the recorded production values between the four test diets (Table 6). Final weight, weekly weight gain, final yield, FCR, and survival among treatments ranged between 19.9 and 20.5 g, 1.56 and 1.61 g/wk, 0.56 and 0.59 kg/tank, 1.1 and 1.13, and 94.2 and 96.7%, respectively. The reference diet had numerically higher values in terms of mean final weight and weekly weight gain, and the lower values in terms of FCR and survival.

Discussion

Replacing animal protein meals with plant proteins in formulated diets may reduce the dependence on the animal protein industry and provides alternative choices when formulating feeds. The replacement of fish meal with poultry meal has been demonstrated in previous research under a variety of conditions (Davis and Arnold 2000; Samocha et al. 2004; Amaya et al. 2007a, 2007b). The replacement of PBM using a combination of soybean meal and distiller grain solubles in feeds formulated for the Pacific white shrimp, *L. vannamei*, could further expand the array of alternative formulations that can be utilized for this species.

To facilitate the evaluation of plant-based diets, this project evaluated the response of shrimp to reductions of PBM under pond production conditions. Research conditions for the pond study were suitable for this species as evidenced by good survival and growth. Production results of the pond study clearly demonstrate that there are no significant differences in mean final weight, yield, weekly gain, FCR, and survival among the four experimental diets for *L. vannamei*. Hence, there was no

TABLE 3. *Summary of water quality parameters observed over a 17-wk growing period for* Litopenaeus vannamei *fed four practical diets with varying levels of PBM and cultured in 0.1 ha ponds. Values are mean ± SD of daily and weekly determinations. Values in parenthesis represent minimum and maximum readings.*

Parameter	15% PBM	10% PBM	5% PBM	0% PBM
Temperature (C)				
AM	28.49 ± 1.72	28.66 ± 1.62	28.53 ± 1.67	28.68 ± 1.64
	(19.24, 32.14)	(22.08, 32.06)	(21.22, 32.12)	(22.12, 32.52)
Noon	30.95 ± 1.64	31.11 ± 1.67	30.92 ± 1.63	31.20 ± 1.67
	(26.57, 34.41)	(26.66, 34.49)	(26.53, 34.34)	(26.87, 35.48)
PM	30.34 ± 1.64	30.54 ± 1.64	30.30 ± 1.63	30.59 ± 1.65
	(25.26, 34.09)	(26.19, 34.21)	(26.13, 33.81)	(26.01, 35.00)
DO (mg/L)				
AM	4.15 ± 1.24	4.12 ± 1.25	4.16 ± 1.22	4.24 ± 1.23
	(0.55, 8.31)	(1.29, 8.39)	(1.09, 8.25)	(0.44, 9.15)
Noon	13.26 ± 3.79	13.59 ± 3.81	13.1 ± 3.36	13.50 ± 4.0
	(4.53, 23.98)	(1.09, 24.77)	(1.68, 21.97)	(0.64, 26.32)
PM	9.80 ± 3.22	9.93 ± 3.12	9.82 ± 2.98	9.82 ± 3.38
	(0.94, 18.07)	(2.14, 18.04)	(0.23, 17.37)	(2.67, 21.74)
Readings <2.5 pH	31	24	19	15
AM	8.03 ± 0.71	7.92 ± 0.68	7.98 ± 0.75	7.93 ± 0.65
	(5.66, 9.34)	(5.69, 9.42)	(5.62, 9.39)	(5.54, 9.35)
Noon	8.73 ± 0.41	8.69 ± 0.34	8.74 ± 0.40	8.64 ± 0.37
	(7.71, 9.77)	(7.79, 9.53)	(7.73, 9.89)	(7.76, 9.73)
PM	8.58 ± 0.58	8.54 ± 0.54	8.58 ± 0.59	8.49 ± 0.58
	(6.10, 9.92)	(5.79, 10.72)	(5.78, 10.10)	(5.87, 9.99)
Salinity (g/L)				
AM	15.23 ± 1.61	15.31 ± 1.93	15.87 ± 1.64	16.20 ± 1.62
	(12.02, 18.73)	(11.41, 19.21)	(12.15, 19.69)	(11.55, 18.75)
Noon	15.25 ± 1.58	15.40 ± 1.92	16.24 ± 1.62	15.92 ± 1.59
	(12.18, 18.87)	(11.44, 19.12)	(12.28, 19.72)	(11.72, 18.76)
PM	15.21 ± 1.60	15.33 ± 1.93	16.16 ± 1.67	15.87 ± 1.80
	(11.90, 18.67)	(11.29, 19.15)	(11.77, 19.67)	(11.39, 18.74)
Secchi	41.190 ± 32.69	37.813 ± 28.32	40.234 ± 31.88	37.813 ± 29.52
	(15, 110)	(15, 110)	(15, 110)	(10, 110)
TAN (mg/L)	1.0314 ± 1.30	1.1492 ± 1.80	0.9454 ± 2.04	1.2219 ± 1.88
	(0.00, 4.99)	(0.00, 2.12)	(0.00, 13.07)	(0.00, 8.91)

PBM = poultry by-product meal; DO = dissolved oxygen; TAN = total ammonia nitrogen.

TABLE 4. *Mean production parameters of* Litopenaeus vannamei, *cultured in 0.1 ha ponds, at the end of a 17-wk culture period and fed four practical diets with varying levels of PBM and plant protein sources.*[a]

	Final weight (g)	Final yield (kg shrimp/ha)	Weight gain (g/wk)[b]	FCR[c]	Survival (%)
15% PBM	23.9	6216	1.4	1.05	78.9
10% PBM	22.0	6451	1.3	1.00	82.2
5% PBM	21.9	6093	1.3	1.09	80.1
0% PBM	24.2	6943	1.5	0.94	80.9
PSE[d]	1.44	63.53	0.08	0.09	8.28
P value	0.5605	0.7901	0.5605	0.7272	0.9337

PBM = poultry by-product meal.

[a]Based on ANOVA, no significant differences ($P > 0.05$) were found among treatment means ($n = 4$).

[b]Weekly weight gain = (final weight − initial weight)/weeks of culture period.

[c]FCR, feed conversion ratio = feed offered per shrimp/weight gain per shrimp.

[d]Pooled standard error of treatment means = $\sqrt{\text{mse}/n}$.

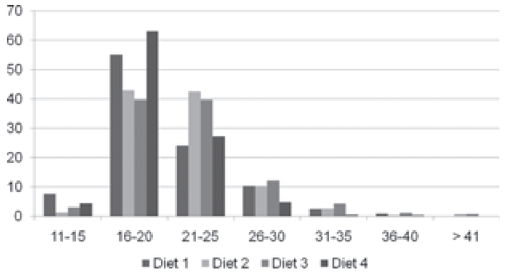

FIGURE 2. *Size distribution (shrimp count per pound) represented as percent population of* Litopenaeus vannamei *fed four practical diets with varying levels of poultry by-product meal and raised in ponds for a 17-wk period at a density of 34 shrimp/m^2.*

difference in performance as PBM was replaced with soybean meal and distiller grain solubles in practical diets for this species reared under pond conditions. The FCR results were particularly interesting as they were quite low (0.9–1.1) when compared with the expected value of 1.2–1.4 which are typical for recent studies at this facility.

The low FCR observed in this study are of great interest as this reduces feed-related costs. The low FCR observed is an example of a well-managed feeding protocol as well as the ability of this species to utilize natural food items in a pond setting. Lawrence and Lee (1997) found that natural productivity accounted for more than 25% of the natural intake of shrimp. Anderson et al. (1987) estimated that the contribution of feed to production of *L. vannamei* at 5 mt/ha/crop was between 23 and 47%, and at the same production level. Lawrence and Houston (1993) estimated that value to be between 24 and 31%. Similar results have also been reported at this facility (Venero et al. 2007) albeit the contribution from natural productivity was not quantified.

The low FCR observed in the ponds is presumably because of the use of historical

TABLE 5. *Summary of water quality parameters observed over a 79-d experimental period for* Litopenaeus vannamei *fed practical diets with varying levels of animal and plant protein sources and cultured in an outdoor semi-closed recirculating culture system. Values are mean ± SD of daily and weekly determinations. Values in parenthesis represent minimum and maximum readings.*

	Temperature (C)	DO (mg/L)	pH	Salinity (g/L)	TAN (mg/L)
AM	27.33 ± 1.45	6.26 ± 0.79	7.89 ± 0.31	15.76 ± 1.06	0.66 ± 0.44
	(24.27, 30.90)	(1.09,[a] 7.64)	(6.00, 8.95)	(13.70, 18.14)	(0.00, 1.57)
PM	29.99 ± 1.46	6.27 ± 0.52	8.14 ± 0.27	15.74 ± 1.06	
	(25.85, 33.50)	(4.37, 7.55)	(6.23, 9.07)	(14.13, 18.10)	

DO = dissolved oxygen; TAN = total ammonia nitrogen.
[a]Value obtained because of system mechanical error; however, this had no effect in regard to survival.

TABLE 6. *Mean productive parameters at the end of a 79-d culture period for* Litopenaeus vannamei *(mean initial weight 2.32 ± 0.02 g) reared in outdoor culture tanks and fed practical diets with varying levels of PBM and a commercial reference diet (Rangen Inc.).*

	Initial weight (g)	Final weight (g)	Final yield (kg shrimp/tank)	Weight gain (g/wk)[a]	FCR[b]	Survival (%)
15% PBM	2.30	19.9	0.562	1.56	1.13	94.2
10% PBM	2.30	20.3	0.574	1.60	1.11	94.2
5% PBM	2.32	20.1	0.582	1.58	1.12	96.7
0% PBM	2.32	20.5	0.595	1.61	1.10	96.7
PSE[c]	0.009	0.28	0.013	0.024	0.018	1.76
P value	0.483	0.465	0.407	0.452	0.588	0.588
Reference[d]	2.33	22.6[e]	0.616	1.80[e]	0.99[e]	90.8

PBM = poultry by-product meal.
[a]Weekly weight gain = (final weight − initial weight)/weeks of culture period.
[b]FCR, feed conversion ratio = feed offered per shrimp/weight gain per shrimp.
[c]Pooled standard error of treatment means = $\sqrt{\mathrm{mse}/n}$.
[d]In a separate analysis, Dunnett's t-test was used to compare the experimental treatments to the reference diet.
[e]Significant differences.

data with the knowledge and understanding of the production ponds' nutrient availability aided in the development of a more conservative feeding protocol. Garza (2001) compared juvenile *L. vannamei* growth between a traditional feeding table and a fixed FCR in 0.1 ha green water ponds over a 16-wk period stocked at 35 shrimp/m^2. There were no significant differences in growth or FCR. A FCR of 2.03 was obtained from both treatments. This work was then expanded on by Zelaya (2005) who demonstrated that commercial feed tables and feeding protocols were in excess. Unfortunately, most farmers encourage higher feed inputs to "load nutrients" into production ponds as they believe it will lead to higher yields. However, it is well known that overfeeding leads to increased pollution loading of the system and the feed inputs must be matched to nutrient requirements. For example, it has been found that in semi-intensive systems, increasing the nutrient density of the diet in combination with reducing feed inputs will allow for reductions in the feed inputs without affecting growth or feed efficiency (Venero et al. 2007). Venero et al. (2007) utilized a high-protein diet (40% crude protein) to reduce feed inputs and FCR as compared with a 30% protein diet. For this type of system, a maximum daily feed load of 100–120 kg/ha/d has been recommended when night-time mechanical aeration is provided (Boyd 1989; Boyd and Tucker 1998; Venero et al. 2007). The maximum feed input in this research was 71 kg/ha/d, which was below the maximum feed load capacity recommended for this type of system. Venero et al. (2007) suggest that lower feed levels in semi-intensive systems might improve water quality, thus improving survival and production. We have found that with well-formulated feeds, proper pond ecosystem management, and the use of historical productive trends, a more conservative feeding protocol results in increased production parameters with systematic improvements in yield as well as reductions in FCR (Fig. 3) (Garza de Yta et al. 2004; Amaya et al. 2007a; Venero et al. 2007; Zelaya et al. 2007).

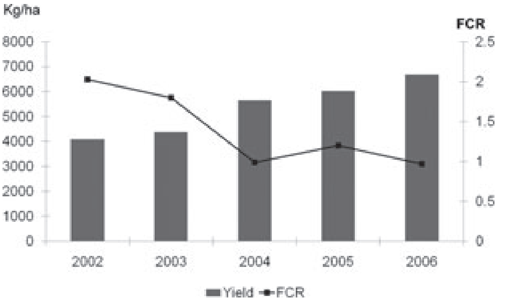

FIGURE 3. *Annual growth improvement of* Litopenaeus vannamei *raised under commercial pond conditions at the Claude Peteet Mariculture Center with the use of historical productive trends, conservative feeding protocol, and well-formulated feeds.*

Given the inherent variability of pond-based systems, the four test diets were also evaluated in outdoor tanks which have far less variability. The pond study results were also supported by the tank trial results, as there were no significant differences among the four PBM replacement diets. A commercial diet was also included as a reference to provide confirmation that there were no problems with the research diets. Under the reported conditions, reference diet did result in larger shrimp. The higher weight may be in part to the reduced survival which could have lead to enhanced growth because of reduced density. Larger shrimp are generally produced in lower population densities, whereas higher population densities are associated with smaller shrimp and slightly higher yields (Williams et al. 1996; Mena-Herrera et al. 2006). Regardless of the difference in survival, FCR, and mean final weight between the reference diet and the experimental diets, the mean final yield in all treatments were not significantly different (around 0.6 kg/tank). These results confirm that the test diets were properly processed and support good growth and survival.

Supporting the results of this study is the work conducted by Samocha et al. (2004) who demonstrated, in outdoor tank systems with primary production, that complete replacement of menhaden fish meal was possible using a coextruded PBM which is primarily soybean meal. Patnaik et al. (2006) tested a complete replacement of fish meal and fish oil using plant protein and non-marine oil sources in practical diets for juvenile *L. vannamei* stocked in outdoor tanks. Furthermore, Roy et al. (2009) most recently demonstrated the use of alternative diets containing various protein sources under low salinity conditions in outdoor tanks and indoor aquaria studies with good results.

The removal of animal proteins from shrimp feeds has been demonstrated by a systematic approach. Amaya et al. (2007a, 2007b) completely removed fish meal using alternative vegetable protein sources in combination with PBM without negatively compromising the productive performance of *L. vannamei* in semi-intensive ponds and outdoor tank systems. The results of this study demonstrate that the PBM can be replaced with soybean meal and distiller grain solubles as the primary protein sources. These results are most likely the product of a number of factors which include high-quality ingredients, balanced feed formulations, good processing of the feed, and the maintenance of palatability by adding low levels (<1%) of squid meal.

Reducing the dependence of marine ingredients and animal by-products by the addition of plant meals in commercially manufactured feeds may provide some relief to the limited resource of animal proteins. The use of all plant ingredients in practical diets for juvenile shrimp may expand to the possibilities of organically raised shrimp, as the popular trend of organically manufactured food has been increasing rapidly. This niche market would also increase farmers' chances to out-compete the rest of the market because of the uniqueness and limited availability of their product, possibly resulting in better economic returns.

Conclusion

Results from this study demonstrate that in well-formulated commercial feeds, PBM can be successfully replaced with soybean meal and corn gluten meal as the primary protein sources without affecting productivity of *L. vannamei* reared in semi-intensive green water systems. These production responses were the result of a combination of a well-formulated diet, accurately manufactured feed, correct feed inputs, favorable meteorological conditions, and good pond management.

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