RENDERED PRODUCTS IN SHRIMP AQUACULTURE FEEDS

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Summary

Fish meal (FM) has become expensive for commercial feed applications. Poultry by-product meal (PBM) and meat and bone meal (MBM) may be used as replacement for FM. This chapter describes research in which PBM and MBM have been evaluated for their impact on feed intake, digestibility, weight gain, carcass sensory characteristics, immune response, and survival rate when used as dietary FM replacements. Nutrient digestibility, maximum FM replacement rate, and digestible essential amino acid (EAA) profile are important least cost formulation criteria for selection of protein ingredients and minimizing the variability in growth performance of aquatic animals. Protein, essential amino acids (EAA), and energy in PBM have been shown to be digested more than 84 percent and 73 percent by *Litopenaeus vannamei* (white shrimp) and *Penaeus monodon* (black tiger shrimp), respectively. Limited meat and bone meal data indicate that protein and EAA digestibility of MBM is similar to that of PBM in *L. vannamei*, but no reliable EAA digestibility data for MBM have been reported for *P. monodon*. Energy digestibility MBM is about 14 percent lower than that of PBM due to the high content of ash and saturated fatty acids.

When used alone, PBM appears to be adequate in meeting digestible EAA requirements of shrimp with a minor deficiency in sulfur amino acids (AAs), whereas MBM needs to be supplemented with histidine and sulfur AAs (methionine and cystine). However, under zero-water exchange (eutrophic) rearing conditions, white shrimp growth was not significantly different between FM and PBM or MBM (100 percent replacement of FM). Supplementation of microencapsulated EAAs may broaden and increase the use of rendered protein meals in shrimp feeds. Feeding PBM or MBM at high rates (up to 80 percent replacement of FM) does not affect shrimp conformation, carcass composition and sensory characteristics, survival rate, or immune response.

Under clean water rearing conditions, and without effective supplementation of EAAs, the maximum FM protein replacement rate by PBM is 80 percent for both *P. monodon* and *L. vannamei* feeds, while the maximum FM protein replacement rate by MBM is 80 percent and 60 percent for *P. monodon* and *L. vannamei,* respectively. With the adequate supplementation of EAAs and essential fatty acids (EFAs), the FM protein replacement rate could be increased to 100 percent by MBM and PBM.

Replacement value of hydrolyzed feather meal (FeM) for FM in shrimp feeds has not been widely researched. The maximum FM protein replacement by FeM is 33 percent (steam-pressure hydrolyzed, SPH), 66 percent (SPH plus crystalline lysine and methionine), and 43 percent (enzyme treated FeM). Greater

use of FeM in shrimp feeds requires supplementation of EAAs, EFAs, and perhaps also, palatability enhancers.

The main advantage of using rendered products in shrimp feeds as FM replacements is the reduction in cost of feed and weight gain. The typical savings at 60 to 80 percent FM replacement by MBM and PBM is a 15 to 25 percent cost reduction. Research supports the use and value of PBM, MBM, and FeM as FM replacement in feeds for carnivorous and omnivorous shrimp species.

Introduction

Animal proteins are considered essential dietary components for carnivorous aquatic animals, and are desirable protein sources for omnivorous species. FM has been the prime choice among all animal proteins in aquaculture feeds for its protein quality and palatability. However, for various reasons, the supply of FM will be insufficient to meet the demand for feeding of both aquatic and terrestrial species. PBM, MBM, and FeM are potentially suitable replacements for FM in aquafeeds due to their resemblance to FM in nutritional composition, but are much lower in cost. Recent studies funded by the National Renderers Association (NRA) and others (Davis, 2000; Kureshy et al., 2000; Kureshy and Davis, 2002; Samocha et al., 2004; Allan and Rowland, 2005; Davis et al., 2005; Tan et al., 2005; Tidwell et al., 2005; Yu, 2006) have demonstrated that a large portion of FM can be replaced by PBM and MBM without impairing the growth of fish and shrimp.

For effective use of PBM and MBM as FM replacements, aquafeed nutritionists need to know the digestibility coefficients of key nutrients preferably measured in the same species for which the diets are being formulated. This improved precision in formulation will not only result in more consistent and predictable growth of the aquatic animal but will also give a more accurate estimate of feed cost of production. Reliable knowledge about the maximum rate of FM substitution by PBM and MBM without causing a negative effect on weight gain is important to avoid erratic growth performance while reducing the dependence on FM. This chapter presents recent findings on digestibility and growth response of shrimp when fed diets with PBM and MBM as FM replacements.

Composition of Poultry By-product Meal, Meat and Bone Meal, and Hydrolyzed Feather Meal

Nutrient and amino acid composition of PBM, MBM, FeM, and FM used in several digestibility and growth trials in China (Xue and Yu, 2005) are listed in Table 1. The FM samples were taken from a leading aquafeed mill in South China, and were identified to be of Peruvian origin. U.S. renderers supplied the PBM, MBM, and FeM which were considered of high quality as evident when compared with compositions listed in *Nutrient Requirements of Fish* published by the National Research Council (1993).

Requirements: Energy, Protein, and Amino Acids

Requirements of energy, protein, and EAA of most aquatic species are interrelated and should be evaluated simultaneously for one particular species. Estimates of requirements for protein and amino acids are given in Table 2 (Bureau, 2000). Gross requirements for EAA can be estimated from the EAA profile of the carcass. For feed mills to meet the requirements of one particular species, it is important to know total protein, EAA as percent of feed, and EAA requirements for the species. Formulation precision can be improved by using digestible protein and EAA for shrimp requirements and ingredient contributions. Utilization of crystalline amino acids may be lower in shrimp feeds as compared with fish or poultry feeds. Coated EAA for slow rate of release may be desirable for shrimp.

Table 1. Nutrient Composition (percent) of Meat and Bone Meal, Poultry By-product Meal, Hydrolyzed Feather Meal, and Fish Meal Used in Shrimp Digestibility and Growth Trials.

	MBM[1]	PBM[2]	FeM[3]	FM[4]
Dry matter	96.6	97.5	97.2	92.6
Crude protein	54.0	65.6	80.0	62.9
Crude fat	12.7	12.5	6.0	11.1
Essential Amino Acids (EAA)				
Arginine	3.33	4.01	5.73	3.20
Histidine	1.43	1.72	0.69	1.61
Isoleucine	1.93	2.69	3.84	2.40
Leucine	3.66	4.85	6.80	4.41
Lysine	3.27	4.42	2.04	4.41
Methionine	1.29	1.59	0.67	1.60
Phenylalanine	2.07	2.70	4.30	2.43
Threonine	2.10	2.71	3.8	2.50
Valine	2.44	3.13	5.87	2.63
Cystine	0.61	0.74	4.16	0.59
Tyrosine	1.39	1.92	2.73	1.91

[1]Meal and bone meal (U.S.).
[2]Poultry by-product meal (U.S.).
[3]Hydrolyzed feather meal (U.S.).
[4]Fish meal (Peruvian).

Table 2. Protein and Amino Acid Requirements of Shrimp.

	P. monodon	***L. vannamei***
Protein % (Juvenile)	40	35
Arginine		
% Protein	5.8	5.8
% Feed [1]	2.32	2.03
Histidine		
% Protein	2.1	2.1
% Feed	0.84	0.73
Isoleucine		
% Protein	3.4	3.4
% Feed	1.36	1.19
Leucine		
% Protein	5.4	5.4
% Feed	2.16	1.89
Lysine		
% Protein	5.3	5.3
% Feed	2.12	1.86
Methionine + Cystine		
% Protein	3.6	3.6
% Feed	1.44	1.26
Phenylalanine + Tyrosine		
% Protein	7.1	7.1
% Feed	2.84	2.48
Threonine		
% Protein	3.6	3.6
% Feed	1.44	1.26
Tryptophan		
% Protein	0.8	0.8
% Feed	0.32	0.28
Valine		
% Protein	4.0	4.0
% Feed	1.6	1.4

[1] On a 90% dry basis.

Digestibility Trials

Nutrients and EAA digestibilities of PBM, MBM, and FM have been measured in *P. monodon* and *L. vannamei* (Table 3). Test protein was typically mixed with a base mix (FM being the only protein source) at a ratio of 3 to 7. A typical base mix analysis used for shrimp trials in China (Xue and Yu, 2005) is given in Table 4. Under similar experimental conditions, protein, and EAAs of all three protein meals were well digested (83 to 88 percent) by *L. vannamei*, suggesting the suitability of PBM and MBM as FM replacement in *L. vannamei* diets.

Limited digestibility data with *P. monodon* suggest that FM's protein, energy, and EAAs were highly digestible (89 to 93 percent, Table 3), and the protein and EAAs in PBM and MBM were 20 percent less digestible than FM. No apparent reasons can be given for the higher digestibility of EAAs noted in *L. vannamei* compared to *P. monodon* when fed the same test protein from the same source. Energy in MBM was least digestible among the three protein meals and was likely related to the high content of ash and saturated fatty acids.

Table 3. Nutrient Digestibilities of Rendered Non-Marine Animal Protein Meals in Shrimp.

	MBM[1]		PBM[2]		FM[3]	
	V[4]	M[5]	V[6]	M[7]	V[8]	M[9]
Protein	82 - 85	77	84 - 90	77	81	93
Energy	69	61	76 - 84	73	85	89
Essential Amino Acids (EAA)						
Arginine	85		86	90	90	93
Histidine	86		89	91	91	93
Isoleucine	86		91	89	89	90
Leucine	86		89	70	70	91
Lysine	93		93	85	85	95
Methionine	86		95	81	81	93
Cystine	76		76	79	79	85
Phenylalanine	86		89	77	77	90
Tyrosine	85		88	89	89	100
Threonine	82		85	79	79	91
Valine	84		81	82	82	91
Avg.	85		88	83	83	92

[1] Meat and bone meal.
[2] Poultry by-product meal.
[3] Hydrolyzed feather meal.
[4] *L. vannamei* (Forster et al., 2003).
[5] *P. monodon* (Smith, D.M., 1995).
[6] *L. vannamei* (Xue et al., 2006).
[7] *P. monodon* (Xue et al., 2006).
[8] *L. vannamei* (Xue et al., 2006).
[9] *P. monodon* (Smith, D.M., 1995).

No reliable digestibility data for EAAs in MBM have been reported for *P. monodon*, but one could assume an average value close to that of protein (77 percent), which is similar to the digestibility of PBM (Table 3).

Data in Table 1 and Table 3 suggest that PBM should be considered one of the best substitutes for FM in shrimp feeds, while the limiting factor for MBM is the relatively low content of EAAs rather than the digestibility of EAAs. More measurements of digestibilities of EAAs are needed for MBM and FeM in order to predict the weight gain response of shrimp to FM substitution by these two proteins.

Table 4. Ingredient Percentages of Base Mix Used in Shrimp Digestibility Trials.

Ingredient	**Percent**
Fish meal	33.0
Soybean meal	8.0
Peanut bran	20.0
Squid meal	3.0
Blood meal	3.0
Fish oil	1.0
Soy oil	1.0
Soy lecithin	1.5
Wheat flour	25.0
Zeolite	2.0
Premix	2.5
Analysis	
Dry matter	89.9
Crude protein	43.7
Fat	8.0
Gross energy (MJ/kg)	18.2
Ash	11.8
Total phosphorus	1.7

Digestible Amino Acids Profile

Digestible EAA specifications in shrimp feeds are important for nutritionists in predicting or ensuring growth performance and protein utilization. When digestible EAAs are expressed as percent of digestible protein of MBM and PBM, and are compared with the established requirements (Table 5), PBM meets all the EAA requirements, with only the exception of sulfur-containing amino acids (methionine + cystine). In clear water rearing systems and with PBM as the only source of dietary protein, the weight gain of shrimp is likely to be reduced by about eight percent compared with the ideal protein feeding condition (i.e. meeting 100 percent of the requirements). A similar comparison for MBM shows the slight deficiency in sulfur-containing amino acids and histidine, which could limit the weight gain by about 40 percent, should MBM be the sole protein source in shrimp diets in clean water conditions. Therefore, in practical shrimp feed formulation, total replacement of FM protein by MBM is not recommended (see details in the section on Growth Trials).

Supplementation of crystalline EAAs in shrimp diets has not produced consistently positive growth response (Cheng et al., 2002; Tan and Yu, 2003; Xue and Yu, 2005) and the critical factor is the effectiveness of the release rate control treatment (e.g., microencapsulation) applied to the EAAs. The success of this technology would allow a greater and broader use of many animal by-product protein meals in shrimp diets.

Under zero water exchange conditions (eutrophic water), Forster et al. (2003) showed that MBM and PBM can replace 100 percent of the FM protein in shrimp diets without causing significant adverse effects on weight gain or feed efficiency. This apparent contradiction to the EAA profile comparison (Table 5) was explained by the nutrients contributed by the microflora flourishing in the water under the minimum water exchange condition. This practice has been gaining acceptance by modern shrimp producing farms worldwide for disease prevention purposes. Therefore, in green water (fertilized pond conditions) shrimp maintain normal weight gains when fed a diet in which FM protein has been 100 percent replaced with either PBM or MBM.

Table 5. Comparison of Digestible Amino Acid Requirements of Shrimp and Amino Acid Profiles in Meat and Bone Meal and Poultry By-Product Meal.

Essential Amino Acids	Requirements [1] (% Protein)	Digestible amino acids profile in	
		MBM[2]	PBM[3]
Arginine	5.3 - 5.8	6.6	3.7
Histidine	2.0	1.7	2.2
Isoleucine	2.5 - 4.2	3.2	3.5
Leucine	4.3 - 8.2	6.2	6.9
Lysine	5.2 - 6.1	5.7	6.1
Methionine + Cystine	3.5	2.1	3.2
Phenylalanine + Tyrosine	4 - 7.2	6.1	6.7
Threonine	3.5 - 4.4	3.5	3.6
Valine	3.4 - 4.0	4.4	3.9

[1] Akiyama et al., 1992; Chen et al., 1992; Millamena et al., 1997; Millanena et al., 1996a; Millamena et al., 1996b; Millamena et al., 1998; Millamena et al., 1999; Dietary protein is 40%.

[2] Meat and bone meal. Total amino acids (Table 1) x AA digestibility coefficient (Table 3) ÷ digestible protein content x 100.

[3] Poultry by-product meal. Total amino acids (Table 1) x AAs digestibility coefficients (Table 3) ÷ digestible protein content x 100.

Protein Efficiency Ratio

Since the main function of MBM and PBM in shrimp diets is to provide protein for its conversion biologically to shrimp body mass, various researchers have measured the protein efficiency ratio (PER) of shrimp fed FM, MBM, or PBM diets (Tan and Yu, 2002a; Tan et al., 2003; Tan and Yu, 2003; Tan and Yu, 2002b; Cruz-Suarez et al., 2004). Substitution of FM protein by MBM or PBM did not cause significant reduction of PER (average 1.75) until high rates (greater or equal to 80 percent) of substitution were reached. The results are in agreement with the comparison of EAA profile versus requirements (Table 5). The main reason for the deterioration of PER at high rates of substitution under clean water conditions is most likely due to deficiency in some EAAs.

Immune Response

Only Chinese workers (Yang et al., 2002; Yang et al., 2003) have evaluated the immune response of shrimp (fresh water shrimp, *Macrobrachiun nipponense*) when fed FM substituted diets with MBM (up to 50 percent replacement) or PBM (up to 100 percent replacement). As shrimp lack true antibodies and have to rely on innate mechanisms, three immune parameters (total haemocyte count, phenoloxidase activity, and respiratory burst or superoxide anion production) were compared between the FM control and FM replacement groups. After a 70-day growth trial, no significant differences in immunological parameters were observed for all groups. It was concluded that MBM or PBM could replace FM up to 50 percent and 80 percent, respectively in diets for shrimp without significant negative effect on the growth, survival, and immune parameters.

Sensory Evaluation

Meat and Bone Meal

Reports on sensory evaluation of shrimp fed MBM diets have been scarce. Australian workers (Smith, 1996) compared *P. monodon* fed either control (FM) or MBM diets (20, 40, 60 percent inclusion rates) for nine flavor characteristics (metallic, meaty, sweet, seafoody, muddy/earthy, fresh, salty, weedy, and other) and found only "meaty" flavor being significantly different. However, this was not correlated with the inclusion level of the MBM. There was also no significant difference in the overall acceptability of the taste of the shrimp. Similar findings, although by a less sophisticated evaluation method, were reported by Chinese workers (Tan and Yu, 2002b) with graded inclusion rates of MBM (up to 40 percent) in diets fed to *L. vannamei*.

Poultry By-product Meal

Only one trial evaluated the flavor of shrimp fed diets with multiple inclusion rates (up to 38 percent) of PBM (Tan et al., 2003). Taste score was reduced only when PBM replaced 100 percent of FM in the diet (3.5 versus 4.1; 5 =

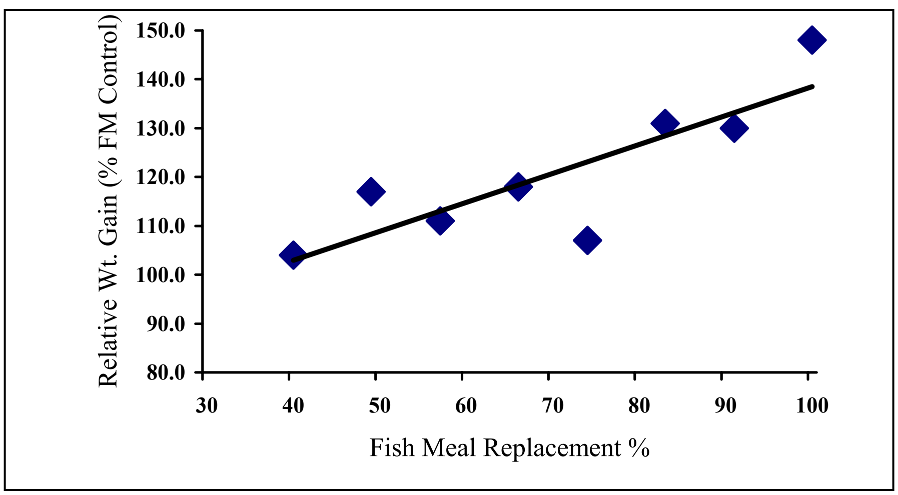
best). These studies indicate that the inclusion of high levels (up to 80 percent) of MBM or PBM in the diet is unlikely to have an adverse effect on shrimp sensory characteristics.

Growth Trials

Poultry By-product Meal

Shrimp growth response to feeding of PBM depends on (1) the inclusion rate, (2) the grade as defined by the manufacturing processes, (3) the complexity of dietary formulation (i.e., single or multi-protein ingredients), (4) total protein content in the diet, (5) stocking density of the shrimp, and (6) nutrients (natural foods) availability from the water. For true comparisons of protein quality, shrimp should be fed a single protein feed in clean (filtered) water rearing conditions. Results of a typical trial in clean water conditions comparing PBM with FM is depicted in Figure 1. Fresh water shrimp (*macrobrachium nipponense*) grew at a faster rate when fed PBM replacing up to 100 percent of FM in diets. Possible reasons for the growth rate difference are that the EAA profile in PBM fits requirements of this particular shrimp species closer than that of FM, and the quality variation (composition and digestibility) of the FM may have been greater than that of the PBM used in this trial.

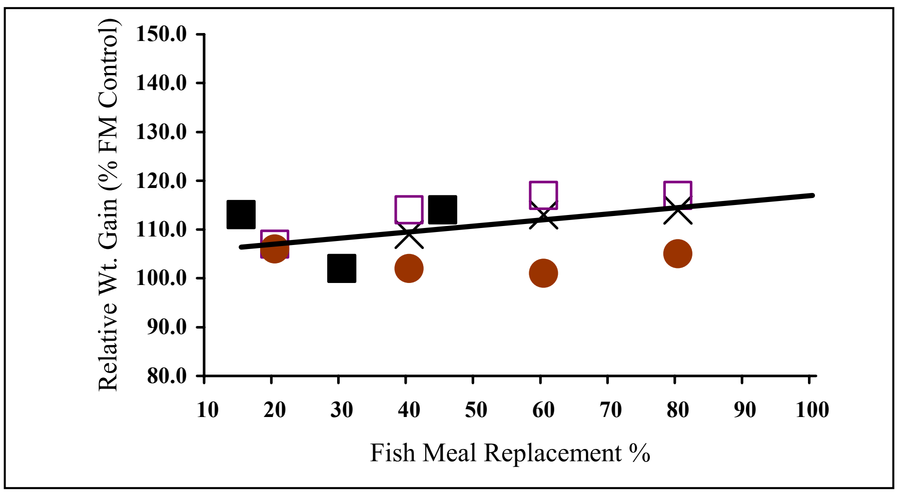
Figure 1. Weight Gain Response of Fresh Water Shrimp (*M. nipponense*) FM Substituted Diets with Graded Levels of PBM (China, 2003).



When formulations with multi-protein ingredients (practical diets) were tested, high grades of PBM (e.g., flash dry, pet food grade, low ash, etc.) all have supported a weight gain equal or superior to FM at high replacement rates (up to 80 percent, Figure 2 for *L. vannamei* and Figure 3 for *P. monodon*).

Details of a recent shrimp growth trial with *P. monodon* are provided in Table 6. Survival rate is not listed because no significant relationship was seen when PBM was substituted in the diets for FM. Since PBM and FM contain comparable levels of crude protein, dietary substitution of FM by PBM has been frequently done on equal weight basis for growth trials as illustrated in the formula for a typical substitution trial with *P. monodon* in China (Table 7; Xue and Yu, 2005). This practice is strongly discouraged as it ignores the possible variability in EAA content and their digestibilities as illustrated in this chapter. Test diets for FM substitution growth trials should be formulated on a digestible nutrients basis (Allan and Rowland, 2005). FM substitution rates ranged from 25 to 100 percent. Among all growth response variables, weight gain is considered to be the most important economic variable for aquaculture producers, and it therefore was selected for analysis of response trend to FM substitution. Maximum replacement rate is defined as the point when weight gain begins to decline sharply.

Figure 2. Weight Gain Response of White Shrimp when Fed FM Substituted Diets with Graded Levels of PBM (Texas, 1998X, 1998□; Hawaii, 2002■; Quigdao, China, 2002●).



P. monodon shrimp fed PBM substituted diets gained more weight (up to six percent) until the replacement reached 75 percent. At 100 percent FM replacement, weight gain was identical to that FM control, and supplementation of crystalline methionine resulted in no further improvement in weight gain. Body composition of shrimp was not affected by PBM replacement up to 100 percent (Table 6).

Figure 3. Weight Gain Response of Shrimp (*P. monodon*) when Fed FM Substituted Diets with Graded Levels of PBM (China, 2005).

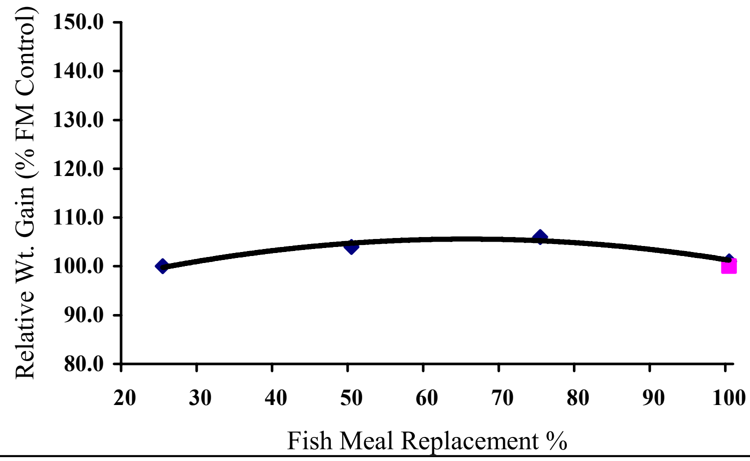


Table 6. Response of *Penaeus monodon* Shrimp to Fish Meal Substitution with Poultry By-product Meal in Growth and Body Composition.

FM Replacement rate (%)	IW[1] (g)	Growth		FI[4] (g)	FCR[5]	Body composition (%)[6]			
		SGR[2]	Gain[3]			Water	CP	Lipid	Ash
0[8]	0.2	4.25	2.28	7.8	3.42	76.0	17.2	.5	4.2
25	0.2	4.23	2.38	8.0	3.37	78.3	15.7	.6	3.7
50	0.2	4.41	2.51	7.9	3.13	78.6	15.4	.5	3.9
75	0.2	4.51	2.70	7.8	2.88	79.2	15.2	.5	3.8
100	0.2	4.28	2.60	8.4	3.22	77.9	16.0	.7	3.6
100+Met.[7] (0.16%)	0.2	4.23	2.44	8.8	3.59	81.3	13.7	.3	3.3

56-day trial by Xue and Yu, 2005.
[1] IW = Initial weight.
[2] SGR = Specific growth rate.
[3] WG = Weight gain.
[4] FI = Feed intake.
[5] FCR = Feed conversion (feed/gain) ratio.
[6] On wet basis.
[7] Met = Crystalline methionine.

Table 7. Nutrient Composition (Percent) of Control and Experimental Diets Used in *Penaeus monodon* Shrimp Growth Trials.

	Percent FM replaced by PBM					
	0	**25**	**50**	**75**	**100**	**100+AA[1]**
Ingredient						
Fish meal	37	28	19	9	0	0
Poultry by-product meal	0	9	18	27	36	35
Soybean meal	12	12	12	12	12	12
Peanut bran	16	16	16	16	16	16
Squid meal	3	3	3	3	3	3
Zeolite	2	2	2	2	2	2
Soy lecithin	1.5	1.5	1.5	1.5	1.5	1.5
Fish oil	1	1	1	1	1	1
Soy oil	1	0.9	0.8	0.7	0.6	0.6
Wheat flour	24	25	25	26	26	26
Na_2HPO_4	1.6	1.6	1.6	1.6	1.6	1.6
Methionine	0	0	0	0	0	0.16
Other	1	1	1	1	1	1
Analysis						
Dry matter	89.0	90.0	90.0	89.0	89.0	90.0
Crude protein	44.2	44.1	43.7	43.6	43.0	43.0
Crude fat	8.0	8.3	8.6	8.6	8.7	8.3
Ash	10.5	10.2	9.7	9.4	8.9	8.9
Total phosphorus	1.5	1.5	1.6	1.5	1.5	1.5
Gross energy (MJ/kg)	18.1	18.5	18.6	18.7	19.1	19.1

[1] Amino acid (methionine). Source: Xue and Yu, 2005.

The growth response of *P. monodon* to PBM substitution for FM is not in full agreement with digestibility data in Table 3, even though the source of PBM was the same for both the digestibility and growth trials. According to Allan et al. (2000), protein and EAA digestibilities of FM by *P. monodon* were in the range of 80 to 90 percent, which are much higher than 59 to 78 percent of PBM reported by Xue and Yu (2005) (Table 3). One possible reason for better weight gain of shrimp fed PBM was the difference in actual EAA content in PBM and FM. This may also explain the zero response in weight gain to methionine supplementation. High quality PBM could meet EAA requirements of *P. monodon* adequately. Another possible explanation could be the increased feed intake resulting from PBM substitution for FM. These results imply the maximum FM protein replacement rate with PBM in shrimp feeds in clean water culturing systems is about 80 percent.

Digestible EAA profile analysis agrees well with weight gain response of *L. vannamei* to FM substitution with PBM but to a less extent with *P. monodon.*

Meat and Bone Meal

Tan et al. (2005) measured growth response of *L. vannamei* to MBM substitution for FM (Table 8). Weight gain was not affected up to 60 percent of replacement, but there was a seven percent reduction in weight gain at 80 percent replacement. Feed conversion ratios also deteriorated by nine percent at the high level of replacement (Table 8). However, data in the literature on weight gain response of *P. monodon* to feeding diets in which FM was replaced by MBM show a slight positive trend (Figure 4; Yu, 2006). This disagrees with the analysis of EAA profiles listed in Table 5. Possible explanations are: (1) EAA digestibilities of MBM by *P. monodon* were under-estimated, (2) some provision of EAAs from natural foods in the water, and (3) increased feed intake with greater levels of substitution. The maximum FM protein replacement rate by MBM under practical culturing conditions is 80 percent for *P. monodon* and 60 percent for *L. vannamei*. However, in a minimum water exchange system, MBM can replace 100 percent FM without significant effect on weight gain and feed utilization (Forster et al., 2003).

Table 8. Response of *Litopenaeus vannamei* Shrimp to Fish Meal Substitution with Meat and Bone Meal.

FM replacement rate (%)	IW[2] (g)	WG[3]	FI[4] (g)	FCR[6]
0	0.9	5.86	8.0	1.37
20	0.9	6.03	8.6	1.42
30	0.9	5.82	4.4	1.39
40	0.9	6.16	8.1	1.32
50	0.9	5.78	8.2	1.41
60	0.9	5.82	8.4	1.44
80	0.9	5.46	8.1	1.49

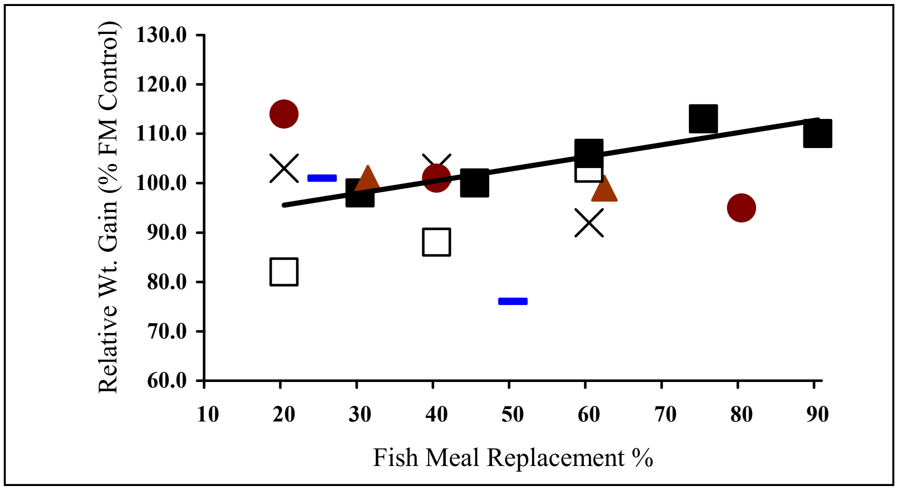
56 day trial by Tan et al., 2005.
[1] 40% protein anchovy FM.
[2] IW = Initial weight.
[3] WG = Weight gain.
[4] FI = Feed intake.
[5] FCR = Feed conversion ratio.

Hydrolyzed Feather Meal

Only a limited number of feeding trials have been conducted with FeM as a FM replacement in shrimp feeds. A Hawaiian study indicated that without the supplementation of crystalline lysine and methionine, steam-pressure-hydrolyzed FeM could replace 33 percent of FM in white shrimp feeds without losing performance (Cheng et al. 2003). Substitution rate could be increased to 66 percent by supplementing lysine and methionine.

When FeM was treated with an enzyme specifically developed for hydrolyzing FeM, Mexican workers have shown that up to 43 percent of FM in white shrimp feed could be replaced by treated FeM (Mendoza et al., 2001). With proper supplementation of microencapsulated EAAs and other nutrients (e.g., essential fatty acids), FeM (steam or enzyme hydrolyzed) may be used to replace FM protein to levels greater than 60 percent in shrimp feeds.

Figure 4. Weight Gain Response of Black Tiger Shrimp when Fed FM Substituted Diets with Graded Levels of MBM (Australia, 1995■, 1996X, 1999▬; Thailand, 2002 (28 days)●, 2002 (60 days)□; Vietnam, 2003▲).



Recommendations for Application of PBM and MBM

The recommended digestion coefficients of protein, energy, and EAA, and the maximum FM replacement rate for *L. vannamei* shrimp are given in Table 9 for MBM and Table 10 for PBM. These values are useful in formulating diets utilizing PBM and MBM as FM replacements while guarding the normal growth performance of shrimp. All digestion coefficients were discounted by five percent as a safety margin.

Table 9. Formulation Recommendation for Meat and Bone Meal in *L. vannamei* Shrimp Feeds.

	Digestibility (Percent)[1]
Protein	78
Energy	66
Maximum fish meal replacement rate (%)	60 - 70

[1] Digestibility coefficient x 0.95 (discount). Source: Tan et al., 2005.

Table 10. Formulation Recommendation for Poultry By-product Meal in *Litopenaeus vannamei* Shrimp Feeds.

	Digestibility (Percent)[1]
Protein	80
Energy	80
Essential Amino acids	
Arginine	81
Histidine	85
Isoleucine	86
Leucine	85
Lysine	88
Methionine	90
Phenylalanine	85
Threonine	81
Valine	77
Cystine	72
Tyrosine	84
Maximum fish meal replacement rate (%)	80

[1] Digestibility coefficient x 0.95 (discount). Source: Xue and Yu, 2005.

Feed nutritionists should use the analyzed nutrients and EAA values of all ingredients available for feed formulation. While digestibilities and the maximum FM replacement rates are higher for PBM than MBM, nutrient requirement specifications of the feed will determine the optimum use rate of the two protein meals. Generally, diets with relatively high digestible protein requirements (20 percent and above) are more likely to use PBM and MBM, while low digestible protein requirement diets will more likely select plant source ingredients.

Conclusion

PBM, MBM, and FeM are high protein source dietary ingredients for carnivorous and omnivorous aquatic animals. Recent research has indicated that PBM resembles FM in nutritive value and could replace most of FM (up to 80 percent) in shrimp and several other economically important fish diets without causing a reduction in weight gain. MBM should be mainly considered for its cost advantage over FM as its nutritive value is slightly lower than FM and PBM. The maximum FM protein replacement rate by MBM is 60 percent for *L. vannamei* and 80 percent for *P. monodon*. Under limited water exchange culturing systems, the FM protein replacement rate could be increased to 100 percent by PBM and MBM. The maximum FM protein replacement rate by FeM should be about 40 percent.

Greater use of FeM requires blending with other quality protein meals to improve palatability and amino acid balance or supplementation with coated crystalline EAAs. Decisions on selection of ingredients and their inclusion rates when formulating aqua diets should be largely based on an accurate nutrient composition, digestibility, palatability, and the risk of anti-nutritional factors.

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