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EFFECT OF PROTEIN SOURCE AND LEVEL ON GROWTH AND PERFORMANCE OF THE CAPTIVE FRESHWATER PRAWN, *MACROBRACHIUM ROSENBERGII*

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ABSTRACT

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Growth, feed conversion and survival were determined for juvenile *Macrobrachium rosenbergii* held in tanks under semi-controlled environmental conditions. Feeding trials incorporated water-stable diets at three levels of protein (15, 25 and 35%). The principal protein source combinations consisted either of soybean and tuna meal, or of soybean, tuna and shrimp meal. In a 244-day comparison of these diets, higher protein content produced larger prawns ($P < 0.01$), but differences between sources were not significant. No significant differences existed between feed conversion ratios (range 1.36—1.72) or percentage survival (range 90.3—93.6%). Trials of several other diets were also conducted, including soybean and *Tilapia* meal, and copra and *Tilapia* meal (25% protein level) as principal protein source combinations. After 167 days on these diets, growth was inferior to that obtained with soybean and tuna meal or soybean, tuna and shrimp meal combinations. No significant differences existed between feed conversion ratios or percentages of survival.

For the 244 days, a control group of prawns received no formulated diet. Growth and survival in this group during the first 110 days suggested that naturally occurring algae contributed substantially to the prawns' nutrition.

Mean prawn length after 244 days on the best diet (35% protein from soybean and tuna meal) was 73 mm, and growth rate was equivalent to that achieved under pilot pond conditions.

INTRODUCTION

The freshwater caridean prawn *Macrobrachium rosenbergii* currently offers a potential for large-scale commercial aquaculture. Attributes favorable to the farming of this animal include successful reproduction in captivity, established techniques for larval rearing, good growth rate and survival, absence of major disease problems, and a wide consumer acceptability and high market value. In Hawaii, where techniques have been developed for the propagation and mass culture of this species, both the technical and economic feasibility of a prawn industry have been demonstrated on a pilot scale (Fujimura, 1966; Fujimura and Okamoto, 1970; Shang, 1972). Postlarvae are reared from eggs in large-volume tanks under partially controlled environmental conditions. Juveniles subsequently are grown in earthen ponds to a market size of 30 g (10.5 cm). Selective periodic harvesting begins approximately 9 months after pond stocking, when an estimated 20% of the crop has reached market size. Food supplements offered during this grow-out period consist of commercial poultry feed and whole fish; however, the extent to which naturally occurring secondary pond organisms contribute to the prawn's nutrition is unknown.

Few data are available on the nutritional requirements of *M. rosenbergii*. Under natural conditions *Macrobrachium* is believed to be omnivorous, feeding on various plant and animal materials including grass roots, detritus, insect larvae and fishes (Ingle and Eldred, 1960; Fujimura, 1972; Maciolek, 1972). In captivity, both caridean and penaeid prawns accept a wide variety of foods; however the flesh of molluscs and crustaceans has been found the most acceptable, producing the best growth (Deshimaru and Shigeno, 1972; Forster and Beard, 1973). Commercially, the use of such foodstuffs in many areas would not normally be practical due to cost, availability and storage problems.

In recent years, several workers have directed preliminary efforts at developing artificial diets capable of sustaining good growth (Kanazawa et al., 1970; Cowey and Forster, 1971; Deshimaru and Shigeno, 1972; Sick et al., 1972; Andrews et al., 1972; Forster, 1972; Balazs et al., 1973). As a dietary constituent of major importance, protein is likely to be the most limiting nutrient to growth. In addition, the cost of diets formulated from available by-product feed ingredients is usually directly proportional to the protein content. Therefore this study was conducted to examine the effect of protein source and level on the growth, feed conversion and survival of *M. rosenbergii.*

MATERIALS AND METHODS

On November 20th, 1973, 7 600 juvenile *M. rosenbergii* averaging 16 mm in length (end of telson to posterior margin of orbit) and 0.1 g in weight ($N = 900$) were distributed at random into 19 round fiberglass tanks. Each of these outdoor tanks (5.5 m diameter, 0.8 m deep) received 400 animals. Stocking density was 17 prawns per square meter of bottom area, a density believed suitable for this species (Fujimura, 1972). Prawns used were mass cultured from ninth generation captive breeding stock and were hatched in August, 1973 at the Anuenue Fisheries Research Center (Hawaii State Division of Fish and Game) in Honolulu. Fine-mesh black plastic nets (12 × 0.8 m) were placed in each tank to provide shade and shelter. Aeration was supplied from perforated plastic tubing at the bottom of each tank. Tanks were half-filled with fresh water (approximately 10 000 l), and temperature was monitored throughout the study. The greater portion of each tank volume was changed periodically to minimize algal growth and other unwanted food sources, and to maintain water clarity. The total number of water changes required for each tank varied considerably (0—22) due to differences in phytoplankton blooms and dominant macrophytes.

The main experimental diets (Table I) contained (1) soybean and tuna meals (STu), or (2) soybean, tuna and shrimp meals (STuSh) as principal protein source combinations. Each diet was formulated to provide three different total protein levels (15, 25 and 35%). Other diets compared consisted of (3) soybean and *Tilapia* meals (STi), (4) copra and *Tilapia* meals (CoTi) and (5) activated sludge, *Tilapia* and duckweed meals (ASTiD) as principal protein source combinations; all these diets were formulated to provide 25% total protein. In addition, (6) an amylose starch preparation (AP) containing 29% protein, and (7) a no-food control were tested. The AP diet was a commercially supplied experimental preparation (American Maize Products Co., Hammond, Indiana, U.S.A.). Except for copra, *Tilapia*, sludge and duckweed meals, all ingredients were obtainable from feed suppliers in the United States. Copra (coconut) meal was incorporated because of its availability and low cost in many areas of the world where there is a potential for prawn culture. Whole body *Tilapia* meal was manufactured locally on a pilot scale. The objection to *Tilapia* as a fish for human consumption is prevalent in many areas, thus restricting full use of this potentially valuable protein source. Hence, the processed meal was tested to determine its value as a protein source in *Macrobrachium* diets. Activated sludge, a proteinaceous substance used by Japanese workers in prawn nutrition studies (Deshimaru and Shigeno, 1972), was obtained in the undigested, dried form at a local sewage treatment facility. Duckweed (*Lemna* sp.) was also collected at this facility, oven dried overnight at 60° C and ground into meal.

Experimental diets were formulated using ground corn as the major common energy source (excepting diets ASTiD and AP). In balancing the diets to provide the three protein levels (Table I), principal protein source ingredients were adjusted at the expense of corn. This resulted in the gross energy content being inversely proportional to protein level. Although biased with respect to energy content, this type of formulation was selected over the establishment of isocaloric diets, which would add supplemental lipids or replace a portion of the corn with a low energy fibrous ingredient. These latter manipulations would also introduce nutrient variables (lipid or fiber), capable of affecting prawn growth and performance as much or more than differing energy levels. Except for the AP diet, all diets were prepared by a method described earlier (Balazs et al., 1973). The inclusion of 20% high-gluten wheat flour in each formulation, as well as the method of processing, resulted in an extruded, dry pellet exhibiting acceptable water-stable properties. Amylose starch was the ingredient responsible for the stability of the AP diet (Hullinger et al., 1973).

With the exception of diets ASTiD, AP and the control, duplicate tanks

TABLE I

Percent composition of experimental diets

Diet	Ingredient	Calculated protein level (%)		
		15	25	35
1	Premix*	21.4	21.4	21.4
STu	Corn, ground	64.6	43.6	20.6
	Soybean meal (46% protein)	6.0	18.0	29.0
	Tuna meal (57% protein)	6.0	17.0	29.0
	Defluorinated phosphate**	2.0	0	0
2	Premix	21.4	21.4	21.4
STuSh	Corn, ground	64.6	42.0	17.3
	Soybean meal	4.0	12.6	21.0
	Tuna meal	4.0	12.0	20.3
	Shrimp meal (45% protein)	4.0	12.0	20.0
	Defluorinated phosphate	2.0	0	0
3	Premix		21.4	
STi	Corn, ground		40.8	
	Soybean meal		18.0	
	Tilapia meal (50% protein)		19.8	
4	Premix		21.4	
CoTi	Corn, ground		25.1	
	Copra meal (21% protein)		25.0	
	Tilapia meal		28.5	
5	Premix		21.4	
ASTiD	Activated sludge (30% protein)		31.4	
	Tilapia meal		15.2	
	Duckweed meal (15% protein)		32.0	
6	Amylose starch			55.0
AP	Corn gluten meal			15.0
	Soybean meal			15.0
	Fishmeal			15.0
7	No formulated food			
Control				

*The premix contained the following ingredients: 16% protein high-gluten wheat flour (20.0%), iodized salt (0.4%) and microingredient mix (1.0%). Microingredient mix provided the following in mg or units per kg of feed: vitamin A, 8,818 I.U.; vitamin D_3, 2,205 I.C.U.; vitamin E, 8.3 I.U.; riboflavin, 4.4; *d*-Ca pantothenate, 8.1; niacin, 33.1; choline chloride, 440.9; thiamin, 2.2; folic acid, 0.33; vitamin B_{12}, 0.011; butylated hydroxytoluene (BHT), 125; menadione sodium bisulfite, 2.2; *p*-amino benzoic acid (PABA), 100; Mn, 60; I, 1.2; Fe, 19.8; Cu, 2; Co, 0.2; and Zn, 44.1.
**32% calcium, 18% phosphorus.

were used for each treatment. Limited tank space required that single tanks be used for diets ASTiD, AP and the control. Prawns were initially fed an amount equivalent to 5% of their body weight, once daily in the afternoon. Each feeding was adjusted to a level based on the amount that was consumed on the previous day. A proportionally smaller amount was offered when uneaten food was observed. When all food was eaten, a greater amount was given. Prawns therefore were fed as much as they would consume, with the amount of feed placed in each tank recorded daily. Dead prawns were removed to minimize cannibalism, hence additional nutrient sources.

Diets STu with 25 and 35% protein levels, and STuSh with 15, 25 and 35% protein levels were fed for 244 days. The control tank also was maintained for 244 days. All other treatments were terminated at 167 days. At days 51, 110, 167 and 244, body length was measured in random samples of 40 prawns from each tank. In addition, at days 167 and 244, the percentage survival was determined and all animals in each tank were weighed in a single group.

Results of the experiment were divided into two groups. Separate comparisons were made (a) among 15, 25 and 35% protein diets formulated from two different protein source combinations, and (b) among the 25% protein diets, including diet AP. Body length, apparent feed consumption, feed conversion ratios and percentage survival for duplicate treatments in these groups were subjected to analysis of variance (Snedecor and Cochran, 1968) to determine if significant differences existed between diets. Differences between means were examined using Duncan's (1955) multiple range test.

RESULTS

Weekly temperature means varied from a low of 22.0° C during the first 51 days (November—December—January) to a high of 27.6° C during the 167 to 244 day period (May—June—July).

15, 25, 35% protein — STu and STuSh diets

Growth

The body length of prawns under the six feeding regimes is presented in Table II and Fig.1. No significant differences occurred between duplicate tanks on the same treatment, indicating that abundance and type of algae, number of water changes, and other environmental variables did not appreciably influence prawn growth. At day 51 no significant differences existed between any of the dietary treatments. Except for the 25 and 35% STuSh diets at 110 days, measurements taken after 51 days showed that increasing levels of protein produced larger prawns ($P < 0.01$). At 110 and 167 days, prawns receiving the 35% protein STu diet were larger ($P < 0.05$) than those fed the 35% protein STuSh diet. However at 244 days, prawns on these two treatments were not significantly different from one another. At the 25% protein

TABLE II

Mean body length (mm) of prawns fed two protein source combinations at three protein levels

Diet (source and % protein)	Days on experiment			
	51	110	167	244
Soybean—tuna				
15*	24.1[a]***	33.2[a]	43.9[a]	—
25	26.9[a]	41.1[b]	53.2[be]	68.0[a]
35	27.4[a]	45.5[c]	58.0[c]	73.0[b]
Soybean—tuna—shrimp				
15	25.2[a]	37.7[d]	46.4[d]	59.9[c]
25	26.4[a]	42.0[be]	51.3[e]	65.8[a]
35	29.1[a]	43.3[e]	54.1[b]	71.5[b]
No food (control)**	24.9 ± 4.2	35.7 ± 6.0	36.1 ± 4.7	40.2 ± 4.2

*Treatment terminated at 167 days.
**Not included in statistical analysis.
***a,b,c,d,e: for a single criterion, mean values in the same column bearing the same superscript are not significantly different ($P > 0.05$) (Duncan, 1955).

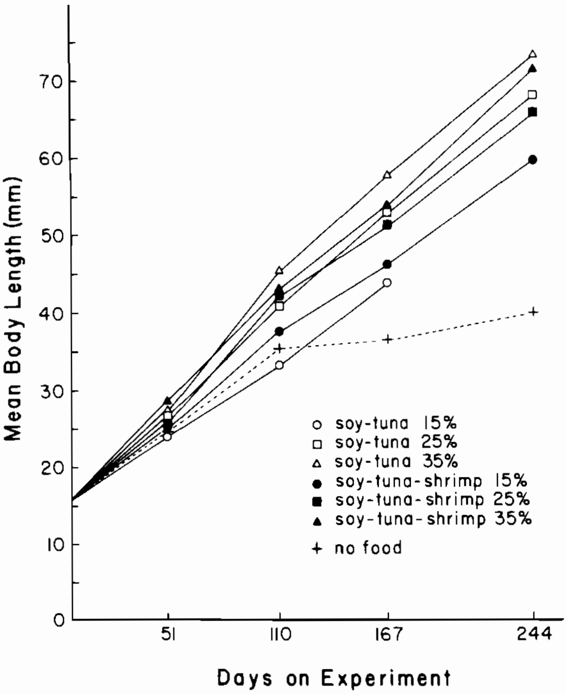

Fig. 1. Rate of growth of prawns fed two protein sources at three protein levels. Broken line represents unreplicated treatment.

level, no significant differences existed between the two protein source combinations throughout the entire 244-day experiment. At the 15% protein level, the STuSh diet produced greater growth than the STu diet at 110 ($P < 0.01$) and 167 ($P < 0.05$) days. Good growth was obtained in the control tank (no formulated diet) for the first 110 days. However, the rate of body length increase for these prawns showed a sharp decrease at day 167 and 244 (Fig.1), indicating that insufficient nutrients were available to sustain the earlier growth rate.

Differences occurred in the ranking order of growth response between prawn length (Table II) and prawn weight (Table III). These differences, at 167 and 244 days for 25% protein diets, and at 244 days for 35% protein diets, probably can be attributed to sampling errors. No significant differences exist between the means involved. Under the experimental conditions, prawn length rather than weight was considered the more sensitive indicator of growth. More body length measurements were obtained than weights, and weights were more subject to error such as that resulting from water adhesion when groups of prawns were weighed. Therefore, weight was used principally for estimating the feed conversion ratios.

Feed consumption, feed conversion and survival

Apparent feed consumption (Table III) for 167 days increased ($P < 0.01$) with increasing levels of dietary protein. In addition, at each protein level, greater feed consumption ($P < 0.05$) occurred with the STuSh diet than with the STu diet. Excluding the 15% protein STu diet, which was terminated at 167 days, the same differences ($P < 0.05$) existed at 244 days. These feed intake differences may have been a function of palatability, greater quantities of protein as well as the presence of shrimp meal both acting as feeding stimulants.

Apparent feed conversion ratios (feed offered/prawn weight increase) for protein sources or levels were not significantly different from one another at 167 or 244 days (Table III). However, between 167 and 244 days a greater amount of feed ($P < 0.05$) was required per unit weight gain with the 15% protein STuSh diet than with the other treatments. Also, in the latter part of the experiment (167—244 days), better feed conversion ($P < 0.05$) occurred with the 35% protein STuSh diet than with the 35% protein STu diet. None of the other conversion values differed significantly from one another during this period. As might be expected, when the prawns reached a larger size (167—244 days), feed conversion became less efficient.

Good survival (> 82%) occurred in tanks receiving experimental diets, with no significant differences between treatments (Table III). Prawns in the control tank also exhibited good survival (90.2%) up to 167 days; however at 244 days a decrease was found, with only 65.0% of the animals remaining alive.

TABLE III

Body weight, apparent feed consumption, feed conversion and survival of prawns fed two protein source combinations at three protein levels for 167 and 244 days

Diet (source and % protein)	Replicate	Final mean body weight (g)		Total consumption (g)		Conversion ratio			Survival (%)	
		167	244	167	244	167	244	167—244	167	244
Soybean—tuna										
15*	1	1.59	—	760	—	1.32	—	—	96.5	—
	2	2.14	—	655	—	0.86	—	—	93.8	—
	mean	*1.86*	—	*708*^{a***}	—	*1.09*^{a}	—	—	*95.2*^{a}	—
25	1	2.99	6.81	1 089	3 267	1.05	1.47	1.84	89.8	82.8
	2	3.99	7.95	1 205	3 842	0.79	1.25	1.71	98.5	97.8
	mean	*3.49*	*7.38*	*1 147*^{b}	*3 554*^{a}	*0.92*^{a}	*1.36*^{a}	*1.78*^{ab}	*94.2*^{a}	*90.3*^{a}
35	1	4.31	8.26	1 437	4 133	0.94	1.41	1.93	91.0	89.8
	2	4.62	8.98	1 544	4 371	0.86	1.34	1.93	99.5	91.8
	mean	*4.46*	*8.62*	*1 491*^{c}	*4 252*^{b}	*0.90*^{a}	*1.38*^{a}	*1.93*^{b}	*95.2*^{a}	*90.8*^{a}
Soybean—tuna—shrimp										
15	1	2.87	5.39	1 061	2 869	1.00	1.51	2.16	95.8	89.8
	2	2.00	4.94	1 157	3 108	1.55	1.92	2.24	98.0	92.2
	mean	*2.43*	*4.94*	*1 109*^{b}	*2 988*^{c}	*1.28*^{a}	*1.72*^{a}	*2.20*^{c}	*96.9*^{a}	*91.0*^{a}
25	1	3.63	8.05	1 358	4 098	1.00	1.42	1.79	96.5	91.0
	2	3.58	8.00	1 469	4 269	1.03	1.40	1.74	100.0	96.2
	mean	*3.60*	*8.02*	*1 414*^{c}	*4 184*^{b}	*1.02*^{a}	*1.41*^{a}	*1.76*^{ab}	*98.2*^{a}	*93.6*^{a}
35	1	3.57	8.86	1 667	4 733	1.26	1.54	1.76	95.0	87.5
	2	4.07	9.63	1 857	5 070	1.23	1.37	1.47	95.5	[illegible]
	mean	*3.82*	*9.24*	*1 762*^{d}	*4 902*^{d}	*1.24*^{a}	*1.46*^{a}	*1.62*^{a}	*95.2*^{a}	*90.*[illegible]^{a}
No food (control)**		1.19	1.34	0	0	—	—	—	90.2	65.0

*Treatment terminated at 167 days.
**Not included in statistical analysis.
***a,b,c,d: for a single criterion, mean values in the same column bearing the same superscript are not significantly different ($P > 0.05$) (Duncan, 1955).

25% protein diets

Growth

Body length values of prawns receiving the 25% protein diets, as well as the 29% protein AP diet, are presented in Table IV. At 51 days no significant differences occurred among the four replicated dietary treatments. At 110 days both the STu and STuSh diets gave better growth ($P < 0.01$) than the STi or CoTi diets. The latter diet produced poorer growth ($P < 0.01$) than any of the others. At 167 days the STu diet continued to be superior ($P < 0.05$) to those treatments which incorporated *Tilapia* meal. No significant differences occurred among the lower growth rates exhibited by prawns on the STuSh, STi and CoTi diets. Although the AP diet contained 4% more protein (29%) than the other compared diets, results do not suggest increased growth. Growth on the ASTiD diet was similar to the STi and CoTi diets.

TABLE IV

Mean body length (mm) of prawns fed 25% protein diets

Diet	Days on experiment		
	51	110	167
Soybean—tuna	26.9^{a}***	41.1^{a}	53.2^{a}
Soybean—tuna—shrimp	26.4^{a}	42.0^{a}	51.3^{ab}
Soybean—*Tilapia*	26.8^{a}	37.1^{b}	49.9^{b}
Copra—*Tilapia*	25.6^{a}	34.5^{c}	47.8^{b}
Sludge—*Tilapia*—duckweed*	23.9 ± 3.8	36.2 ± 6.5	48.9 ± 6.9
Amylose preparation*, **	25.4 ± 3.6	39.0 ± 5.3	50.4 ± 5.5
No food (control)*	24.9 ± 4.2	35.7 ± 6.0	36.1 ± 4.7

*Not included in statistical analysis.
**29% protein.
***a,b,c: for a single criterion, mean values in the same column bearing the same superscript are not significantly different ($P > 0.05$) (Duncan, 1955).

Feed consumption, feed conversion and survival

Apparent feed consumption (Table V) was greater ($P < 0.05$) for the STuSh diet than for the other protein source combinations compared. A smaller amount ($P < 0.05$) of the CoTi diet was consumed than the STu and STuSh diets; however, the difference between the CoTi and STi diets was not significant.

None of the feed conversion ratios (Table V) were significantly different from one another. Results from the single tank receiving the ASTiD diet indicated poor feed conversion. In contrast, good conversion was obtained in the single tank of prawns receiving the AP diet.

TABLE V

Body weight, apparent feed consumption, feed conversion and survival of prawns fed 25% protein diets for 167 days

Diet/replicate	Final mean body weight (g)	Total consumption (g)	Conversion ratio	Survival (%)
Soybean—tuna				
1	2.99	1 089	1.05	89.8
2	3.99	1 205	0.79	98.5
mean	*3.49*	*1 147*[a]***	*0.92*[a]	*94.2*[a]
Soybean—tuna—shrimp				
1	3.63	1 358	1.00	96.5
2	3.58	1 469	1.03	100.0
mean	*3.60*	*1 413*[b]	*1.02*[a]	*98.2*[a]
Soybean—*Tilapia*				
1	2.78	991	0.97	95.5
2	2.91	1 055	0.98	95.5
mean	*2.84*	*1 023*[ac]	*0.98*[a]	*95.5*[a]
Copra—*Tilapia*				
1	2.68	984	1.07	89.5
2	2.55	849	1.02	85.0
mean	*2.62*	*917*[c]	*1.04*[a]	*87.3*[a]
Sludge—*Tilapia*—duckweed*	2.90	1 262	1.83	61.5
Amylose preparation*, **	2.45	786	0.81	100.0
No food*	1.19	0	—	90.3

*Not included in statistical analysis.
**29% protein.
***a,b,c: for a single criterion, mean values in the same column bearing the same superscript are not significantly different ($P > 0.05$) (Duncan, 1955).

None of the percentage survival means were significantly different from one another. Low survival occurred on the ASTiD diet, while good survival (100%) was obtained on the AP diet.

Summary of results

The 35% protein STu diet produced the best growth for 244 days, followed by the 35% protein STuSh diet. Feed conversion ratios and percentage survival for 244 days were similar on all formulated diets. Poorest growth and survival occurred in the control tank.

The STu diet gave the greatest growth of the 25% protein diets tested for 167 days, followed by the STuSh diet. Feed conversion ratios and percentage survival were similar for all 25% protein replicated diets compared.

DISCUSSION

The paucity of research on nutrition of *M. rosenbergii* provides few direct comparisons with other results. In a preliminary study conducted under similar conditions (Balazs et al., 1974) diets consisting of five protein sources (soybean, tuna, shrimp, STu and STuSh) were examined at three protein levels (15, 25 and 35%) in an unreplicated 175-day feeding trial. Each protein source gave greater growth with increasing levels of protein, except for the STuSh diet where growth decreased with higher protein levels. This latter response was not substantiated in the present study. Results from the earlier work suggested that only the STu diets gave greater growth ($P < 0.01$) than soybean, tuna or shrimp meals individually, while growth on the other sources did not differ significantly. By calculating the average daily increase in length, a comparison with the present results at 167 days can be made with the earlier growth data. Growth in the current experiment ranged from 0.17 to 0.25 mm/day; growth on the diets in the preliminary study ranged from 0.14 to 0.19 mm/day. Unlike the current experiment, tank management in the preliminary study was less well controlled.

Another experiment with juvenile *M. rosenbergii* was conducted in large volume tanks at a similar stocking density (Fujimura and Okamoto, 1970). Growth was evaluated using four commercial diets (pig starter, poultry starter, gamebird feed and trout chow containing, 18, 24, 24 and 40% protein, respectively). No significant differences were found between treatments, although differences existed between duplicate tanks ($P < 0.01$). Good survival occurred (84—100%) and prawn length and survival were positively correlated ($P < 0.05$). Although an attempt was made to maintain similar environmental conditions in each tank, it would appear that variables other than diet had an appreciable effect on growth. Average daily increase in length ranged from 0.13 to 0.17 mm for 123 days. For a comparable period during the present study (110 days), daily increase ranged from 0.16 to 0.27 mm. Only one of the commercial diets (trout chow) used by Fujimura and Okamoto (1970) was an extruded, water-stable pellet; the other three were compressed pellets or "crumbles", unstable in water. Considering the trout chow's water-stable properties and higher protein content, it is surprising that superior growth did not occur. The absence of dietary differences in the Fujimura and Okamoto (1970) study suggest that *M. rosenbergii* is able to locate and use small feed particles, such as those resulting from the breakdown of compressed pellets. Additionally, in view of the current results, algae must also be of nutritional importance even in semi-controlled tanks. These observations are probably related to the prawn's omnivorous mode of feeding, which in part consists of meticulous searching and ingestion of various items. Also, for a period following final metamorphosis, juveniles will at times swim freely through the water column. Filter-feeding may contribute to the prawn's nutrition during this activity. Although the protein levels of the compressed, pelleted diets used by Fujimura and Okamoto (1970) were lower than that of their trout chow, sorting and selection by prawns of the disintegrated pellet could have resulted in a protein intake greater than was obtained on the water-stable trout chow. Selection of feed particles in the present study was limited because of the water-stable form of the experimental diets. The growth response to the actual formulated protein level in each diet, as well as the protein source, is therefore considered to be more accurately reflected in the current results.

Use of compressed pellets and "crumbles" in a pond environment remains an unresolved but important question. Such diets comprise the major food items offered in pilot pond studies where *Macrobrachium* has been grown to market size (Fujimura and Okamoto, 1970). The soluble fraction of these diets probably serves as an organic fertilizer for algal growth. However, it is not known to what degree insoluble feed particles are consumed directly by the prawns or to what extent they may be channeled through other pond organisms, eaten in turn by prawns. Prawn growth in the present study can be compared with results previously obtained under pond conditions. Fujimura and Okamoto (1970) reported mean lengths of 8.3 cm (13.5 g) in approximately 275 to 305 days after stocking with juveniles ranging in length from 1.3 to 2.2 cm. At the end of these periods, 20% of the population measured 10.5 cm (30 g) and minimum survival was believed to be 38%. Assuming a continuation of trends found in the present study, a projection of the highest growth rates would yield a mean length of 8.3 cm at 285 days.

Although not designed to assess nutritional requirements, a 112-day study conducted in small laboratory aquaria (Forster and Beard, 1974) is among the few reports available on growth and performance of *M. rosenbergii.* The diet used was a mixture of mussel flesh (*Mytilus* sp.) and shrimp (*Crangon* sp.). Two stocking densities were tested (25 and 166 animals/m^2) with juveniles averaging 0.15 g. At the end of the study, prawns averaged 11.9 g on the lower stocking density, and 6.7 g on the higher stocking density, with survival rates of 45 and 73% respectively. A comparison with current results shows that Forster and Beard's (1974) animals grew faster but with decreased survival.

Using juvenile prawns of the marine caridean *Palaemon serratus*, Forster and Beard (1973) evaluated a number of high protein feed ingredients in 28-day laboratory growth trials. Each test ingredient was directly substituted in place of whitefish meal, the major single protein source in a control diet consisting of 11 other protein-rich ingredients. Protein levels in these diets were not comparable and ranged from 38 to 62%. The results suggested that shrimp meals, as a major protein source, were slightly better than whitefish meal, and that Peruvian and Norwegian fish meals were of lower value. Also of lesser value were meat, whale and soybean meals, and casein. Results from the current study showed no beneficial effects when shrimp meal was combined with tuna and soybean meals at the 25 and 35% protein levels.

Several workers have conducted preliminary studies on the nutrition of penaeid prawns, which differ significantly from *Macrobrachium* in feeding behavior, digestive physiology and reproduction. The degree to which such differences affect nutritional requirements is unknown, and comparisons must be made with caution. Using *Penaeus japonicus*, Deshimaru and Shigeno (1972) examined 12 high-protein feed ingredients. Growth and conversion efficiency were positively correlated with level of protein, although all diets contained in excess of 60% protein. Diets showing high conversion efficiency had amino acid distributions similar to clams (*Venerupis* sp.) as well as to the prawns themselves. High proportions of fish meal gave poor growth, while diets rich in squid meal produced good growth.

Andrews et al. (1972) used semi-purified diets to study the effects of protein, carbohydrate and lipid levels in *Penaeus setiferus*. The protein source was menhaden fish meal, with other ingredients consisting of glucose, starch, lipid and cellulose in the purified form. In diets ranging from 14 to 52% protein, 28 to 32% was the optimum for growth. However, the large quantities of fish meal used to obtain higher protein levels may have been responsible for these results. The inclusion of a lipid supplement reduced both growth and survival. The addition of glucose also depressed growth, although added starch gave increased growth. The data of Andrews et al. (1972) suggest that corn and wheat starch should be successful components in prawn diets.

Semi-purified diets were also used by Sick et al. (1972) in studies with *Penaeus aztecus*. Several levels of shrimp meal, anchovy fish meal, and protein hydrolysates were used as principal protein sources with numerous purified ingredients making up the remaining portions. The total amount of protein in each diet was not given. Standard feed composition tables (National Research Council, 1969) would suggest that the levels ranged from 40 to 60%. Results indicated that higher proportions of shrimp to fish meal produced optimal growth. Casein as a major protein source gave poor growth, as did the protein hydrolysates. Growth was directly proportional to the three levels of feeding (5, 10 and 15% of body weight) with the best feed conversion ratio (5.5) obtained at the highest feeding rate.

These and other previous studies provide a beginning in the establishment of baseline data on the protein requirements of *M. rosenbergii*. However, considerable additional research is needed to define all of the prawn's dietary requirements. Current results suggest that a protein level in excess of 35% may be required for maximum growth in *M. rosenbergii*. Composition of the protein used is an important factor, and lower levels may be adequate provided a favorable amino acid balance can be achieved. Growth in the prawns not receiving a formulated diet suggests that certain types of algae in outdoor tanks may contribute substantially to the animal's nutrition. Further studies are needed to identify the algal species involved. The feeding behavior of *Macrobrachium* also suggests the need to further examine growth of prawns on water-stable diets compared to that obtained through direct feeding on granular feed particles resulting from water-unstable diets.

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