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34

A brief review of nutritional studies for *Penaeus monodon*

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Abstract. — *In order to develop effective formulated for* ***Penaeus monodon****, sufficient information is needed on its nutritional requirements. Unfortunately, research on this area has been very limited. This paper outlines the results of such research. Since data on the nutritional requirements of* ***P. japonicus*** *are relatively well established, some of these data are also reviewed in this paper and are used as a basis for assessing the nutritional requirements of* ***P. monodon****. Protein, lipid, carbohydrate, mineral and vitamin requirements are evaluated from the parameters of growth survival and feed efficiency. Studies on the effects of enzymes and the development of microparticulate diet for larvae are also summarized.*

INTRODUCTION

Due to the high market value and great demand for the grass prawn, *Penaeus monodon*, in the world market, it has become one of the most promising prawns in the southwest Pacific region. It is ideal for culture because of some of its advantageous features such as rapid growth, tolerance to high temperatures and a wide range of salinities, large size and simple pond construction requirements. It is quite appealing to consumers because it has an attractive red color when cooked. Because of the early success of its artificial propagation and the availability of support industries such as manufacturers of feed and aquaculture facilities, the country's *P. monodon* culture industry has become well established and Taïwan is now regarded as one of the major producers of cultured prawn in the whole world (Liao et *al.* 1969, Liao and Chao 1983, Liao and Chiang, 1986, Liao, 1988a).

In the past, when *P. monodon* was commonly cultured under extensive culture systems, not much attention had to be paid to nutritional studies, since the extensive system relied mainly on natural food. However, with the shift from extensive to semi-intensive and intensive culture systems, nutritionally balanced artificial diets became crucial. It became increasingly necessary to determine the nutritional requirements of this prawn to be able to formulate an effective and economically efficient diet for it.

At present, the nutritional requirements of *P. japonicus* are well know and reported. Several reviews on this subject already been published, notably those by New (1976), Kanazawa (1985a, 1985b) and Liao (1988b). The paper by New (1976) covered prawns in general, while the one by Liao (1988b) focused particularly on larval rearing of *P. japonicus*. Unfortunately, for *P. monodon*, research on this field has hitherto been rare. Nevertheless, based on the nutritional requirements of *P. japonicus*, the requirements for protein, lipid, carbohydrate, minerals and vitamins of *P. monodon* will be discussed and evaluated from the parameters of growth, survival and feed efficiency. Since information is very limited, the discussion will include works referring to different stages of growth of the above species.

PROTEIN REQUIREMENT

Gross protein

Protein is an essential component in a diet. Under an intensive culture system, feeding becomes more costly because it requires the use of artificial feed with several components, of which protein is the most expensive. This expensive protein fraction should therefore be utilized at an optimum level for growth, rather than for maintenance of the prawn. In this regard, the feed cost may be reduced by considering the optimum level of protein and the protein-sparing effect of nonprotein nutrients such as carbohydrates and lipid.

The optimum protein level usually varies depending on the source of nitrogen, the composition and ratio of essential amino acids, the cultured species and its stage of growth, the culture environment, the culture method, the energy value of the diet and many other factors. It has been ascertained that there is a correlation between feed efficiency and the amount of crude protein in the diets. Also, it has been known that diets containing suitable amounts of protein are capable of showing favorable feed efficiency. Kitabayashi et *al.* (1971d) reported that the optimum protein level for *P. japonicus* is estimated to be 53.5 %, while Shigeno et *al.* (1972) indicated that diets containing crude protein higher than 60 % have better feed efficiency for the same species. Similarly, Deshimaru and Kuroki (1974a) and Deshimaru and Yone (1978c) found that the suitable protein content is between 48 and 57 % and that a 52 % protein diet produces the maximum weight gain. On the other hand, in *Metapenaeus monoceros*, a diet containing 55 % protein gives the best growth (Kanazawa et *al.*, 1981). *P. brasiliensis* requires 54 % protein, while *P. penicillatus* requires 22 % protein for best growth (Liao et *al.*, 1986, 1988a).

As for *P. monodon*, Lee (1971) reported that better growth was obtained with 45 % protein in the diet. However, Lin et *al.* (1981) contended that protein in the diet of *P. monodon* should be about 35 %. Bages and Sloane (1981) revealed that the range of 35-45 % protein level in the diet produces the maximum weight gain in 40 days old postlarvae. Alava and Lim (1983) recorded an improvement in the growth, feed conversion ratio (FCR), protein efficiency ratio (PER) and survival rate of *P. monodon* juveniles fed with a 40 % protein diet. More recently, Liu and Cheng (1988) proved that a 45 % protein diet showed significant effect on growth Table 1 shows the desirable level of protein in some penaeid prawns.

Table 1. Summary of data available on optimum dietary protein levels for penaeid prawns.

Species	main diet ingredient	Optimum protein level (%)	Author
P. japonicus	Casein	64	Deshimaru and Kuroki, 1974
	Squid meal	60	Deshimaru and Shigeno, 1974
P. monodon	Casein		
	egg albumin	52-57	Deshimaru and Yone, 1978
		46	Lee, 1977
		40	Khannapa, 1977
		35	Bages and Sloane, 1981
	White fish meal	35	Lin et *al.*, 1982
		45	Liu and Cheng, 1988

The efficiency with which protein is assimilated by prawns is most likely affected by the relative proportion of lipids and carbohydrates in the formula as well as the amino acid composition of the protein source. Bautista (1986) found a significant change in growth of *P. monodon* juveniles despite a reduction in protein content of the diet from 50 % to 40 % at an energy level of 330 Kcal/100g (Fig.1). He suggested that protein may be separed by carbohydrate or lipid as long as the calorie requirement was met, thus permitting more efficient utilization of protein. If the diet

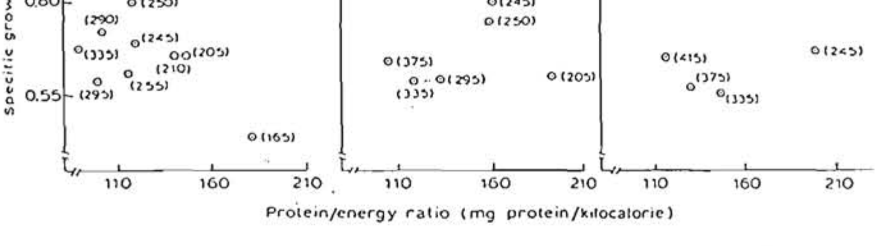

Fig. 1. — Specific growth rate of *Penaeus monodon* juveniles fed with diets with varying protein/energy ratios. Numbers in parentheses are energy levels (kcal/100 g) (Bautista 1986).

does not contain sufficient energy, protein may be used for supplying energy rather than for promoting growth. Therefore, one way of making the feed more economically efficient is by using the calorie sources as energy source and sparing the protein for growth.

Weight, feed efficiency and protein utilization of *P. monodon* juveniles increased with a constant dietary protein level and a increasing dietary energy level of up to 412.6 Kcal/100g (Hajra et *al.* 1988). In addition, a low calorie diet results in a high feed conversion ratio and hence, in low efficiency, implying that prawns consume more food to overcome energy insufficiency. From this, it appears that control of food consumption through dietary energy density is possible and is economical.

As to the source of nitrogen, Kanazawa (1985b) suggested that some extent, substituting soybean meal for the more expensive marine animal meals at a rate of 20-30 % is a feasible way to reduce prawn feed cost. Yang et *al.* (1988b) further indicated that the substitution rate could be increased to 40 % without significantly decreasing the growth rate. The effectiveness of soybean meal used as protein source for the feed of *P. monodon* was confirmed by Yang et *al* (1988a), and also by Wu and Yang (1989).

Table 2. Essential amino acid requirements of *Penaeus japonicus* and *P. monodon* (Kanazawa, 1985b).

Amino acid	*Penaeus japonicus*	*Penaeus monodon*
Alanine	–	–
Aspartic acid	–	–
Cystine	–	–
Glutamic acid	–	–
Glycine	–	–
Proline	–	–
Serine	–	–
Tyrosine	–	+
Arginine	+	+
Histidine	+	+
Leucine	+	+
Isoleucine	+	+
Lysine	+	+
Methionine	+	+
Phenylalanine	+	+
Threonine	+	+
Tryptophan	+	+
Valine	+	+
Author	Kanazawa and Teshima	Coloso and Cruz

+ : Essential; – : Non essential

AMINO ACIDS

Shigeno et *al.* (1972) reported that the diets which gave the best results were those that most closely approximated the amino acid composition of the prawn. Kitabayashi et *al* (1971c) contended that both arginine and methionine, at a concentration of 0.83 % and 0.52 %, respectively, have growth-promoting effects on *P. japonicus.* Kanazawa and Teshima (1981) proved that the essential amino acids (EAA) of *P. japonicus* are as follows : valine, methionine, isoleucine, leucine, phenylalanine, lysine, histidine, arginine, threonine and tryptophan. They indicated that the essential amino acids of *P. monodon* are approximately the same of those of *P. japonicus.* Deshimaru et *al.* (1985) also observed that the content and/or balance of the EAA is one of the major factors relating to the nutritional quality of the diet of *P. monodon* (Table 2).

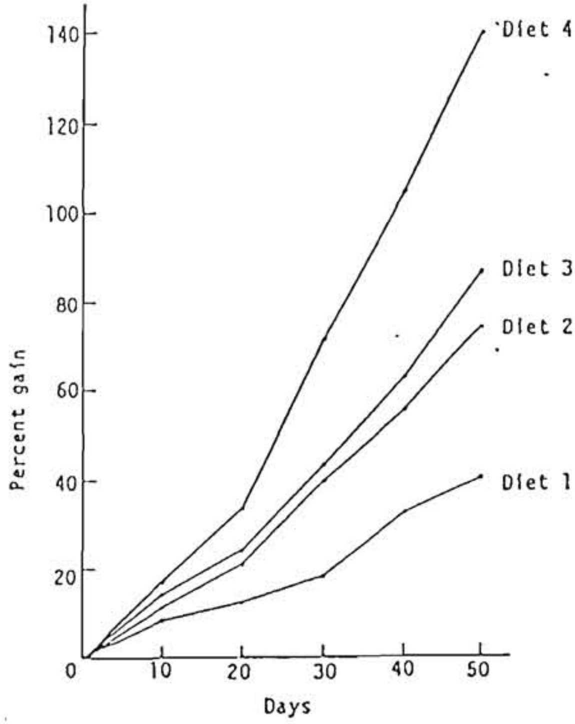

Fig. 2. — Effects of dietary linoleic and linolenic acids on the growth of *Penaeus japonicus.* Diet 1 : 5 % oleic acid; Diet 2 : 4 % oleic acid and 1 % linoleic acid; Diet 3 : 4 % oleic acid and 1 % linolenic acid; Diet 4 : 5 % pollack residual oil (Kanazawa et *al.*, 1977).

LIPID REQUIREMENTS

Essential Fatty Acids (EFA)

Nutritional studies on lipids have shown that several crustaceans require essential fatty acids (EFA) for their normal growth and that nutritive values of lipids for crustaceans are highly influenced by the dietary content of EFA. Teshima et al. (1976), Kanazawa and Teshima (1977) and Kanazawa et *al.* (1977b. 1979b) suggested that the linoleic (C18 : 2w6), linoleic (C18 : 3w3) and w3-long chain highly unsaturated fatty acid (HUFA) may be essential for the prawn, *P. japonicus* and that the nutritive value of linolenic acid was higher compared with linoleic acid (Fig. 2). Moreover, Kanazawa et *al.* (1978, 1979d) indicated that docosahexaenoic (C22 : 6w3) and eicosapentaenoic (C20 : 5w3) are more effective as EFA's rather than linoleic or linolenic acids. This is probably because *P. japonicus* is able to convert 18 : 3w3 to 20 : 5w3 and 22 : 6w3. The optimum content for each w3 is about 1 % (Kanazawa et *al.* 1979a) (Fig. 3, 4, 5, 6 and 7).

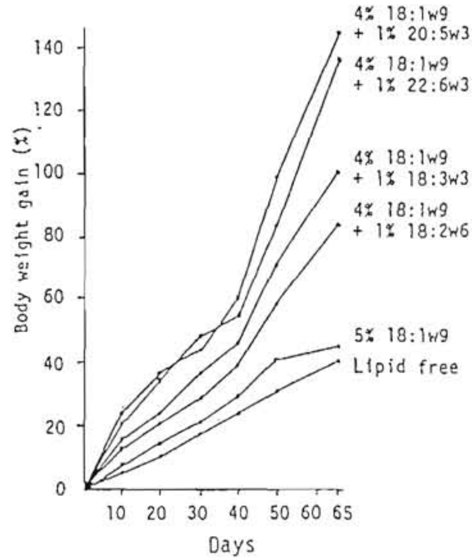

Fig. 3. — Growth of *Penaeus japonicus* fed with diets containing fatty acids (Kanazawa, 1985b).

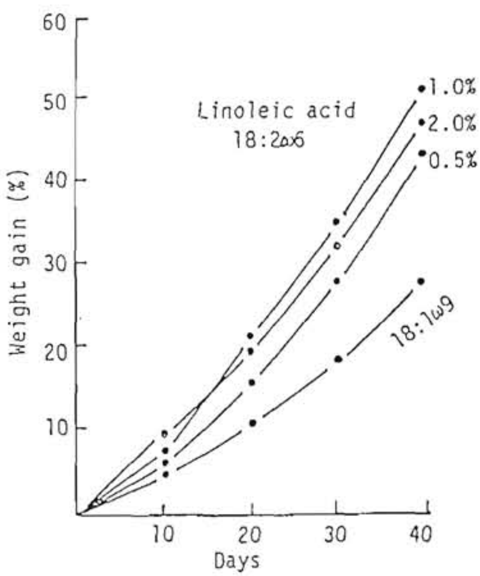

Fig. 4. — Effects of dietary linoleic acid on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

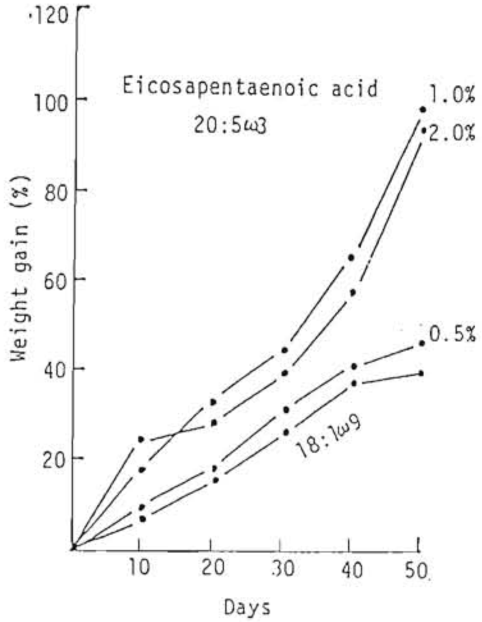

Fig. 5. — Effects of dietary eicosapentaenoic acid on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

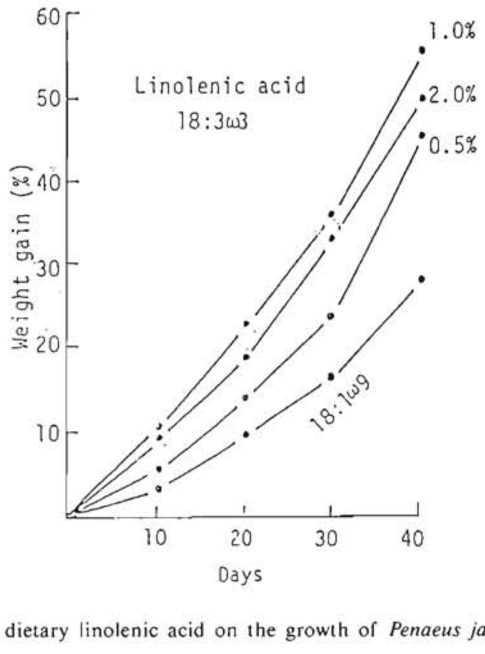

Fig. 6. — Effect of dietary linolenic acid on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

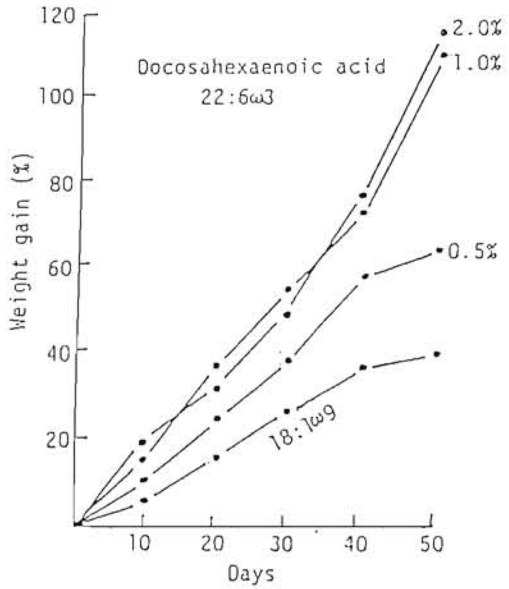

Fig. 7. — Effects of dietary docosahexaenoic acid on growth of *Penaeus japonicus* (Kanazawa, 1985b).

Regarding the effects of different dietary lipids on the growth of *P. japonicus*, Kanazawa et *al.* (1977a, 1979c) observed that the addition of either pollack residual oil or short-necked clam lipid (as compared with soybean oil) increased the percentage of 20 : 5w3 and 22 : 6w3 in lipids of the whole body of *P. japonicus.* Consequently, the fatty acid composition in lipids of *P. japonicus* is remarkably affected by dietary lipids. Deshimaru et *al.* (1979) mixed pollack liver oil and soybean oil in ratio ranging from 3 : 1 to 1 : 1 at 6 % lipid level. Use of these as dietary lipid source for *P. japonicus* resulted in good growth performance and feed efficiency for this species. Due to lack of HUFA, soybean oil may not be as good as squid visceral oil, as a source of lipid diet for *P. monodon* (Wang and Yeh 1987, Wang 1988, Wang and Yeh 1988).

Fatty acid such as C18 : 2w6, C18 3w3, C20 5w3 and C22 : 6w3 are considered as the EFA's for *P. monodon* (Kanazawa et *al.* 1979d), Wu (1983) reported that the C22 : 6, C22 : 1, C20 : 5, C18 : 3, C18 : 2, C18 : 0, C16 : 1, C16 : 0 and C14 : 0 acids were the main fatty acids of the lipid of *P. monodon.* The lipid composition of neutral and polar lipids is shown in Tables 3 and 4.

Bautista (1986) indicated that the inclusion of 15 % lipid in the diet was detrimental to the growth of *P. monodon.* This means that when *P. monodon* is fed with lipids higher that the amount they can normally tolerate, lipids may accumulate rapidly in their body and may cause an imbalance in the protein/energy ratio. This finding is consistent with that of Deshimaru and Kuroki (1974a). The latter reported that diets containing pollack liver oil of up to 6 % would improve the growth rate of *P. japonicus*, while at the 12 % level, it will inhibit growth. Wu (1986) also pointed out that 6 % lipid level contained in the diet would bring about the best growth in *P. monodon.*

Table 3. Lipid composition of neutral lipids in *Penaeus monodon* (Wu, 1983)

Lipids	Weight (%)					
	Muscle		Exoskeleton		Viscera	
	Male	Female	Male	Female	Male	Female
MG	tr	tr	8.6	8.1	tr	tr
ST	49.7	47.1	49.0	46.1	14.8	16.4
FA	10.7	6.1	tr	tr	3.7	2.6
DG	23.5	31.2	25.7	20.5	9.1	6.6
TG	16.1	15.6	14.7	22.0	69.5	72.0
SE	tr	tr	1.6	3.3	2.2	2.1

Table 4. Lipid composition of complex lipido in *Penaeus monodon* (Wu, 1983)

Lipids	Weight (%)					
	Muscle		Exoskeleton		Viscera	
	Male	Female	Male	Female	Male	Female
PE	19.6	22.0	22.5	22.9	26.2	16.8
PD	5.8	5.5	3.3	3.5	2.6	3.7
PC	56.8	51.8	63.9	61.2	61.0	68.9
Ps	11.8	13.1	6.4	5.9	4.8	4.8
Unknown	6.0	7.5	3.9	6.5	5.4	5.8

Sterol requirements

It was found that when prawn was fed with sterol-free diets, the sterol content of the body tissues decreased after feeding. However, in the case of the prawn fed with sterol-added diets, the sterol contents before and after feeding were the same. Furthermore, when the prawn was fed with sterol-added diets, it was found that 96-99 % of the sterol content was composed of cholesterol (Kanazawa et *al.* 1971b).

Table 5. Effect of dietary cholesterol levels on the growth and survival of *Penaeus japonicus* (Kanazawa et *al.*, 1971a).

Cholesterol added (g/100 g of diet)	Experimental period (days)	Nº of prawnat start	Rate of survival (%)	Rate of growth (%)
0.05	30	24	82	45
0.1	30	24	88	57
0.5	30	24	88	84
1.0	30	24	92	84

Teshima and Kanazawa (1971) also reported that cholesterol was the major sterol (73-100 %) in crustaceans. The growth and survival of *P.*

japonicus supplied with cholesterol-added diets are better compared with those fed with cholesterol-free diets (Kanazawa et *al.* 1971a). Table 5 shows the effect of cholesterol levels on growth of *P. japonicus*. Crustaceans are incapable of synthesizing cholesterol and require dietary sources of cholesterol or other sterols for normal growth and survival. Kanazawa et *al.* (1971a and b) showed that *P. japonicus* fed with diets containing ergosterol (C28), stigmasterol (C29) and i-sitosterol had survival rates similar to those of *P. japonicus* fed with cholesterol in the diet. Where growth rate was concerned, these sterols were inferior to cholesterol (Table 6). Teshima and Kanazawa (1987) confirmed that *P. japonicus* can convert i-sitosterol to cholesterol, possibly via the 24-methylene-cholesterol.

Table 6. Effect of various sterols on the growth and survival of *Penaeus japonicus* (Kanazawa et *al.*, 1971a).

Sterol added 0.5 g/100 g of diet	Rate of survival (%)			Rate of growth (%)		
	Experiment			Experiment		
	1	2	3	1	2	3
Cholesterol	95	86	88	72	98	56
Ergosterol	94	87	92	51	79	48
Stigmasterol	96	83	88	62	67	56
β-sitosterol	89	83	92	56	29	50

Number and average weight of surviving prawn were determined at the end of 30 or 40 day feeding trials.

Several authors (Kanazawa et *al.* 1971a, Shudo et *al.* 1971, Deshimaru and Kuroki 1974b, Teshima et *al.* 1974) estimate the optimum desirable content of cholesterol, as an effective growth-promoting factor, to be in following percentages : 0.5 %, 0.1 %, 0.05 %-1.0 % and 2.1 %. For *P.monodon*, more than 94 % of the sterol content was found to be cholesterol and the optimum level of cholesterol content was around 0.5 % (Wu 1983, 1986) (Table 7).

Table 7. Sterol contents of *Penaeus monodon* (WU, 1983).

Lipids	Weight (%)					
	Muscle		Exoskeleton		Viscera	
	Male	Female	Male	Female	Male	Female
Free ST	0.62	0.38	0.42	0.30	2.92	2.03
Total ST	0.63	0.38	0.45	0.33	2.78	2.35

Phospholipid Requirements

In one study (Teshima et *al.* 1986a), one group of *P. japonicus* was fed with 3 % soybean lecithin diet (phospholipid-supplemented diet or

PL-supplemented diet) and another group was fed with no supplemental phospholipid diet (PL-deficient diet) for 30 days. It was found that the PL-deficient significantly reduced the weight gain and feed efficiency (Fig.8). Further, the prawn contained a lower concentration of phospholipids, such as phosphatidylcholine (PC) and phosphatidylinositol (PI) in the whole body than the prawn receiving PL-supplemented diet. It was concluded that the nutritional role of dietray Pl was possibly related to the transport of dietary lipids, such as cholesterol and triglyceride, in the body. On the other hand, the retarded growth of *P. japonicus* receiving PL-deficient diet can be attributed to the insufficient mobilization of dietary lipids (Teshima et *al.*, 1986a, b, c and d, 1987).

The optimum level of PL for *P. japonicus* is about 1.0 % (Kanazawa et *al.* 1985), while for *P. penicillatus*, the value was estimated to be 1.25 % (Jenn and Chen 1988). Deshimaru et *al.* (1985) suggested that both polar-lipids and sterols may be essential ingredients in the diet of *P. monodon* and of *P. japonicus.*

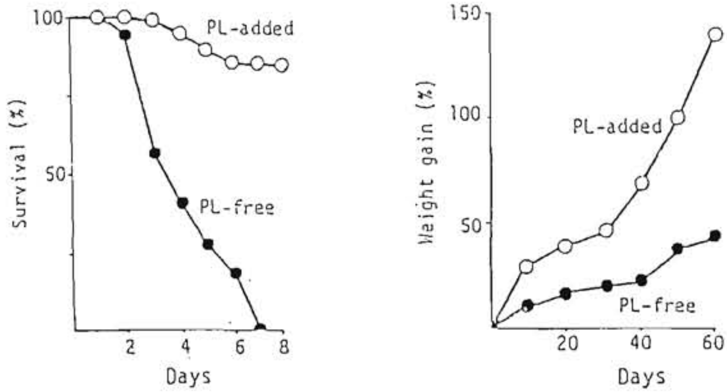

Fig. 8 A. — Survival rate of larval *Penaeus japonicus* fed on PL-added and PL-free diets (Kanazawa, 1985b).

B. — Weight gain of juvenile (1g) *Penaeus japonicus* fed on PL-added and PL-free diets.

Carbohydrate Requirement

As mentioned above, energy production from protein oxidation is both nutritionally and economically wasteful. Therefore, it is necessary to supply protein for growth by optimizing the level of nonprotein energy sources. The type and level of carbohydrate in the diet have been proven to affect the growth and survival of *P. japonicus* (Deshimaru and Yone 1978b).

According to Deshimaru and Yone (1978b), the desirable sources of dietary carbohydrate for *P. japonicus* are sucrose and glycogen, while less suitable sources are starch, dextrin and particularly glucose. The growth, weight gain, feed efficiency and mortality of *P. japonicus* fed with various carbohydrate sources are shown in fig. 9 and 10. Abdel-Rhaman et *al.* (1979) observed that the dietary glucose was absorbed rapidly in comparison with disaccharides and polysaccharides, but Kanazawa (1985b)

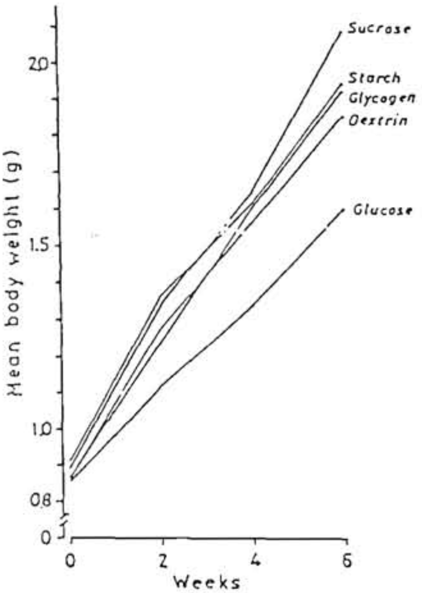

Fig. 9. — Growth curves of *Penaeus japonicus* fed with the test diets (Deshimaru and Yone, 1978).

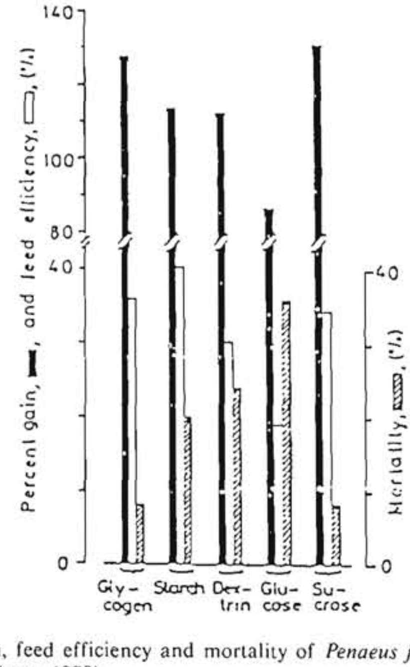

Fig. 10. — Percent gain, feed efficiency and mortality of *Penaeus japonicus* fed on the test diets (Deshimaru and Yone, 1978).

pointed out that the absorbed glucose was probably not utilized efficiency for the growth of *P. japonicus* (Fig. 11). He also demonstrated that diets containing 19.5 % maltose brought about the best growth performance for this species. Similar results were obtained by Deshiamru and Kuroki (1974a) for the same species.

Glucosamine can also be used as carbohydrate source at a content level of 0.53 % (Kitabayashi et *al.*, 1971a). Its growth-promoting effect has been reconfirmed by Kanazawa (1985b), as shown in Fig. 12.

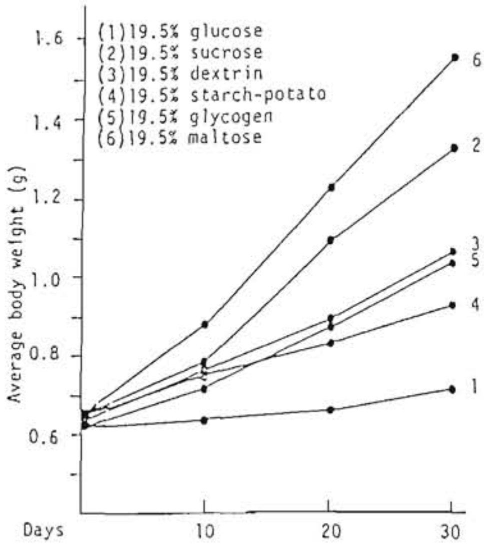

Fig. 11. — Effect of dietary carbohydrates on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

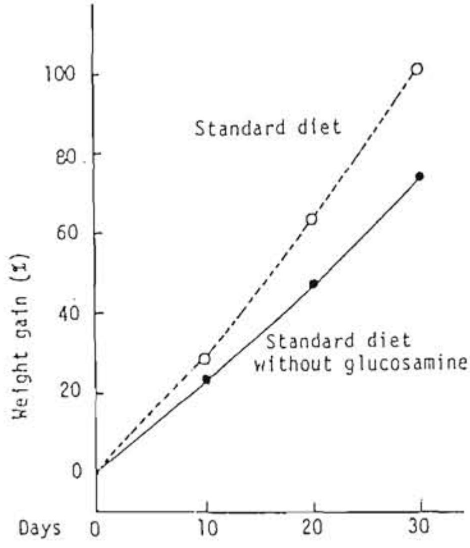

Fig. 12. — Effect of dietary glucosamine on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

For *P. monodon*, Pascual et *al.* (1983) found that the highest survival rate (56 %) was obtained in juveniles fed with a diet containing 10 % sucrose (Fig. 13). However, the growth was generally poor on all the trials using carbohydrate-containing diets (Table 8). In addition, histopathological changes were observed at all levels of carbohydrate content. Pascual et *al.* (1983) suspected that sucrose is the « best » source of carbohydrate for *P. monodon.*

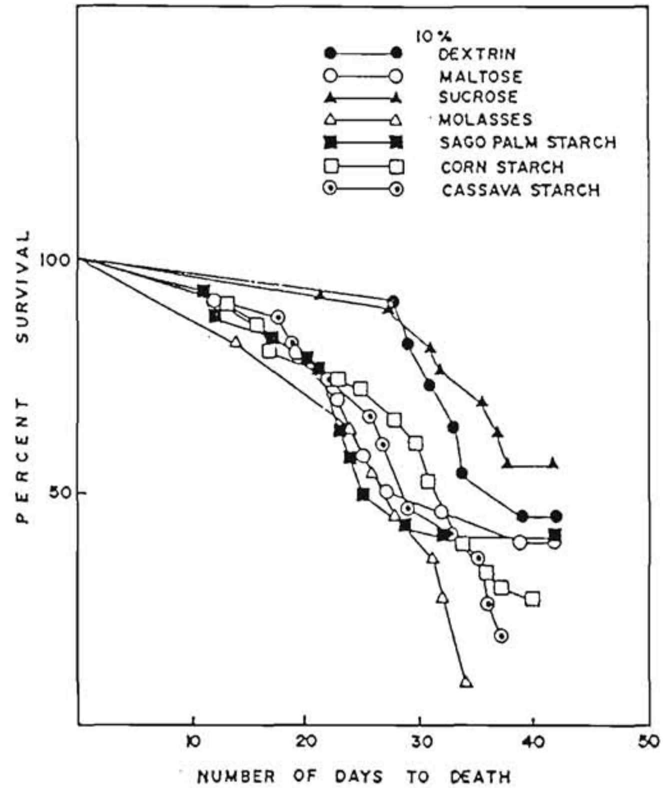

Fig. 13. — Survival vs. time before death curves of *Penaeus monodon* juveniles fed with various carbohydrates at 10 % level in the diet (Pascual et *al.*, 1983).

Table 8. Mean survival rate and weight gain of juvenile *Penaeus monodon* fed with diets containing various carbohydrate levels, after 6 weeks of rearing (Pascual et *al.*, 1983).

Carbohydrate Level (%)	Survival rate (%)		Average weight gain (%)	
	10	40	10	40
Dextrine	(22) 36	(23) 23	24	34
Maltose	(23) 35	(23) 0	5	—
Sucrose	(23) 56	(22) 38	7	28
Molasses	(22) 0	(21) 0	—	—
Sago palm starch	(22) 42	(22) 0	7	—
Cornstarch	(23) 27	(22) 32	14	26
Cassava strarch	(23) 0	(21) 0	—	—

Supporting this view, Alava and Pascual (1987) observed that *P. monodon* fed with a diet containing 20 % trehalose brought about the highest gain and survival, followed by sucrose ; glucose ranked last. Carbohydrate, at its optimum value, could be used as precursor for the various metabolic intermediates necessary for growth, i.e., dispensable amino acids. However, if the amount is too high, energy utilization tends to be less efficient, resulting in poor digestibility. An optimum dietary sugar level for *P. monodon* is therefore considered to be 20 % (Bautista 1986; Alava and Pascual, 1987).

MINERAL REQUIREMENTS

Little is known about the mineral requirements of prawn, due to the limited studies in this field. Kitabayashi et **al**. (1971a) considered that 1.04 % of Phosphorus (P) and 1.24 % of calcium (Ca) are indispensable in the diet for *P. japonicus*. Kanazawa et **al**. (1984) observed that the suitable levels of Ca, P, Potassium (K) and Magnesium (Mg) in diets for *P. japonicus* juveniles were 1.0 %, 0.9 % and 0.3 % respectively. Deshimaru and Yone (1978a) suggested that 2 % of P, 1 % of K and 2 % of trace metals should be supplemented into a purified diet for favorable growth of *P. japonicus*, while Ca, Mg and Iron are indispensable. The data available for the mineral requirement of *P. japonicus* are shown in Table 9.

Table 9. Mineral requirements of juvenile *Penaeus japonicus* (Kanazawa, 1985b).

Minerals	Requirements (%)	
	Kanazawa	Deshimaru and Yone
Ca	1.0	Dispensable
P	1.0	2.0
K	0.9	1.0
Mg	0.3	Dispensable
Mn	Dispensable	—
Fe	Dispensable	Dispensable
Cu	0.06	—
Trace metals	—	0.2

VITAMIN REQUIREMENTS

The growth of *P. japonicus* was remarkably accelerated by adding ascorbic acid into a diet containing a fixed amount of glucose (Kitabayashi et *al.*, 1971b). Kanazawa et *al.*(1976) estimated the adequate levels of choline chloride and inositol in the diet to be 60 mg and 200 mg, respectively, for each gram of the diet. In addition, the desirable level of dietary ascorbic acid, inositol, thiamine (B1) and pyridoxine (B6) were approximately evaluated at 300 mg, 400 mg, 6-12 mg and 12 mg, respectively (Deshimaru and Kuroki 1976, 1979).

The vitamin deficient diet could cause high mortality in *P. japonicus* larvae and may inhibit the larval development; most likely, the prawn larvae will fail to reach the postlarvae stage. Kanazawa (1985a) studied the effect of vitamin on the growth and survival of *P. japonicus*. The results of his experiments are shown in Fig. 14, 15, 16, 17 and 18. Desirable vitamin requirements for both larvae and juveniles of *P. japonicus* are shown in Table 10.

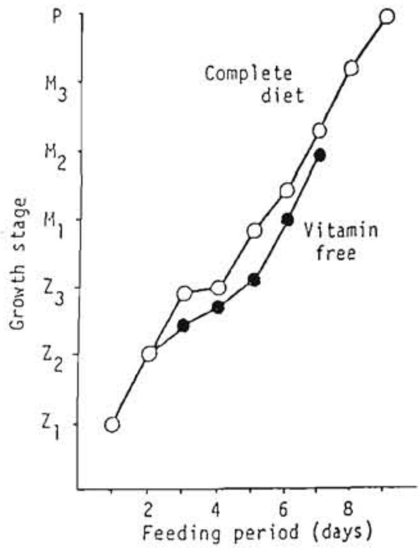

Fig. 14. — Effect of vitamin on the growth of *Penaeus japonicus* (Kanazawa, 1985b).

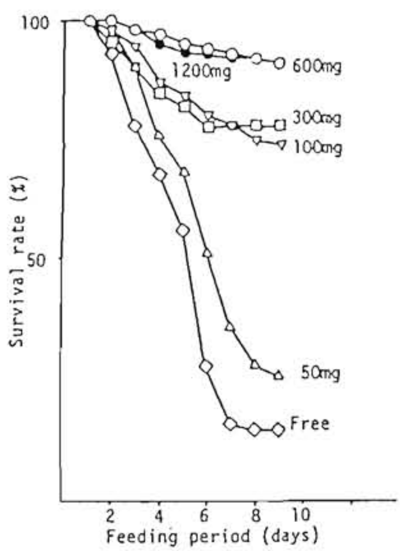

Fig. 15. — Effect of choline-Cl levels on survival of *Penaeus japonicus* (Kanazawa, 1985b).

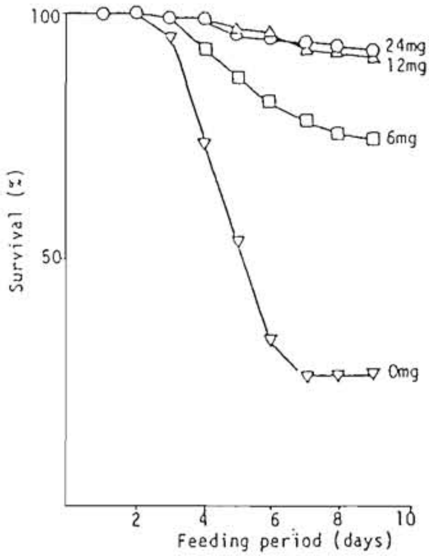

Fig. 16. — Effect of pyridoxine-HCl levels on survival of *Penaeus japonicus* larval (Kanazawa, 1985b).

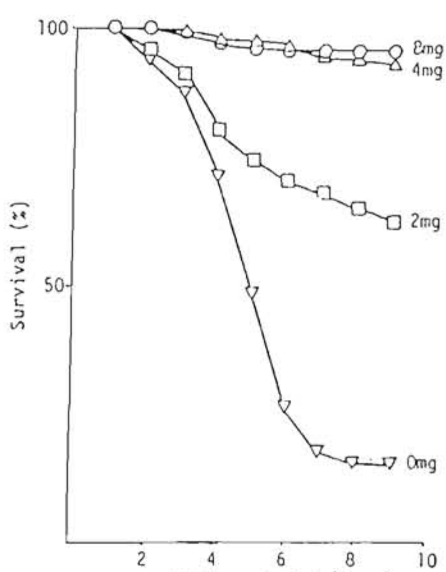

Fig. 17. — Effect of thiamine-HCl levels on survival of *Penaeus japonicus* larval (Kanazawa, 1985b).

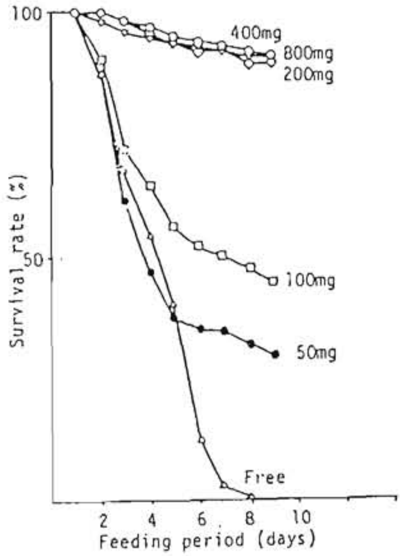

Fig. 18. — Effect of inositol levels on survival of *Penaeus japonicus* (Kanazawa, 1985b).

Table 10. Vitamine requirement of juvenile *Penaeus japonicus* (Kanazawa, 1985b).

Minerals	Requirements (%)	
	Kanazawa	Deshimaru and Yone
Ascorbic acid	1000-2000	300
Choline	600	Dispensable
Inositol	200	400
Thiamine	—	6-12
Pyridoxine	—	12

EFFECT OF ENZYMES ON DIGESTION

Enzymes originating from animals food sources (exogenous enzymes) have been shown to affect prawn digestion positively. Maugle et *al.* (1982) indicated that protease and amylase act to control the utilization of dietary food *P. japonicus.*. Furthermore, Maugle et *al* (1983) reported that bovine trypsin dietary supplements may have activated the endogenous protease zymogen of *P. japonicus*, resulting in increased growth and a complete cycle of protease activities. They also found that the hepatopancreas was the primary site of enzyme secretion (Fig. 19). In contrast, Lin and Chen (1988) contended that the growth of postlarvae of *P. monodon* was not correlated with midgut gland amylase or protease activities, although the inclusion of exogenous enzymes *(P. monodon* hepatopancreas acetone powder) in the diets significantly promoted growth. Hence, further studies concerning the effect of exogenous enzymes on the endogenous enzymes should be encouraged.

Vogt et *al.* (1985) suggested that R-cells of the hepatopancreas could be used to monitor the nutritional value of prawn diets. The effect of feed was visible on the cellular or organ level after only a few days of feeding, whereas the effect on the individuals (organism level) occured after 10 days. Therefore, it is suggested that histology may be applied to nutrition studies to provide supplementary information to statistical and biochemical parameters (Vogt et *al.*, 1986).

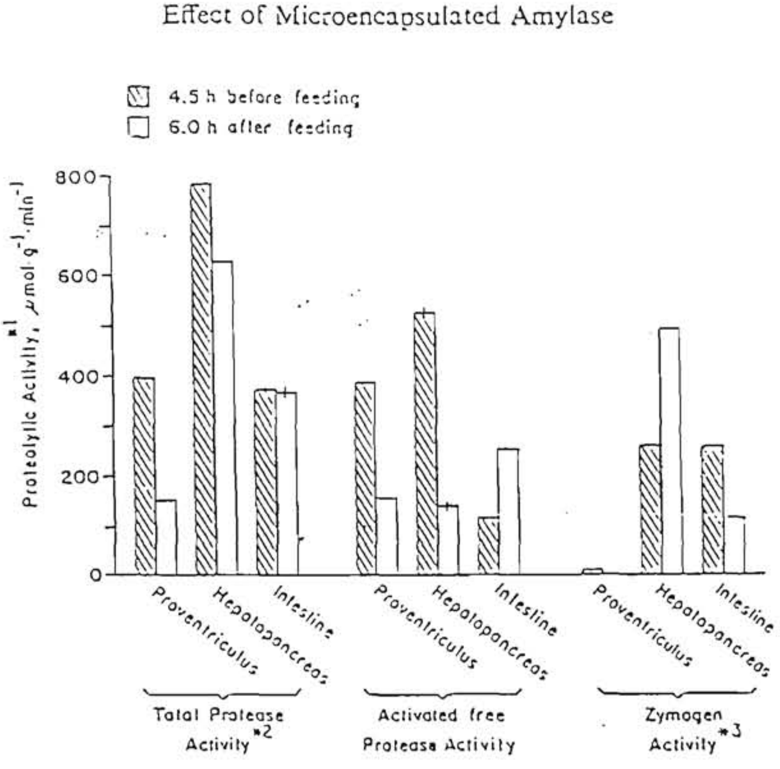

Fig. 19. — Activities of protease and protease-zymogen in the proventriculus, hepatopancreas, and intestine of the shrimp 4.5h before and 6.0h after feeding with a control diet which did not contain digestive enzyme microcapsule supplement (Maugle, 1983).

* 1. As μmol tyrosine liberated per g wet tissue per minute

* 2. Activated free protease activity + protease-zymogen activity

* 3. Total protease activity - activated free protease activity.

In the hepatopancreas, except for the protease and amylase, a specific trypsin-like enzyme was visible in the cell near the sides of the intestine (Liu 1986, Liu and Shyong 1987). Through histological methods, it was also found that there were small blind tubules in the hepatopancreas of *P. monodon.* In addition, protease in the hepatopancreas was categorized as a carboxypeptidase A-like, B-trypsin-like and C-trypsin-like enzymes (Liu and Shyong 1987).

DEVELOPMENT OF LARVAL MICROPARTICULATE DIET

Research on compounded diet for *P. monodon* larvae has remained scarce. Forster (1973) reported that *P. monodon* larvae fed with a compounded diet showed good survival but slow growth, as compared with those fed with fresh food. Khannapa (1977) found that 30 % protein in diet is suitable for *P. monodon* larvae. Bages and Sloane (1981) further demonstrated that feeding *P. monodon* postlarvae exclusively with the compounded diet retarded growth, with the survival rate between 39 and 74 %.

Results of research on compounded diet have not been very encouraging, as can be gleaned from the above studies. Natural food has still proven to be more effective than artificial food. Nevertheless, because the use of natural food entails many inconveniences, research on the development of artificial diet must be emphasized. Fortunately, researchers are still persevering towards this direction and some novel products have recently emerged.

Microparticulate diet (MD) is a newly developed product found effective for prawn larvae. Several types of microparticulate diets, such as artificial plankton B.P. (Liao et *al.*, 1988b), nylon-protein microencapsulated diet (Nylon MED), zein microcoated diet (Zein MCD) and carrageenan micro-bound diet and others have been used successfully in rearing prawn larvae. In one study which used microparticulate diet, the survival rate obtained was 94 % (Kanazawa et *al.* 1982). The dietary value of these microparticulate diets is almost comparable with that of live food, such as *Chaetoceros* sp. and *Artemia salina* (Kanazawa et *al.* 1982, 1985; Teshima et *al.* 1982; Teshima and Kanazawa 1983).

Microparticulate diet for *P. monodon* larvae was also tried and the survival rate of experimental MD and control (*Skeletonema, Artemia*) groups were 40 % and 20 %, respectively (Kuo 1986). In addition, a simple but satisfactory microencapsulation method for laboratory nutrition studies with postlarvae of *P. monodon* was introduced by Chen and Tsai (1986), who revealed that the w3 polyunsaturated fatty acid requirement of *P. monodon* is no less than 0.5-1 %, as reported for *P. japonicus.*

Likewise, the microencapsulated feed could be used to replace part or all of the conventional live food diet. The survival of the *P.monodon* larvae fed with MED may be superior to that larvae fed with live food. In addition, the application of MED reduces labor, raising its economic value (Jones et *al.*, 1987). A similar result was obtained by using cross-linked protein-walled microcapsules to feed mysis and postlarvae of *P. monodon*; 80-100 % growth and survival rates were obtained (Clark et *al.*, 1987). Liao et *al.* (1989b) found that the particle size of artificial diet was not a limiting factor in the growth and survival of *P. monodon* larvae. Moreover, Liao et *al.* (1989a) proved the feasibility of using several kinds of microbound diet (MBD) in rearing *P. monodon* larvae (Zoea to postlarvae), since the survival rates in all MBD groups were higher than 50 %.

CONCLUSION

To date, although some progress has been achieved in this respect, knowledge on the nutritional requirements of *P. monodon* is still too insufficient to provide reference for effective diet levels. More extensive and detailed research in nutrition must be carried out, covering such topics as feeding behavior and preferences of prawn, optimization of the nutritional requirements, nutritional variation during manufacturing of MED, mechanism of digestive enzymes and acceptability of feed given.

While *P. monodon* culture has now become well established and has come to occupy an important place in the entire prawn production industry, new problems continue to emerge and challenge its stability. Since nutrition is a highly crucial factor, with feed accounting for about half of total production cost, the industry will need all the research and development support it can get in this area.

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