Aquaculture Nutrition

Aquaculture Nutrition 2012 doi: 10.1111/j.1365-2095.2012.00962.x

Nutrient composition of fairy shrimp *Streptocephalus sirindhornae* nauplii as live food and growth performance of giant freshwater prawn postlarvae

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Abstract

Nutritional efficacy of fairy shrimp (*Streptocephalus sirindhornae*) nauplii, as a live food, was studied for growth performance and survival rate of giant freshwater prawn (*Macrobrachium rosenbergii*) postlarvae. A feeding experiment was designed with four different feeds: dry commercial feed, fairy shrimp nauplii, *Artemia* sp. nauplii and adult *Moina macrocopa*. Results from the nutritional composition revealed that fairy shrimp nauplii had protein and lipid contents of 54.58 ± 2.8 g kg^{-1} and 255 ± 2.8 g kg^{-1}, respectively. The highest value for an individual amino acid in fairy shrimp was lysine (140.7 ± 1.6 g kg^{-1}). The essential amino acids content in the whole body of the larval prawns was in the range of 66.7–67.5 g kg^{-1}. Fairy shrimp nauplii had the highest essential amino acid ratio (A/E) of lysine, similarly, in musculature of prawn larvae. Weight gain and specific growth rate of the postlarvae fed with fairy shrimp nauplii were significantly higher than those fed with *Artemia* nauplii, adult *Moina* and dry commercial feed. The presented results suggest that *S. sirindhornae* nauplii can be used as a nutritionally adequate food for freshwater prawn *M. rosenbergii* postlarvae.

KEY WORDS: Anostraca, *Artemia*, essential amino acid, fatty acid, *Macrobrachium rosenbergii*, *Moina*

Received 3 December 2011; accepted 9 March 2012

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Introduction

Fairy shrimp are entomostracan crustaceans living in ephemeral waters worldwide. To date, three species – *Streptocephalus sirindhornae* Sanoamuang, Murugan, Weekers and Dumont; *Branchinella thailandensis* Sanoamuang, Saengphan and Murugan; and *S. siamensis* Sanoamuang and Saengphan – have been recorded in Thailand. They belong to the phylum Arthropoda, subphylum Crustacea, class Branchiopoda and order Anostraca (Sanoamuang *et al*. 2000, 2002; Sanoamuang & Saengphan 2006). Currently, they can be successfully cultured in circular concrete outdoor ponds and earthen ponds for mass production (Sriputhorn & Sanoamuang 2011). Adults of these fairy shrimp species contain high levels of protein, 502–744 g kg^{-1}, and essential amino acids of 439.6–784.9 mg g^{-1} dw (Dararat *et al*. 2012). They can be used as suitable feeds for aquatic animals such as ornamental fish and giant freshwater prawn (Saejung *et al*. 2011; Sornsupharp 2012). The nutritional importance of fairy shrimps in terms of protein and as a carotenoid source for fish and prawn has been highlighted because of their high individual biomass, high reproductive rate and rapid growth (Munuswamy *et al*. 1997; Dararat *et al*. 2011). The giant freshwater prawn, *Macrobrachium rosenbergii* (de Man), is an important aquaculture species in Thailand and other Southeast Asian countries (New 2005). Success in aquaculture is based on various criteria, where selection of a suitable feed and its potential use is important (Velu & Munuswamy 2007). It is well established that live feed organisms are favoured more than artificial feeds in larval and early postlarval stages of various fish and shellfish (Lee *et al*. 2010; Dahms *et al*. 2011). Sornsupharp (2012) studied the digestibility of dried fairy shrimp *S. sirindhornae* as a feed ingredient for flower-horn fish and found that the dried fairy shrimp meal is a suitable food for smaller sized fish. Growth and survival of freshwater prawn are highly dependent on the type of feeds provided at early postlarval stages (Alam *et al*. 1993). The postlarval stages of the giant freshwater prawn are highly

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predacious in nature and they prefer live feed organisms (Martín *et al*. 2006; Das *et al*. 2007). Their larvae cannot be easily acclimatized with artificial feeds. Live feeds supply all the necessary nutrients for development and can contribute exogenous digestive enzymes that aid in digestion (Barros & Valenti 2003a; Dahms *et al*. 2007a). Live feed, for example, *Moina* sp., *Artemia* spp. and fairy shrimp nauplii, can be used for aquaculture organisms. However, several authors believe that *Artemia* nauplii do not fulfil the nutritional requirements of prawn larvae and therefore recommend the use of supplementary diets (New 2002). The possibility of using fairy shrimps as a live feed for giant freshwater prawn culture was suggested by Velu & Munuswamy (2008). Sriputhorn & Sanoamuang (2011) evaluated the potential of the adults of the fairy shrimp *S. sirindhornae* as a live feed for growth and enhancement of the carotenoid content in freshwater prawn. They found that the prawns showed high specific growth rate (SGR), survival rate and a low feed conversion ratio. Therefore, supplementation of live feed organisms is necessary when used as food at the postlarval stages of prawns. Therefore, this study investigated the nutrient composition of the fairy shrimp *S. sirindhornae* nauplii and their potential as live food for growth performance of giant freshwater prawn postlarvae.

Materials and methods

Food preparation and feeding

Dry commercial food for giant freshwater prawn (*M. rosenbergii*) larvae was purchased from Grobest Corporation Ltd., Phetchaburi Province, Thailand. Fairy shrimp (*S. sirindhornae*) eggs were hatched according to the procedure described by Saengphan *et al*. (2005). Fairy shrimp samples were collected alive at the instar-I stage (1 day of age; mean length, 0.36 ± 0.04 mm) and provided daily as food. *Artemia* sp. (bisexual) eggs, Great Salt Lake strain, INVE (Thailand) Ltd., Pichit Province, Thailand, were hatched according to the procedure described by New (2002), and the nauplii were collected alive at instar-I (1 day of age; mean length, 0.71 ± 0.09 mm) and provided daily for feeding. Adult *Moina macrocopa* (Straus, 1820) with a mean length of 0.72 ± 0.17 mm were obtained from the Inland Fisheries Research and Development Institute, Khon Kaen Province, Thailand, and continuous cultures were maintained using *Chlorella* sp. as a staple food. During the complete rearing cycle, freshwater prawn larvae were exclusively fed with dry commercial food, fairy shrimp nauplii, *Artemia* nauplii, and adult *Moina*.

Experimental trials

Experimental postlarvae of *M. rosenbergii* were obtained from an aquaculture farm in Suphanburi Province, Thailand, and acclimatized to laboratory conditions at Khon Kaen University. Giant freshwater prawn larvae were reared for 30 days in 100 L PE tanks at the Applied Taxonomic Research Center, Khon Kaen University. Two hundred prawn postlarvae (PL1) per PE tank with an initial weight of 9.94 ± 0.13 mg were fed in four treatments each with different feeds in four replicates. Water was exchanged every day (10%) to remove remaining feed from the previous day by siphoning. After water exchange, live feed was offered twice a day at 10% of total body weight, at 8:00 h and 16:00 h. At the end of the experiment, length and weight of thirty prawns per tank were determined. Growth rate (GR), weight gain (WG), SGR and survival rate (SR) were calculated following the method from Chettri *et al*. (2007).

Proximate composition analysis

Nutrient composition content of four experimental feeds [dry commercial feed (control), fairy shrimp nauplii, *Artemia* nauplii and adult *Moina*] was determined according to standard methods (AOAC 1995). Preparations of four different feeds were dried in an electric oven at 60 °C for 4 h. Moisture was determined by oven drying at 105 °C for 24 h. Crude protein ($N \times 6.25$) was determined by the Kjeldahl method after acid digestion using a Kjeldahl System. Crude lipid was gained by the ether extraction method using a Soxhlet extractor. Ash content was determined by muffle furnace at 550 °C for 5 h. Crude fibre was determined by the fritted glass crucible method and ash was determined by a muffler furnace, exposing the samples to 550 °C for 4 h. The content of carbohydrate was calculated from the difference of the percentages between crude protein, moisture, crude fibre and ash.

Amino acid analysis

Acid oxidation was performed prior to hydrolysis to oxidize cystine and methionine. Sodium metabisulfite was added to decompose performic acid before hydrolysis. Proteins were hydrolysed with 6 M HCl. Hydrolysates were diluted with sodium citrate buffer or neutralized, pH was adjusted to 2.20 and individual amino acid components were separated by ion-exchange chromatography (AOAC 2000 method 994.12). Amino acids were determined using GC-MS (GC: Agilent technologies model 6890N made in

Germany and MS: Agilent technologies model 5973 made in USA) equipped with a Phenomenex Zebron ZB-AAA (10 m × 0.25 mm) column. The protein-bound tryptophan was not analysed, because it was destroyed by acid hydrolysis.

Fatty acid analysis

Fatty acids were determined by a hydrolytic method according to the standard method 996.06 AOAC (2000). Lipids were extracted into ether, then methylated to fatty acid methyl esters (FAMEs) using BF_3 in methanol; the FAMEs were then quantitatively measured by capillary gas chromatography (GC-MS, GC: Agilent technologies model 6890N made in Germany and Ms: Agilent technologies model 5973 made in USA). The GC was equipped with a capillary column (SP-2560, 100 m × 0.25 mm ID, 0.20-μm films and a fused silica capillary) using helium as a carrier gas. Injection was performed by the split method at 260 °C. FAMEs were separated with the following oven programme: (a) 140 °C for 5 min; (b) increase at a rate of 4 °C min^{-1} up to 240 °C. The fatty acids were identified with reference to the retention time and gas chromatography. Total fat was calculated as the sum of individual fatty acids expressed as triglyceride equivalents. Saturated and unsaturated fats were calculated as the sum of respective fatty acids.

Statistical analysis

All data were subjected to statistical verification using one-way analysis of variance. Significant differences between means were evaluated by a Duncan's multiple range test (Steel & Torrie 1980). Differences were regarded as significant at $P < 0.05$.

Results

The proximate composition of the experimental feeds (dry commercial feed, fairy shrimp nauplii, *Artemia* nauplii and adult *Moina*) are presented in Table 1. Significant differences ($P < 0.01$) in the protein, lipid, carbohydrate, fibre and ash contents were observed between the samples. The highest protein levels were determined in adult *Moina*, followed by fairy shrimp nauplii, *Artemia* nauplii and dry commercial feeds as 585 ± 0.8 g kg^{-1}, 546 ± 5 g kg^{-1}, 538 ± 4 g kg^{-1} and 414 ± 2 g kg^{-1}, respectively. The lipid content in fairy shrimp nauplii was the highest (255 ± 2.3 g kg^{-1}) among all feed compositions. Commercial dry feed had higher amounts of carbohydrate (278 ± 2.3 g kg^{-1}) and ash (162 ± 0.7 g kg^{-1}) than the other feed compositions. The fibre content, however, in fairy shrimp nauplii was not significantly different from the other feeds. Significant differences ($P < 0.01$) in dry weight amino acid composition (g kg^{-1} dry diet) in different feeds showed that adult *Moina* had a higher total amino acid (TAA) content than fairy shrimp nauplii, followed by *Artemia* nauplii and dry commercial feeds (Table 2). Individual amino acids in the dry commercial feeds had a high glutamic acid content (55.7 ± 0.8 g kg^{-1} dry diet), followed by aspartic acid, alanine, glycine and leucine. However, fairy shrimps had the highest lysine content (140.7 ± 1.6 g kg^{-1} dry diet) followed by tyrosine, leucine, phenylalanine and glutamic acid. *Artemia* nauplii had a high content of glutamic acid (72.8 ± 0.5 g kg^{-1} dry diet), followed by aspartic acid, alanine, leucine and tyrosine. Similarly, adult *Moina* included individual amino acids such as glutamic acid (82.7 ± 1.2 g kg^{-1} dry diet), aspartic acid, leucine, tyrosine and alanine.

Amino acid concentrations in the body of *M. rosenbergii* fed with different feeds showed some correlations (Table 3). A significant difference ($P < 0.01$) in the dry weight of TAA composition was noted in the body. The postlarvae fed with fairy shrimp nauplii had the highest TAA (678.8 ± 2.2 g kg^{-1} dry weight) followed by *Artemia* nauplii (663.9 ± 2.6 g kg^{-1} dry weight), dry commercial feed (644.1 ± 1.9 g kg^{-1} dry weight) and adult *Moina* (632.8 ± 0.7 g kg^{-1} dry weight). The essential amino acid (EAA) contents of the body from postlarvae fed upon

Table 1 Proximate composition (g kg^{-1} dry diet) of feeds used in the present study

Nutrient composition	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Protein	414 ± 2^{d}	546 ± 5^{b}	538 ± 4^{c}	588 ± 0.8^{a}
Lipid	64 ± 0^{d}	255 ± 2^{a}	187 ± 0.3^{b}	82 ± 2^{c}
Carbohydrate	278 ± 2^{a}	30 ± 2^{d}	59 ± 2^{c}	110 ± 1.9^{b}
Moisture	51 ± 0.5^{c}	54 ± 4^{c}	88 ± 2^{b}	106 ± 0.6^{a}
Fiber	31 ± 0.6^{b}	46 ± 0.2^{ab}	63 ± 5^{a}	56 ± 12^{a}
Ash	162 ± 0.7^{a}	69 ± 0.2^{b}	66 ± 4^{b}	61 ± 2^{c}

Values are means ± standard deviations, $n = 3$. Mean values in rows followed by different superscript are significantly different ($P < 0.01$).

Table 2 Amino acid concentrations (g kg^{-1} dry diet) of four different feeds

Amino acid	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Alanine	26.21 ± 0.73^{b}	17.78 ± 0.38^{c}	36.74 ± 1.60^{a}	40.22 ± 1.45^{a}
Aspartic acid	40.60 ± 1.44^{c}	21.02 ± 0.81^{d}	49.24 ± 0.97^{b}	56.29 ± 1.38^{a}
Glutamic acid	55.69 ± 0.79^{c}	32.27 ± 1.41^{d}	72.84 ± 0.50^{b}	82.67 ± 1.21^{a}
Glycine	25.82 ± 0.24^{a}	12.02 ± 0.50^{c}	21.18 ± 0.47^{b}	27.21 ± 1.13^{a}
Histidine	7.64 ± 0.08^{c}	23.75 ± 1.61^{a}	8.17 ± 0.19^{c}	12.08 ± 0.26^{b}
Isoleucine	4.98 ± 0.19^{c}	22.36 ± 0.69^{a}	19.79 ± 0.12^{b}	22.51 ± 0.54^{a}
Leucine	21.14 ± 0.81^{d}	41.10 ± 0.32^{b}	35.23 ± 0.51^{c}	44.92 ± 1.29^{a}
Lysine	19.04 ± 0.27^{c}	140.65 ± 1.64^{a}	34.41 ± 0.35^{b}	38.68 ± 1.09^{b}
Methionine	7.34 ± 0.19^{c}	9.08 ± 0.22^{c}	11.43 ± 0.25^{b}	29.80 ± 1.01^{a}
Phenylalanine	14.46 ± 0.04^{d}	40.04 ± 1.66^{a}	22.22 ± 0.30^{c}	27.68 ± 0.77^{b}
Proline	17.50 ± 0.14^{c}	17.31 ± 0.45^{c}	28.79 ± 0.12^{a}	27.02 ± 0.48^{d}
Serine	17.29 ± 0.32^{c}	7.75 ± 0.56^{c}	29.85 ± 0.52^{a}	27.72 ± 0.37^{d}
Threonine	10.96 ± 0.34^{c}	7.85 ± 0.58^{d}	22.70 ± 0.24^{a}	26.85 ± 0.28^{b}
Tyrosine	14.65 ± 0.14^{c}	45.00 ± 0.87^{b}	35.08 ± 0.22^{c}	54.70 ± 1.33^{a}
Valine	6.61 ± 0.22^{d}	20.95 ± 0.64^{b}	23.43 ± 0.13^{a}	12.86 ± 0.75^{c}
TAA	289.93 ± 1.54^{c}	458.96 ± 2.32^{b}	451.12 ± 2.13^{b}	531.22 ± 1.41^{a}
EAA (%)	31.79	66.63	39.32	40.55
NEAA (%)	68.21	33.37	60.68	59.45

TAA, total amino acid; EAA, essential amino acid; NEAA, non-essential amino acid.
Values are means ± standard deviations, $n = 3$. Mean values in rows followed by different superscript are significantly different ($P < 0.05$).

different feeds were in the range of 667–675 g kg^{-1}. Non-essential amino acids (NEAA) ranged between 324 g kg^{-1} and 333 g kg^{-1}. Individual amino acid concentrations in the body of *M. rosenbergii* fed with fairy shrimp nauplii had the highest levels of lysine, glutamic acid and phenylalanine (214.4, 61.3 and 60.7 g kg^{-1} dry weight, respectively). The body of postlarvae fed with dry commercial feed had the highest levels of lysine, phenylalanine and leucine (207.9, 59.4 and 57.9 g kg^{-1} dry weight, respectively). The body of postlarvae fed with *Artemia* nauplii had the highest levels of lysine, phenylalanine and leucine (212.6, 62.2 and 59.1 g kg^{-1} dry weight, respectively). The body of postlarvae fed with adult *Moina* had the highest levels of lysine, phenylalanine and leucine (202.6, 57.0 and 56.7 g kg^{-1} dry weight, respectively).

The essential amino acid ratio (A/E) of in different feeds showed that fairy shrimp nauplii had the highest A/E ratio of lysine, leucine and phenylalanine (460, 134 and 131, respectively) (Table 4). The highest A/E ratio in the dry commercial feed was provided by leucine, lysine and phenylalanine (229.4, 206.9 and 156.88, respectively). The A/E ratio of *Artemia* nauplii had high values for leucine, lysine and valine (198.6, 194 and 132.1, respectively). Adult *Moina* had high leucine, lysine and methionine contents (208.6, 179.6 and 138.4, respectively). The A/E ratio in the body content of postlarvae that were fed with different diets is shown in Table 5. The body of postlarvae fed on fairy shrimp nauplii had the highest A/E ratio of lysine, phenylalanine and leucine (465.2, 131.7 and 129, respectively). The body of postlarvae fed on dry commercial feeds had the highest A/E ratio of lysine, phenylalanine and leucine (469.8, 134.3 and 130.9, respectively). The body of postlarvae fed on *Artemia* nauplii had the highest A/E ratio of lysine, phenylalanine and leucine (468.4, 137.0 and 130, respectively). The body of postlarvae fed adult on *Moina* had the highest A/E ratio of lysine, phenylalanine and leucine (469.1, 131.9 and 131.3, respectively).

The fatty acid contents of experimental feeds are shown in Table 6. The present results demonstrate that the fatty acid concentrations were significantly different ($P < 0.05$) among the different feeds. Fairy shrimp nauplii had the highest total fatty acid content of 277.8 ± 0.9 g kg^{-1} from the dry diet. The total saturated fatty acid content was 91.9 ± 0.7 g kg^{-1} for the dry diet, and the total unsaturated fatty acid content was 185.9 ± 0.5 g kg^{-1}. The omega-6 and omega-3 contents were 33.07 ± 0.10 and 71.95 ± 0.28 g kg^{-1} in the dry diet, respectively. The polyunsaturated fatty acid (PUFA) content was 105.02 ± 0.27 g kg^{-1} and the eicosapentaenoic acid (EPA)+docosahexaenoic acid (DHA) content was 22.67 ± 0.05 g kg^{-1} in the dry diet. The unsaturated fatty acid profile in the fairy shrimp nauplii had the highest levels of oleic acid (C18:1n9), linolenic acid (C18:3n3) and linolenic acid (C18:2n6) (71.59, 47.63 and 23.91 g kg^{-1} dry diet,

Table 3 Amino acid concentrations (g kg^{-1} dry weight) in the body of *Macrobrachium rosenbergii* fed with four different feeds

Amino acid	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Alanine	23.47 ± 0.42^{a}	23.76 ± 0.54^{a}	23.11 ± 0.88^{a}	23.29 ± 0.76^{a}
Aspartic acid	32.06 ± 0.39^{b}	36.28 ± 0.73^{a}	33.69 ± 0.66^{b}	32.30 ± 0.66^{b}
Glutamic acid	52.82 ± 1.55^{c}	61.27 ± 0.36^{a}	57.89 ± 0.85^{b}	54.30 ± 0.55^{c}
Glycine	20.38 ± 0.70^{a}	19.52 ± 0.86^{a}	19.14 ± 0.55^{a}	19.04 ± 0.08^{a}
Histidine	38.25 ± 0.58^{ab}	39.88 ± 0.96^{a}	39.62 ± 1.13^{ab}	36.72 ± 0.69^{b}
Isoleucine	30.23 ± 0.62^{b}	33.99 ± 1.14^{a}	30.44 ± 0.53^{b}	29.93 ± 1.32^{b}
Leucine	57.92 ± 1.07^{a}	59.44 ± 0.43^{a}	58.98 ± 0.92^{a}	56.72 ± 0.67^{a}
Lysine	207.90 ± 0.50^{b}	214.44 ± 0.74^{a}	212.59 ± 0.79^{a}	202.63 ± 0.64^{c}
Methionine	14.64 ± 0.28^{a}	16.19 ± 0.35^{a}	15.88 ± 1.54^{a}	15.02 ± 0.33^{a}
Phenylalanine	59.43 ± 0.95^{b}	60.69 ± 0.40^{ab}	62.19 ± 0.57^{a}	56.99 ± 0.61^{c}
Proline	16.89 ± 0.84^{a}	17.62 ± 0.39^{a}	16.77 ± 0.44^{a}	16.42 ± 0.49^{a}
Serine	8.77 ± 0.70^{a}	9.55 ± 0.76^{a}	8.83 ± 0.21^{a}	9.31 ± 0.31^{a}
Threonine	9.15 ± 0.35^{a}	9.76 ± 0.86^{a}	9.55 ± 0.91^{a}	9.30 ± 0.42^{a}
Tyrosine	47.14 ± 0.50^{b}	49.86 ± 0.61^{a}	50.56 ± 0.84^{a}	46.14 ± 0.29^{b}
Valine	25.02 ± 0.37^{a}	26.58 ± 1.0^{a}	24.62 ± 1.08^{a}	24.66 ± 0.38^{a}
TAA	644.07 ± 1.91^{c}	678.84 ± 2.23^{a}	663.86 ± 2.56^{b}	632.75 ± 0.67^{c}
EAA (%)	67.48	66.70	67.34	67.32
NEAA (%)	32.52	33.30	32.66	32.68

TAA, total amino acid; EAA, essential amino acid; NEAA, non-essential amino acid.
Values are means ± standard deviations, $n = 3$. Mean values in rows followed by different superscript are significantly different ($P < 0.05$).

Table 4 A/E ratio of four different feeds

Amino acid	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Histidine	82.86	77.67	46.06	56.09
Isoleucine	54.01	73.12	111.55	104.49
Leucine	229.39	134.41	198.63	208.55
Lysine	206.56	459.96	193.95	179.60
Methionine	79.68	29.70	64.44	138.36
Phenylalanine	156.88	130.95	125.27	128.53
Threonine	118.94	25.67	127.99	124.66
Valine	71.69	68.52	132.10	59.72

A/E ratio = (EAA/total EAA) × 1000 (Arai 1981).

Table 5 A/E ratio in the body of *Macrobrachium rosenbergii* fed with four different feeds

Amino acid	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Histidine	86.43	86.52	87.29	85.01
Isoleucine	68.31	73.74	67.07	69.28
Leucine	130.89	128.95	129.96	131.30
Lysine	469.78	465.19	468.39	469.10
Methionine	33.09	35.11	34.99	34.76
Phenylalanine	134.28	131.66	137.03	131.93
Threonine	20.67	21.17	21.04	21.52
Valine	56.55	57.67	54.25	57.10

respectively). The overall fatty acid contents in body of the postlarvae fed with different feeds are provided in Table 7. The present results showed that the total fatty acid concentrations of *Artemia* nauplii (64.25 ± 0.68 g kg^{-1} dry weight) and fairy shrimp nauplii (60.64 ± 0.28 g kg^{-1} dry weight) were not significantly different. The total saturated fatty acid content was not significantly higher (26.71 ± 0.41 g kg^{-1} dry weight) when fed with dry commercial feed, but the total unsaturated fatty acid was significantly higher (38.03 ± 0.27 g kg^{-1} dry weight) when fed with *Artemia* nauplii. Omega-6 and omega-3 were the highest when fed with adult *Moina* (11.01 ± 0.26 g kg^{-1} dry weight) and *Artemia* nauplii (16.01 ± 0.35 g kg^{-1} dry weight), respectively. The PUFA and EPA +DHA contents were the highest when fed with adult *Moina* (25.80 ± 0.32 g kg^{-1} dry weight) and dry commercial feed (11.68 ± 0.11 g kg^{-1} dry weight), respectively. The major unsaturated fatty acid profile of postlarvae fed with four different feeds was found to be oleic acid (C18:1n9), linolenic acid (C18:2n6, C18:3n3), arachidonic acid (C20:4n6), EPA (C20:5n3) and DHA (C22:6n3). Weight gain of the postlarvae fed with fairy shrimp nauplii (75 ± 8.69 mg) was significantly ($P < 0.01$) higher than those fed with *Artemia* nauplii, adult *Moina* and dry commercial feed (56.43 ± 3.86, 39.26 ± 3.35, 20.57 ± 2.54 mg, respectively) (Table 8). The SGR of the postlarvae fed with fairy shrimps (7.10 ± 0.60% day^{-1}) was higher than those fed with *Artemia* nauplii (6.34 ± 0.44% day^{-1}), adult *Moina* (5.36 ± 0.17% day^{-1}) and dry commercial feed (3.71 ± 0.35% day^{-1}). However, survival rates for each treatment were not significantly different ($P > 0.05$).

Discussion

Live feeds can have an important role in larval nutrition of ornamental fish (Lim *et al.* 2003), marine shrimp (Farhadian *et al.* 2007) and freshwater prawn (Barros & Valenti 2003b). However, high-quality live feed, in general, may also be costly to produce. Several live and inert feeds were investigated as either a replacement or as a supplement for *Artemia* nauplii in *M. rosenbergii* (Alam *et al.* 1995; Silva & Rodrigues 1997) and brown shrimp *Farfantepenaeus aztecus* larvae (Robinson *et al.* 2005). Indeed, one of the major research themes in aquaculture is directed towards exploring low-cost alternatives to *Artemia* sp., such as inert larval diets for *M. rosenbergii* or other types of live feed (Martín *et al.* 2006; Dahms *et al.* 2007b). In the present study, although some variation was found in the crude protein, lipid and total carbohydrate, these were within the normal range. Protein content in all the live feed items in our study was higher than in the commercial feeds. This study also showed that adult *Moina* had higher protein content (585 g kg^{-1}) than the other feeds. Previous investigations reported a high level of protein in *Moina* (Das *et al.* 2007). They observed that the protein, lipid and carbohydrate levels of *Moina* were 663, 108 and 198 g kg^{-1}, respectively. In addition, *S. sirindhornae* nauplii had a high protein content (546 g kg^{-1}) comparable to *S. dichotomus* nauplii (506 g kg^{-1}) reported by Velu & Munuswamy (2008). However, Dararat *et al.* (2012) studied the biochemical composition of three fairy shrimp species from Thailand and found that the adults of *S. sirindhornae* had a protein content of 744 g kg^{-1}. Similarly, our *Artemia* nauplii showed a high protein content of 538 ± 2.3 g kg^{-1}

Table 6 Fatty acid concentrations (g kg^{-1} dry diet) of four different feeds

Fatty acid	Commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Total fatty acids	98.90 ± 1.68^{b}	277.83 ± 0.91^{a}	100.87 ± 1.37^{b}	99.58 ± 0.88^{b}
Total saturated fatty acids	47.58 ± 2.82^{b}	91.92 ± 0.67^{a}	22.45 ± 0.94^{d}	41.59 ± 0.43^{c}
Total unsaturated fatty acids	51.325 ± 1.96^{c}	185.91 ± 0.53^{a}	78.42 ± 1.44^{b}	57.99 ± 0.44^{c}
PUFA	28.42 ± 1.56^{d}	105.02 ± 0.27^{a}	43.86 ± 1.92^{b}	33.31 ± 0.24^{c}
Omega-6	20.09 ± 1.16^{b}	33.07 ± 0.10^{a}	8.17 ± 0.36^{d}	14.68 ± 0.11^{c}
Omega-3	8.33 ± 0.40^{d}	71.95 ± 0.28^{a}	35.69 ± 1.56^{b}	18.53 ± 0.13^{c}
EPA+DHA	5.56 ± 0.25^{b}	22.67 ± 0.05^{a}	1.46 ± 0.64^{c}	0.35 ± 0.21^{d}
Saturated fatty acid				
Lauric acid (C12:0)	0.25 ± 0.01^{b}	0.15 ± 0.01^{c}	0.10 ± 0.01^{d}	0.29 ± 0.01^{a}
Myristic acid (C14:0)	4.39 ± 0.02^{a}	2.83 ± 0.03^{c}	0.97 ± 0.04^{d}	3.36 ± 0.05^{b}
Pentadecanoic acid (C15:0)	1.28 ± 0.06^{c}	2.35 ± 0.06^{b}	0.26 ± 0.01^{d}	2.80 ± 0.04^{a}
Palmitic acid (C16:0)	29.39 ± 1.60^{b}	63.35 ± 0.20^{a}	14.31 ± 0.59^{d}	25.81 ± 0.27^{c}
Heptadecanoic acid (C17:0)	1.92 ± 0.10^{c}	3.73 ± 0.02^{a}	0.92 ± 0.04^{d}	2.34 ± 0.02^{b}
Stearic acid (C18:0)	9.12 ± 0.51^{b}	16.77 ± 0.45^{a}	5.66 ± 0.24^{c}	6.16 ± 0.03^{c}
Arachidic acid (C22:0)	0.62 ± 0.03^{b}	0.78 ± 0.02^{a}	0.18 ± 0.01^{d}	0.25 ± 0.01^{c}
Behenic acid (C22:0)	–	1.96 ± 0.06^{a}	–	0.35 ± 0.01^{b}
Tricosanoic acid (C23:0)	0.63 ± 0.31^{a}	–	–	0.06 ± 0.01^{b}
Lignoceric acid (C24:0)	–	–	0.07 ± 0.01^{b}	0.19 ± 0.04^{a}
Unsaturated fatty acid				
Palmitoleic acid (C16:1n7)	4.74 ± 0.26^{b}	7.75 ± 0.19^{a}	3.16 ± 0.12^{c}	7.72 ± 0.11^{a}
Oleic acid (C18:1n9)	17.76 ± 1.03^{c}	71.59 ± 0.08^{a}	31.09 ± 1.38^{b}	16.89 ± 0.10^{c}
Erucic acid (C22:1n9)	0.10 ± 0.01^{b}	0.28 ± 0.01^{a}	0.05 ± 0.01^{c}	–
Linolenic acid (C18:2n6)	17.73 ± 1.04^{b}	23.91 ± 0.04^{a}	7.71 ± 0.34^{c}	14.2 ± 0.10^{d}
Linolenic acid (C18:3n3)	2.66 ± 0.15^{d}	47.63 ± 0.32^{a}	33.36 ± 1.45^{b}	18.15 ± 0.12^{c}
Eicosadienoic acid (C20:2)	0.32 ± 0.01^{b}	1.28 ± 0.05^{a}	0.27 ± 0.01^{b}	0.08 ± 0.01^{c}
Eicosatrienoic acid (C20:3n6)	0.13 ± 0.01^{b}	1.11 ± 0.01^{a}	0.09 ± 0.01^{c}	0.06 ± 0.01^{d}
Eicosatrienoic acid (C20:3:n3)	0.12 ± 0.01^{c}	1.65 ± 0.05^{a}	0.87 ± 0.04^{b}	0.13 ± 0.16^{c}
Arachidonic acid (C20:4n6)	2.24 ± 0.01^{b}	8.05 ± 0.03^{a}	0.37 ± 0.02^{c}	0.37 ± 0.01^{c}
EPA (C20:5n3)	4.36 ± 0.11^{b}	21.76 ± 0.04^{a}	1.46 ± 0.06^{c}	0.35 ± 0.10^{d}
DHA (C22:6n3)	1.20 ± 0.06^{a}	0.91 ± 0.01^{b}	–	–

PUFA, polyunsaturated fatty acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.
Values are means ± standard deviations, $n = 3$. Mean values in rows followed by different superscript are significantly different ($P < 0.05$).

Table 7 Fatty acid concentrations (g kg^{-1} dry weight) in the body of *Macrobrachium rosenbergii* fed with four different feeds

Fatty acid	Commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Total fatty acids	51.05 ± 0.44^{b}	60.64 ± 0.28^{ab}	64.25 ± 0.68^{a}	59.53 ± 0.47^{b}
Total saturated fatty acids	26.71 ± 0.41^{a}	25.85 ± 0.97^{a}	26.22 ± 0.40^{a}	26.23 ± 0.76^{a}
Total unsaturated fatty acids	32.34 ± 0.16^{d}	34.79 ± 0.27^{b}	38.03 ± 0.27^{a}	33.30 ± 0.56^{c}
PUFA	22.61 ± 0.08^{bc}	22.12 ± 0.28^{c}	23.72 ± 0.63^{b}	25.80 ± 0.32^{a}
Omega-6	9.6 ± 0.14^{b}	8.40 ± 0.07^{c}	7.70 ± 0.30^{c}	11.01 ± 0.26^{a}
Omega-3	12.96 ± 0.07^{d}	13.73 ± 0.20^{c}	16.01 ± 0.35^{a}	14.79 ± 0.21^{b}
EPA+DHA	11.68 ± 0.11^{a}	9.33 ± 0.15^{b}	7.99 ± 0.06^{c}	7.85 ± 0.14^{c}
Saturated fatty acid				
Lauric acid (C12:0)	0.06 ± 0.01^{a}	0.04 ± 0.06^{a}	0.06 ± 0.31^{a}	0.07 ± 0.29^{a}
Myristic acid (C14:0)	1.33 ± 0.04^{a}	0.80 ± 0.04^{b}	1.00 ± 0.22^{ab}	1.36 ± 0.04^{a}
Pentadecanoic acid (C15:0)	0.54 ± 0.03^{ab}	0.46 ± 0.04^{cb}	0.32 ± 0.61^{c}	0.70 ± 0.15^{a}
Palmitic acid (C16:0)	14.30 ± 0.25^{a}	15.09 ± 1.12^{a}	13.94 ± 0.13^{a}	13.58 ± 0.23^{a}
Heptadecanoic acid (C17:0)	0.95 ± 0.05^{a}	0.99 ± 0.56^{a}	1.01 ± 0.02^{a}	1.19 ± 0.06^{a}
Stearic acid (C18:0)	7.05 ± 0.10^{ab}	6.55 ± 0.14^{b}	7.53 ± 0.74^{a}	6.58 ± 0.33^{b}
Arachidic acid (C22:0)	0.72 ± 0.05^{a}	0.52 ± 0.09^{a}	0.65 ± 0.63^{a}	0.72 ± 0.05^{a}
Behenic acid (C22:0)	0.89 ± 0.06^{ab}	0.82 ± 0.79^{b}	0.97 ± 0.01^{ab}	1.07 ± 0.19^{a}
Tricosanoic acid (C23:0)	0.17 ± 0.03^{a}	0.11 ± 0.03^{a}	0.14 ± 0.02^{a}	0.21 ± 0.08^{a}
Lignoceric acid (C24:0)	0.70 ± 0.11^{ab}	0.48 ± 0.06^{b}	0.62 ± 0.71^{ab}	0.74 ± 0.13^{a}
Unsaturated fatty acid				
Palmitoleic acid (C16:1n7)	1.65 ± 0.09^{a}	0.81 ± 0.08^{c}	1.66 ± 0.19^{a}	1.18 ± 0.04^{b}
Oleic acid (C18:1n9)	7.71 ± 0.10^{c}	11.43 ± 0.10^{b}	12.30 ± 0.21^{a}	5.90 ± 0.11^{d}
Erucic acid (C22:1n9)	–	–	0.07 ± 0.33^{b}	0.08 ± 0.51^{a}
Linolenic acid (C18:2n6)	4.85 ± 0.04^{b}	3.39 ± 0.08^{c}	3.69 ± 0.36^{c}	6.48 ± 0.22^{a}
Linolenic acid (C18:3n3)	1.29 ± 0.06^{d}	3.94 ± 0.16^{c}	7.42 ± 0.31^{a}	6.43 ± 0.10^{b}
Eicosadienoic acid (C20:2)	0.36 ± 0.03^{a}	0.43 ± 0.34^{a}	0.29 ± 0.01^{a}	0.35 ± 0.07^{a}
Eicosatrienoic acid (C20:3n6)	0.47 ± 0.04^{a}	0.31 ± 0.13^{b}	0.59 ± 0.15^{a}	0.53 ± 0.43^{a}
Eicosatrienoic acid (C20:3:n3)	–	0.46 ± 0.24^{a}	0.61 ± 0.05^{a}	0.50 ± 0.29^{a}
Arachidonic acid (C20:4n6)	4.34 ± 0.09^{ab}	4.69 ± 0.44^{a}	3.42 ± 0.28^{b}	4.00 ± 0.68^{c}
EPA (C20:5n3)	5.88 ± 0.05^{b}	6.34 ± 0.23^{a}	5.22 ± 0.02^{c}	4.68 ± 0.19^{d}
DHA (C22:6n3)	5.80 ± 0.06^{a}	3.00 ± 0.11^{c}	2.77 ± 0.72^{c}	3.17 ± 0.36^{b}

PUFA, polyunsaturated fatty acid; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.
Values are means ± standard deviations, $n = 3$. Mean values in rows followed by different superscript are significantly different ($P < 0.05$).

Table 8 Growth performance of *Macrobrachium rosenbergii* postlarvae fed with four different feeds for 30 days

Growth performance	Dry commercial feed	Fairy shrimp nauplii	*Artemia* nauplii	Adult *Moina*
Initial weight (mg)	10.02 ± 0.32^{d}	10.08 ± 0.16^{a}	9.86 ± 0.18^{b}	9.81 ± 0.24^{c}
Final weight (mg)	30.59 ± 2.23^{d}	85.58 ± 6.92^{a}	66.28 ± 3.78^{b}	49.06 ± 1.78^{c}
Weight gain (mg)	20.57 ± 2.54^{d}	75.49 ± 8.69^{a}	56.43 ± 3.86^{b}	39.26 ± 3.35^{c}
Specific growth rate (% day^{-1})	3.71 ± 0.35^{d}	7.10 ± 0.60^{a}	6.34 ± 0.44^{b}	5.36 ± 0.17^{c}
Survival rate (%)	81.25 ± 2.6^{a}	80.00 ± 1.19^{a}	79.63 ± 1.08^{a}	78.12 ± 1.38^{a}

Values are means ± standard deviations, $n = 30$. Mean values in rows followed by different superscript are significantly different ($P < 0.01$).

compared with the *Artemia* nauplii reported by Helland *et al*. (2003). The protein content of the dry commercial feed (414 g kg^{-1}) was similar to an inert diet (434–451 g kg^{-1}) for *M. rosenbergii* (Barros & Valenti 2003b) and 420–432 g kg^{-1} for kuruma prawn *Marsupenaeus japonicus* (Alam *et al*. 2002). Kovalenko *et al*. (2002) suggested that semi-purified microbound diets containing 461 g kg^{-1} crude protein had a good potential for successful larval culture of *M. rosenbergii*. In addition, the most suitable diet for rearing *M. rosenbergii* should be supplemented with protein levels ranging from 300 to 450 g kg^{-1} (Davassi 2011). Terrazas-Fierro *et al*. (2010), however, reported that fish soluble protein concentrate, squid meal, shrimp head meal, Catarina scallop by-product meal and fish meal were all good sources of available protein and amino acids for juvenile *Litopenaeus vannamei* (Boone). Meanwhile, Sookying & Davis (2011) demonstrated the feasibility of four diets formulated to contain high levels of soybean meal (364 g kg^{-1} crude protein) in combination with poultry by-products, fish meal, distiller's dried grains with soluble or pea meal in the production of diets for Pacific white shrimp (*L. vannamei*). Barclay *et al.* (2006) formulated a pelleted dry feed (612 g kg^{-1} CP) for the tropical spiny lobster, *Panulirus ornatus,* and they suggested that the diet supported excellent growth and survival rates for the juvenile stages.

Results from our study showed that the total amino acid contents of live feeds had the highest levels of lysine, glutamic acid, phenylalanine, leucine and tyrosine in *S. sirindhornae* nauplii. Slight differences are shown in high levels of lysine, phenylalanine, leucine, glutamic acid and tyrosine in *Artemia* nauplii and adult *Moina*. However, Velu *et al.* (2003) reported that amino acid analysis revealed high levels of asparagine, glutamine and glycine in *S. dichotomus* and *M. micrura*. Similar to Velu & Munuswamy (2007), our results showed that the amino acid composition of adult *S. dichotomus* had high levels of the following essential amino acids: lysine, methionine, histidine, arginine, isoleucine, leucine, valine, glycine and threonine. Dararat *et al.* (2012) investigated the amino acid composition in adult *S. sirindhornae* and discovered high levels of lysine, phenylalanine, leucine and glutamic acid. Amino acid profiles of the body of postlarvae fed *S. sirindhornae* nauplii showed high lysine levels that were not significantly different from those fed with *Artemia* nauplii. However, in both treatment groups the amino acid concentration was higher than those in postlarvae fed with dry commercial feed and adult *Moina*. Reed & D'Abramo (1989) suggested that whole body amino acid profiles can be used as a reference dietary profile for *M. rosenbergii*. Alam *et al.* (2002) found that amino acid profiles of juvenile prawn protein and squid meal protein provided suitable amino acid compositions for good growth of kuruma prawn *Marsupenaeus japonicus* juveniles.

The concept of A/E ratio was introduced by Arai (1981) to formulate test diets for coho salmon *Oncorhynchus kisutch*. The A/E ratios of various animal protein sources generally show high arginine, lysine and methionine A/E ratios (Mente *et al.* 2002). In our study, *S. sirindhornae* nauplii showed the highest A/E ratio of lysine, leucine and phenylalanine. Besides the A/E ratio of essential amino acids, postlarvae fed with *S. sirindhornae* nauplii had the highest A/E ratios of lysine, phenylalanine and leucine. In our study, the considered A/E ratios for the body of postlarvae for lysine and leucine were somewhat higher when compared with reported values for kuruma prawn, *M. japonicus* (Alam *et al.* 2002). A comparison of essential amino acid proportions (A/E ratios) between *M. rosenbergii* and penaeid species suggest only minor, if any, differences in the requirements for essential amino acids (D'Abramo 1998). The other A/E ratios in the body of postlarvae did not show major differences compared to Velu & Munuswamy (2008).

The present study showed the highest fatty acid concentration in the body of postlarvae fed with *Artemia* nauplii followed by *S. sirindhornae* nauplii. *S. sirindhornae* nauplii had the highest total fatty acid, total unsaturated fatty acid, omega-6 and 3, PUFA and EPA+DHA contents. The fatty acid profiles of *S. sirindhornae* nauplii in this study were similar to those reported by Velu & Munuswamy (2008). They found that fatty acids (C18 series and C16 series) in *S. dichotomus* appeared to be around 20.50 and 161.12 g kg^{-1}, respectively. Moreover, the present results reveal that the highest total fatty acid, highly unsaturated fatty acid (HUFA), PUFA and EPA+DHA concentrations were found in *S. sirindhornae* nauplii. Velu & Munuswamy (2007) reported that the fatty acids in *S. dichotomus* showed a high level of major fatty acids compared with *Moina* sp. and *Artemia* sp. The fatty acid profiles of adult fairy shrimps showed high levels of both PUFA and unsaturated fatty acids. Dararat *et al.* (2012) investigated fatty acid profiles in three species of Thai fairy shrimps. They found that fatty acid profiles in adult *B. thailandensis*, *S. siamensis* and *S. sirindhornae* were 7.46, 5.89 and 4.75 mg g^{-1}, respectively.

Larval stages of crustacean species most likely require higher levels of dietary lipids relative to juveniles and adults (D'Abramo 1989). In addition, the levels of lipids in freshwater prawn diets can be as low as 20 g kg^{-1} if sufficient dietary energy is available and the requirements for PUFA s are satisfied (D'Abramo & Sheen 1994). Bragagnolo & Rodriguez-Amaya (2001) reported that in freshwater prawn *M. rosenbergii*, the major fatty acids were C16:0, C20:5n-3, C18:1n-9, C18:0, C22:6n-3, C18:2n-6, C17:0 and C18:1n-7. Nevertheless, 80% of the total fatty acids in *Artemia* are composed of 16:0, 16:1n-7, 18:2n-6, 18:3n-3 and 20:5n-3 fatty acids as reviewed by Bengston *et al.* (1991). Lim *et al.* (2001) reported that the fatty acid profile of on-grown *Artemia* sp was deficient in linoleic acid. However, linoleic acid, DHA and EPA were the highest among all the four diets tested in on-grown *Artemia*. Velu & Munuswamy (2008) reported that *S. dichotomus* met all the nutritional requirements of *M. rosenbergii* larvae with regard to fatty acid requirements. In the present study, the body of postlarvae fed with live feeds containing high levels of total fatty acids and unsaturated fatty acids was compared with the body of postlarvae fed with dry commercial feed. *S. sirindhornae* nauplii, *Artemia* nauplii and adult *Moina* were reflected their higher levels of fatty acids and their effective utilization. In a previous study, dietary lipid levels used in crustacean larvae feeds were up to 374 g kg^{-1} (Kovalenko *et al.* 2002). The essential fatty acids (EFA) in the diet of consumer organisms are important for their growth (Velu & Munuswamy 2004). In addition, *M. rosenbergii* can make use of palmitic acid for the synthesis of saturated and unsaturated fatty acids (Roustaian *et al.* 1999). A slight difference is shown in the results of fatty acids in the body of postlarvae fed with *Artemia* nauplii and *S. sirindhornae* nauplii. In the present study, postlarvae fed with adult *Moina* had higher fatty acid contents in the body than reported for *M. rosenbergii* by Das *et al.* (2007). Our results also show that the body of prawn postlarvae fed with dry commercial feed had a higher EPA +DHA concentration than the body of postlarvae fed with fairy shrimp nauplii. This can be explained by the process of metabolization. Dry commercial feed also had the highest carbohydrate composition with 278 ± 2.3 g kg^{-1} in contrast to fairy shrimp nauplii which showed a lower carbohydrate composition with 30 ± 1.6 g kg^{-1}. Carbohydrates can be metabolized to fatty acids. Tacon (1987), for example, reported the ability of fish and shrimp to convert high amounts of dietary carbohydrate to energy acquisition (e.g. glucose), non-essential amino acids or lipids. This might have taken place during our experiment.

Nhan *et al.* (2010) demonstrated that larval stocking density and feeding regime strongly affected larval development, survival and the duration of the life cycle. In the present study, larval growth and survival were strongly affected by feed composition. Weight gain and SGR of *M. rosenbergii* postlarvae fed with *S. sirindhornae* nauplii were significantly ($P < 0.01$) higher than when fed with *Artemia* nauplii, adult *Moina* and dry commercial feed. The present results suggest that *S. sirindhornae* nauplii can be used as nutritionally adequate food for growing freshwater prawn *M. rosenbergii* postlarvae. During the study period, prawn fed with live feed showed large increases in their weight from 9.81-75.49 mg except for those fed only dry commercial feed (10.02–20.57 mg). The gain in body weight of *M. rosenbergii* fed *S. sirindhornae* nauplii was significantly higher than those fed *Artemia* nauplii, adult *Moina* and dry commercial diets. Survival rates within each of the treatments were not significantly different ($P > 0.05$). Das *et al.* (2007) reported that growth and survival rates of *M. rosenbergii* postlarvae increased with increasing amounts of EPA and DHA in dietary *Moina*. Similarly, studies on fatty acids demonstrated that HUFA is important for normal growth and survival of *M. rosenbergii* postlarvae (Romdhane *et al.* 1995), *P. monodon* (Glencross & Smith 2001; Hoa *et al.* 2009), tropical spiny lobster *Panulirus ornatus* (Barclay *et al.* 2006) and Chinese mitten crab *Eriocheir sinensis* (Sui *et al.* 2007; Wu *et al.* 2007). Nonwachai *et al.* (2010) reported that Pacific white shrimp (*L. vannamei*) raised on diets supplemented with marine algal meals rich in DHA and ARA showed significant improvement in immune parameters. Additionally, the survival rate after challenge with *Vibrio harveyi* was increased. Although the amino acid and fatty acid profiles in the live feed showed enrichment containing highly unsaturated fatty acids, according to our analyses, a microbound diet can also be used as a source of dietary protein and highly unsaturated fatty acids (Genodepa *et al.* 2004). Sookying & Davis (2011) provided soybean meal diets with four levels of protein content meal (mean, 364 g kg^{-1} crude protein) for the outdoor production of *L. vannamei*. This study resulted in survival percentages ranging from 86.6% to 93.7% (in outdoor ponds) and 97.3% to 98.7% (reared in outdoor tanks). Coutteau *et al.* (1996) studied the effect of dietary purified phosphatidylcholine on growth, survival and fatty acid composition of early postlarval *L. vannamei*. They found that the growth response of shrimps fed 15 g kg^{-1} purified soybean phosphatidylcholine or 65 g kg^{-1} de-oiled soybean lecithin was significantly greater than that of shrimps fed a phosphatidylcholine-deficient diet, whereas no effect was observed either on survival or on stress resistance.

Acknowledgements

This work was supported by the Commission on Higher Education, Thailand, under the programme Strategic Scholarships for Frontier Research Network. Dr Jolyon Dodgson is thanked for helping with English corrections. The authors wish to thank Assistant Professor Aruneepong Srisathaporn for her help with the proximate analysis.

References

Alam, M.S., Ang, K.J. & Cheah, S.H. (1993) Use of *Moina micrura* (Kurz) as an *Artemia* substitute in larval rearing of the production of *Macrobrachium rosenbergii* (de Man) post-larvae. *Aquaculture*, **109**, 337–349.

Alam, M.J., Ang, K.J. & Begum, M. (1995) Use of egg custard augmented with cod liver oil and *Moina micrura* on production of freshwater prawn post larvae. *Aquacult. Int.*, **3**, 249–259.

Alam, M.S., Teshima, S., Yaniharto, D., Ishikawa, M. & Koshio, S. (2002) Dietary amino acid profiles and growth performance in juvenile kuruma prawn *Marsupenaeus japonicas*. *Comp. Biochem. Physiol. B*, **133**, 289–297.

Arai, S. (1981) A purified test diet for Coho salmon, *Oncorhynchus kisutch*, fry. *Bull. Japan. Soc. Sci. Fish.*, **47**, 547–550.

Association of Official Analytical Chemists (AOAC). (1995) Official Methods of Analysis, 16th edn. AOAC, Arlington, VA.

Association of Official Analytical Chemists (AOAC). (2000) Official Methods of Analysis, 17th edn. AOAC, Gaithersburg, MD.

Barclay, M.C., Irvin, S.J., Williams, K.C. & Smith, D.M. (2006) Comparison of diets for the tropical spiny lobster *Panulirus ornatus*: astaxanthin supplemented feeds and mussel flesh. *Aquacult. Nutr.*, **12**, 117–125.

Barros, H.P. & Valenti, W.C. (2003a) Food intake of *Macrobrachium rosenbergii* during larval development. *Aquaculture*, **216**, 165–176.

Barros, H.P. & Valenti, W.C. (2003b) Ingestion rates of *Artemia* nauplii for different larval stages of *Macrobrachium rosenbergii*. *Aquaculture*, **217**, 223–233.

Bengston, D.A., Leger, P. & Sorgeloors, P. (1991) Use of *Artemia* as a food source for aquaculture. In: Artemia Biology (Brown, R.A., Sorgeloos, P. & Trotman, C.N.A. eds), pp. 255–285. CRC Press Inc., Boca Raton, FL.

Bragagnolo, N. & Rodriguez-Amaya, D.B. (2001) Total lipid, cholesterol, and fatty acids of farmed freshwater prawn (*Macrobrachium rosenbergii*) and wild marine shrimp (*Penaeus brasiliensis, Penaeus schmitti, Xiphopenaeus krøyeri*). *J. Food Compos. Anal.*, **14**, 359–369.

Chettri, J.K., Sahu, N.P., Pal, A.K., Reddy, A.K., Kumar, S. & Kumar, V. (2007) Comparative performance of gamma amino butyric acid (GABA) and 5-hydroxytryptamine (5-HT) in the diet of larvae and post larvae of giant freshwater prawn, *Macrobrachium rosenbergii*: effect of dose and route of administration on growth and survival. *Aquaculture*, **270**, 240–248.

Coutteau, P., Camara, M.R. & Sorgeloos, P. (1996) The effect of different levels and sources of dietary phosphatidylcholine on the growth, survival, stress resistance, and fatty acid composition of postlarval *Penaeus vannamei*. *Aquaculture*, **147**, 261–273.

D'Abramo, L.R. (1989) Lipid requirements of shrimp. *Adv. Trop. Aquac.*, **9**, 271–285.

D'Abramo, L.R. (1998) Nutritional requirements of the freshwater prawn *Macrobrachium rosenbergii*: comparisons with species of penaeid shrimp. *Rev. Fish. Sci.*, **6**, 153–163.

D'Abramo, L.R. & Sheen, S.S. (1994) Nutritional requirements, feed formulations and feeding practices for intensive production of the freshwater prawn *Macrobrachium rosenbergii*. *Rev. Fish. Sci.*, **2**, 1–21.

Dahms, H.-U., Gao, Q.-F. & Hwang, J.-S. (2007a) Optimized maintenance and larval production of the bryozoan *Bugula neritina* (Bryozoa) in the laboratory. *Aquaculture*, **265**, 169–175.

Dahms, H.-U., Li, X., Zhang, G. & Qian, P.-Y. (2007b) Resting stages of *Tortanus forcipatus* (Crustacea, Calanoida) in sediments of Victoria Harbor, Hong Kong. *Estuar. Coast. Shelf Sci.*, **67**, 562–568.

Dahms, H.-U., Hagiwara, A. & Lee, J.-S. (2011) Ecotoxicology, ecophysiology, and mechanistic studies with rotifers. *Aquat. Toxicol.*, **101**, 1–12.

Dararat, W., Starkweather, P.L. & Sanoamuang, L. (2011) Life history of three fairy shrimps (Branchiopoda: Anostraca) from Thailand. *J. Crust. Biol.*, **31**, 623–629.

Dararat, W., Lomthaisong, K. & Sanoamuang, L. (2012) Biochemical composition of three species of fairy shrimps (Branchiopoda: Anostraca) from Thailand. *J. Crust. Biol.*, **32**, 81–87

Das, S.K., Tiwari, V.K., Venkateshwarlu, G., Reddy, A.K., Parhi, J., Sharma, P. & Chettri, J.K. (2007) Growth, survival and fatty acid composition of *Macrobrachium rosenbergii* (de Man, 1879) post larvae fed HUFA-enriched *Moina micrura*. *Aquaculture*, **269**, 464–475.

Davassi, L.A. (2011) Survival and growth of the freshwater prawn *Macrobrachium rosenbergii* in relation to different nutrient composition. *J. Fish. Aquat. Sci.*, **6**, 649–654.

Farhadian, O., Yusoff, F.Md. & Arshad, A. (2007) Ingestion rate of postlarvae *Penaeus monodon* fed *Apocyclops dengizicus* and *Artemia*. *Aquaculture*, **269**, 265–270.

Genodepa, J., Zeng, C. & Southgate, P.C. (2004) Preliminary assessment of a microbound diet as an *Artemia* replacement for mud crab, *Scyllaserrata megalopa*. *Aquaculture*, **236**, 497–509.

Glencross, B.D. & Smith, D.M. (2001) Optimising the dietary levels of eicosapentaenoic and docosahexaenoic essential fatty acids for the prawn, *Penaeus monodon*. *Aquacult. Nutr.*, **7**, 101–112.

Helland, S., Terjesen, B.F. & Berg, L. (2003) Free amino acid and protein content in the planktonic copepod *Temora longicornis* compared to *Artemia franciscana*. *Aquaculture*, **215**, 213–228.

Hoa, N.D., Wouters, R., Wille, M., Thanh, V., Dong, T.K., Hao, N.V. & Sorgeloos, P. (2009) A fresh-food maturation diet with an adequate HUFA composition for broodstock nutrition studies in black tiger shrimp *Penaeus monodon* (Fabricius, 1798). *Aquaculture*, **297**, 116–121.

Kovalenko, E.E., D'Abramo, L.R., Ohs, C.L. & Buddington, R.K. (2002) A successful microbound diet for the larval culture of freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture*, **210**, 385–395.

Lee, C.H., Dahms, H.U., Cheng, S.H., Souissi, S., Schmitt, F.G., Kumar, R. & Hwang, J.S. (2010) Predation of *Pseudodiaptomus annandalei* (Copepoda: Calanoida) by the grouper fish fry *Epinephelus coioides* under different hydrodynamic conditions. *J. Exp. Mar. Biol. Ecol.*, **393**, 17–22.

Lim, L.C., Soh, A., Dhert, P. & Sorgeloos, P. (2001) Production and application of on-grown *Artemia* in freshwater ornamental fish farm. *Aquac. Econ. Manag.*, **5**, 211–228.

Lim, L.C., Dhert, P. & Sorgeloos, P. (2003) Recent developments in the application of live feeds in the freshwater ornamental fish culture. *Aquaculture*, **227**, 319–331.

Martín, L., Arenal, A., Fajardo, J., Pimentel, E., Hidalgo, L., Pacheco, M., García, C. & Santiesteban, D. (2006) Complete and partial replacement of *Artemia* nauplii by *Moina micrura* during early post larval culture of white shrimp (*Litopenaeus schmitti*). *Aquacult. Nutr.*, **12**, 89–96.

Mente, E., Coutteau, P., Houlihan, D., Davidson, I. & Sorgeloos, P. (2002) Protein turnover, amino acid profile and amino acid flux in juvenile shrimp *Litopenaeus vannamei*: effects of dietary protein source. *J. Exp. Biol.*, **205**, 3107–3122.

Munuswamy, N., Nazar, A.K.A., Velu, C.S. & Dumont, H.J. (1997) Culturing the fairy shrimp *Streptocephalus dichotomus* Baird using livestock waste – a reclamation study. *Hydrobiologia*, **358**, 199–203.

New, M.B. (2002) Farming freshwater prawns. A manual for the culture of the giant river prawn (*Macrobrachium rosenbergii*). FAO Fish Technical Paper No. 428. FAO, Rome, Italy.

New, M.B. (2005) Freshwater prawn farming: global status, recent research and glance at the future. *Aquacult. Res.*, **36**, 210–230.

Nhan, D.T., Wille, T.M., Hung, L.T. & Sorgeloos, P. (2010) Effects of larval stocking density and feeding regime on larval rearing of giant freshwater prawn (*Macrobrachium rosenbergii*). *Aquaculture*, **300**, 80–86.

Nonwachai, T., Purivirojkul, W., Limsuwan, C., Chuchird, N., Velasco, M. & Dhar, A.K. (2010) Growth, nonspecific immune characteristics, and survival upon challenge with *Vibrio harveyi* in Pacific white shrimp (*Litopenaeus vannamei*) raised on diets containing algal meal. *Fish Shellfish Immunol*., **29**, 298–304.

Reed, L. & D'Abramo, L.R. (1989) A standard reference diet for crustacean nutrition research. 3. Effects on weight gain and amino acid composition of whole body and tail muscle of juvenile prawn *Macrobrachium rosenbergii*. *J. World Aquacult. Soc*., **20**, 107–113.

Robinson, C.B., Samocha, T.M., Fox, J.M., Gandya, R.L. & McKee, D.A. (2005) The use of inert artificial commercial food sources as replacements of traditional live food items in the culture of larval shrimp, *Farfantepenaeus aztecus*. *Aquaculture*, **245**, 135–147.

Romdhane, M.S., Devresse, B., Léger, P.H. & Sorgeloos, P. (1995) Effects of feeding (ω-3) HUFA-enriched *Artemia* during a progressively increasing period on the larviculture of freshwater prawns. *Aquacult. Int*., **3**, 236–242.

Roustaian, P., Kamaruddin, M.S., Omar, H., Saad, C.R. & Ahmad, M.H. (1999) Changes in fatty acid profile during larval development of freshwater prawn *Macrobrachium rosenbergii* (de Man). *Aquacult. Res*., **30**, 815–824.

Saejung, C., Hatai, K., Wada, S., Kurata, O. & Sanoamuang, L. (2011) Clinical observations of black disease in fairy shrimps, *Streptocephalus sirindhornae* and *Branchinella thailandensis*, from Thailand and pathogen verification. *J. Fish Dis*., **34**, 911–920.

Saengphan, N., Shiel, R.J. & Sanoamuang, L. (2005) The cyst hatching pattern of the Thai fairy shrimp, *Branchinella thailandensis* Sanoamuang, Saengphan and Murugan, 2002 (Anostraca). *Crustaceana*, **78**, 513–523.

Sanoamuang, L. & Saengphan, N. (2006) A new species of *Streptocephalus* fairy shrimp (Crustacea, Anostraca) with tetrahedral cysts from central Thailand. *Int. Rev. Hydrobiol*., **91**, 250–256.

Sanoamuang, L., Murugan, G., Weekers, P.H.H. & Dumont, H.J. (2000) *Streptocephalus sirindhornae*, new species of freshwater fairy shrimp (Anostraca) from Thailand. *J. Crustacean Biol*., **20**, 559–565.

Sanoamuang, L., Saengphan, N. & Murugan, G. (2002) First record of the family Thamnocephalidae (Crustacea, Anostraca) from Southeast Asia and description of a new species of *Branchinella*. *Hydrobiologia*, **486**, 63–69.

Silva, F.M. & Rodrigues, J.B.R. (1997) Effect of the replacement of the *Artemia* sp. for the nematode *Panagrellus redivivus* on the larval growth and survival of the freshwater prawn (*Macrobrachium rosenbergii*). *B. Inst. Pesca*., **24**, 35–38.

Sookying, D. & Davis, D.A. (2011) Pond production of Pacific white shrimp (*Litopenaeus vannamei*) fed high levels of soybean meal in various combinations. *Aquaculture*, **319**, 141–149.

Sornsupharp, B. (2012) Digestibility of dried fairy shrimp *Streptocephalus sirindhornae* as feed ingredient for flower-horn fish. Ph. D. thesis, Khon Kaen University, Thailand.

Sriputhorn, K. & Sanoamuang, L. (2011) Fairy shrimp (*Streptocephalus sirindhornae*) as live feed improve growth and carotenoid contents of giant freshwater prawn *Macrobrachium rosenbergii*. *Int. J. Zool. Res*., **7**, 138–146.

Steel, R.D.G. & Torrie, J.H. (1980) Principles and Procedures of Statistics. A Biometrical Approach, 2nd edn, p. 633. McGraw-Hill Publishing, New York.

Sui, L., Wille, M., Cheng, Y. & Sorgeloos, P. (2007) The effect of dietary n−3HUFA levels and DHA/EPA ratios on growth, survival and osmotic stress tolerance of Chinese mitten crab, *Eriocheir sinensis* larvae. *Aquaculture*, **273**, 139–150.

Tacon, A.G.J. (1987) The nutrition and feeding of farmed fish and shrimp-a training manual. 1. The essential nutrients. GCP/RLA/075/ITA. Field Document 2/E. FAO, Brasilia, Brazil.

Terrazas-Fierro, M., Civera-Cerecedo, R., Ibarra-Martínez, L., Goytortúa-Bores, E., Herrera-Andrade, M. & Reyes-Becerra, A. (2010) Apparent digestibility of dry matter, protein, and essential amino acid in marine feedstuffs for juvenile whiteleg shrimp *Litopenaeus vannamei*. *Aquaculture*, **308**, 166–173.

Velu, C.S. & Munuswamy, N. (2004) Improving the fatty acid profile of fairy shrimp, *Streptocephalus dichotomus*, using a lipid emulsion rich in highly unsaturated fatty acids. *J. Agric. Food Chem*., **52**, 7033–7038.

Velu, C.S. & Munuswamy, N. (2007) Composition and nutritional efficacy of adult fairy shrimp *Streptocephalus dichotomus* as live feed. *Food Chem*., **100**, 1435–1442.

Velu, C.S. & Munuswamy, N. (2008) Evaluation of *Steptocephalus dichotomus* nauplii as a larval diet for freshwater prawn *Macrobrachium rosenbergii*. *Aquacult. Nutr*., **14**, 331–340.

Velu, C.S., Czeczuga, B. & Munuswamy, N. (2003) Carotenoprotein complexes in entomostracan crustaceans (*Streptocephalus dichotomus* and *Moina micrura*). *Comp. Biochem. Physiol. B*., **135**, 35–42.

Wu, X., Cheng, Y., Sui, L., Zeng, C., Southgate, P.C. & Yang, X. (2007) Effect of dietary supplementation of phospholipids and highly unsaturated fatty acids on reproductive performance and offspring quality of Chinese mitten crab, *Eriocheir sinensis* (H. Milne-Edwards), female broodstock. *Aquaculture*, **273**, 602–613.