Aquaculture 228 (2003) 351–360

The effect of light color on the growth of Chinese shrimp *Fenneropenaeus chinensis*

Fang Wang, Shuanglin Dong*, Guoqiang Huang, Lixin Wu, Xiangli Tian, Shen Ma

Mariculture Research Laboratory, Ocean University of China, Qingdao 266003, PR China

Received 17 July 2002; received in revised form 20 March 2003; accepted 26 March 2003

Abstract

The specific growth rate (SGR) over 45 days of *Fenneropenaeus chinensis* shrimp with initial body weight of 1.979±0.036 g under different light color was as follows: natural>green>yellow>blue light. The SGR of shrimp under blue light was only 73.0% and 85.8% of those under natural light and green light, respectively. The maximal and minimal feed intake (FI) of the animal occurred under blue light and yellow light (difference 16.6%), respectively. The lowest food conversion efficiency (FCE) occurred in the blue light group (64.5% and 75.8% of that under natural and green light, respectively). FCE values between blue and natural light groups were significantly different ($P<0.05$). *F. chinensis* was relatively sensitive to blue light, under which the animal was active in feeding behavior, and gained a higher FI as well as a lower FCE, and therefore, a lower SGR.Shrimp may grow faster in the organically rich earthen ponds than in organically poor waters because there is less blue light spectrum in earthen ponds.

Keywords: Shrimp; *Fenneropenaeus chinensis*; Growth; Light color

1. Introduction

Virus diseases have seriously attacked the worldwide shrimp culture industry since 1988. To prevent diseases from breaking out, some chemical and physical measures taken for treating cultivation pond water by Chinese farmers result in the waters becoming organically poor. However, the organically rich pond waters abundant in plankton promote

* Corresponding author. Tel.: +86-532-2032964; fax: +86-532-2894024.
E-mail address: dongsl@mail.ouc.edu.cn (S. Dong).

0044-8486/$ - see front matter © 2003 Elsevier Science B.V. All rights reserved.
doi:10.1016/S0044-8486(03)00312-0

better shrimp growth than the organically poor waters. Some scholars reported "growth enhancement" factors in organically rich earthen ponds (Leber and Pruder, 1988). As revealed by Moss (1990), the growth rate of the cultivated shrimp was positively correlated with the densities of Particle Organic Carbon (POC), ATP and unicellular algae, and these suspended particles were favorable for shrimp growing (Moss et al., 1992; Moss, 1995). Some scholars also reported that the organically rich pond waters would be able to stimulate the activities of shrimp's digestion enzymes, resulting in an increase of food assimilation and promotion of shrimp growth (Jones et al., 1993; Rodriguez et al., 1994; Moss et al., 2001).

There might exist significant differences of light intensity and spectrum between the organically rich pond waters and the organically poor waters (McFarland, 1986). The effects of light intensity and spectrum on fish behavior, feeding activities and growth have been proved (Blaxter, 1968; Dabrowski and Jewson, 1984; Gehrke, 1994). Light spectrum also significantly affects the ovarian maturation, reproduction and growth of some crustaceans (Emmerson, 1980; Emmerson et al., 1983; Kelemec and Smith, 1980; Pudadera and Primavera, 1981; Hillier, 1984; Primavera and Caballero, 1992). Our hypothesis, therefore, is that the light spectrum difference of the organically poor and organically rich waters may be one of the most important "growth enhancement" factors. Therefore, this experiment is to test the hypothesis by observing the growth of *Fenneropenaeus chinensis* shrimp under four light colors, and to analyze its mechanisms by means of estimating energy budgets.

2. Material and methods

2.1. Source and acclimation of shrimp

The experiment was carried out from June 24 to August 8, 2001 at the Mariculture Research Laboratory, Ocean University of China, Qingdao, PR China. The shrimp used in the experiment were collected from the Fengcheng Shrimp Farm, Qingdao. Prior to the experiment, all the health-selected shrimp were transferred into aquaria and underwent a 7-day acclimation period during which they were fed formulated feed (43.39±0.22% crude protein, 9.74±0.30% fat, 9.91±0.01% ash, 8.41±0.06% moisture) at satiation level twice a day (at about 6:00 and 18:00 h).

2.2. Rearing condition

Shrimp were kept in glass aquaria (45×30×30 cm, water volume of 35 l). Each rearing unit was stocked with four shrimps. The separate light treatments (shaded from each other) were held in one room where temperature was controlled using an air conditioner. Water exchanges were made to all treatments at the same time and from the same water source. Aeration was provided continuously and one-half to two-thirds of volume water was exchanged every other day to ensure high water quality. Seawater used in the experiment was filtered by composite sand filters. During the course of the experiment, dissolved oxygen was maintained above 6.0 mg/l, the pH was around 7.8,

ammonia was less than 0.24 mg/l, water temperature was 25.0±0.5 °C, the salinity of seawater was within 28 to 30 ppt, and a simulated natural photoperiod (14:10 h light/darkness) was used.

2.3. Experiment design

The four light colors tested were natural light (simulated from incandescent lamp, FSL, ZS230-25w) and three types of colored lights, i.e., yellow, green and blue lights (from Huaxing Fluorescent Lamp, 36 W). The peak wavelength of the four types of lights was 590 nm (natural light), 580 nm (yellow light), 525 nm (green light) and 435 nm (blue light), respectively, and the luminance on the bottom of experimental aquaria (around 200 lx, max 250 lx, min 150 lx) was measured by an underwater illumination photometer (JD-1A, made in Shanghai Xuelian Instruments). The experiment on each light color was conducted in separate wooden rooms set in an experimental room. Four replicates were set up for the experiment on each light color. Normally, the lamps were hung 60–80 cm above the aquaria. The illumination intensity was controlled by adjusting the distances between lamps and water surface to keep the luminance on the bottom of the aquaria as equal as possible.

2.4. Experimental procedure and samples collection

After 12-h feed deprivation, 100 size-selected shrimp with initial weight range 1.727–2.232 g (1.979±0.036 g, mean±S.E.) were pooled into a large fiberglass tank. From the pooled shrimp, about 30 shrimps were randomly sampled for the later analysis (including initial dry weight, energy and protein of shrimp). The remains were randomly selected, individually weighed and stocked into 16 aquaria with each aquarium holding four individuals. During the experiment, the shrimps were fed twice a day (at 6:00 and 18:00 h). The uneaten feed and feces were collected into cups by siphon within 2.5 h after each meal. The collected uneaten feed and feces in cups were settled, and then the water above was removed carefully. The molted shells were collected at times. The collected uneaten feed, feces and shells were dried at 65 °C, respectively, and kept for further analysis. At the end of the 45-day experiment, all the test shrimps were collected and dried at 65 °C for 48 h.

2.5. Determination of energy contents and estimation of energy budget

The energy contents of the shrimp bodies, feed and feces were measured by Parr 1281 Oxygen Bomb Calorimeter. The energy budget was calculated as the following equation for the crustacean energy budget (Petrusewicz and Macfadyen, 1970):

$$C = G + F + U + E + R$$

where C is the energy consumed in food; G, the energy deposited for growth; F, the energy lost in feces, U, the energy in excretion; E, the energy spent for exuvia, and R, the energy for respiration.

The estimation of U was based on the nitrogen budget equation (Levine and Sulkin, 1979; Lemos and Phan, 2001):

$$U = (C_N - G_N - F_N - E_N) \times 24\ 830$$

where C_N is the nitrogen consumed from food; F_N, the nitrogen lost in feces; G_N, the nitrogen deposited in shrimp body; E_N, the nitrogen lost in molting; 24 830, the energy content in excreted nitrogen per gram (J/g). The nitrogen contents in the formulated feed, shrimp, feces and molting shell were determined by Kjeldahl method.

The value of R was calculated as the following energy budget equation:

$$R = C - G - F - U - E$$

2.6. Calculation of data

Specific growth rate (SGR_d), feed intake (FI_d) and food conversion efficiency (FCE_d) in terms of the dried weight were calculated as follows:

$$SGR_d(\% \cdot day^{-1}) = 100(\ln W_2 - \ln W_1)/T$$

$$FI_d(\%B \cdot W \cdot day^{-1}) = 100C/[T(W_2 + W_1)/2]$$

$$FCE_d(\%) = 100(W_2 - W_1)/C$$

where, W_2 and W_1 are the final and initial dried body weight of the shrimp; T, the time of the experiment lasted; C, the total food consumed in dry weight.

SGR, FI andFCE in terms of protein (SGR_p, FI_p, FCE_p) and energy (SGR_e, FI_e, FCE_e) were calculated similarly.

2.7. Statistical analysis

Statistics were performed using SPSS 10.0 statistical software with possible differences among groups being tested by one-way ANOVA. Duncan's multiple range tests were used to test the differences between treatment groups. Differences were considered significant at a probability level of 0.05.

3. Results

3.1. Growth

There were significant differences in final wet body weight of test shrimp between blue light and natural light treatments ($P<0.05$) (Table 1). Specific growth rates (SGR) of the test shrimp in terms of dry weight, protein and energy varied with the different colors and showed a declining gradient of natural>green>yellow>blue light (Fig. 1). The lowest SGR was observed under the blue light and the growth differences between the groups under blue and natural colors were significant ($P<0.05$) while the differences among the groups under natural, green and yellow colors were below the level of significance ($P>0.05$).

Table 1
Growth, survival and food consumed by *F. chinensis* (Osbeck) under different treatments during the course of the experiment (mean±S.E.)[1]

Treatments	Body wet weight (g)		Survival (%)	Food consumed[2] (g/individual)
	Initial	Final		
Natural light	1.962±0.021	4.150±0.198[a]	90.0±5.8	6.863±0.331[ab]
Yellow light	2.005±0.038	3.708±0.242[ab]	100.0±0.0	6.320±0.031[b]
Green light	2.018±0.030	3.802±0.182[ab]	90.0±5.8	6.530±0.179[b]
Blue light	1.929±0.041	3.398±0.207[b]	90.0±5.8	7.365±0.342[a]

[1] Values (expressed as mean±S.E., n=4) with different letters in the same column are significantly different from each other (P<0.05).
[2] Food consumed (per individual): total food consumed on a dry weight basis (g) during the experiment

3.2. Feed intake

The total food consumed on a dry weight basis showed a declining gradient of blue>natural>green>yellow light (Table 1). There was no significant difference of blue and natural light (P>0.05) but there were between blue and the other colors (P<0.05). The feed intakes (FI_d) under blue light not only ranked the top among these four treatment groups but also differed with that under natural light significantly (P<0.05), but not significantly (P>0.05) from those under yellow or green light (Fig. 2). FI_p and FI_e exhibited the same pattern. The feed intakes (FI_d, FI_p and FI_e) under any one of the four colors declined as FI_e>FI_d>FI_p.

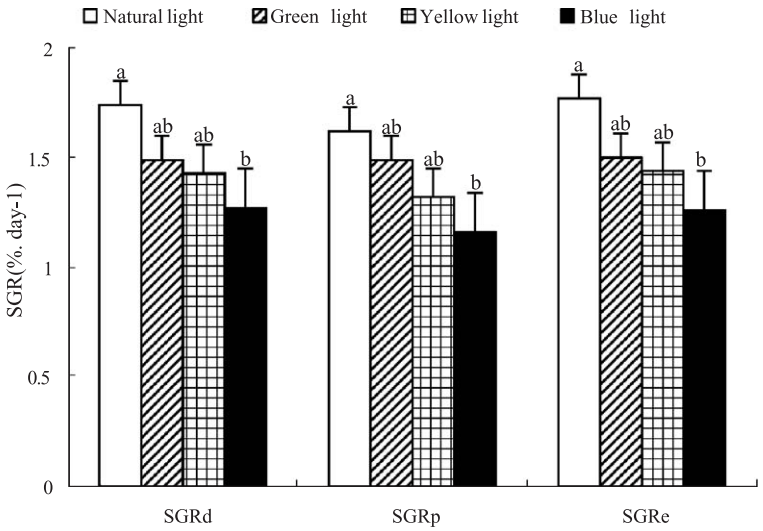

Fig. 1. Specific growth rates (SGR) of *F. chinensis* during the 45-day experiment. Means (n=4) with different letters indicate significant differences (P<0.05) and bars represent standard errors of the means. The indices SGRd, SGRp and SGRe indicate specific growth rate in terms of dry matter, protein and energy, respectively.

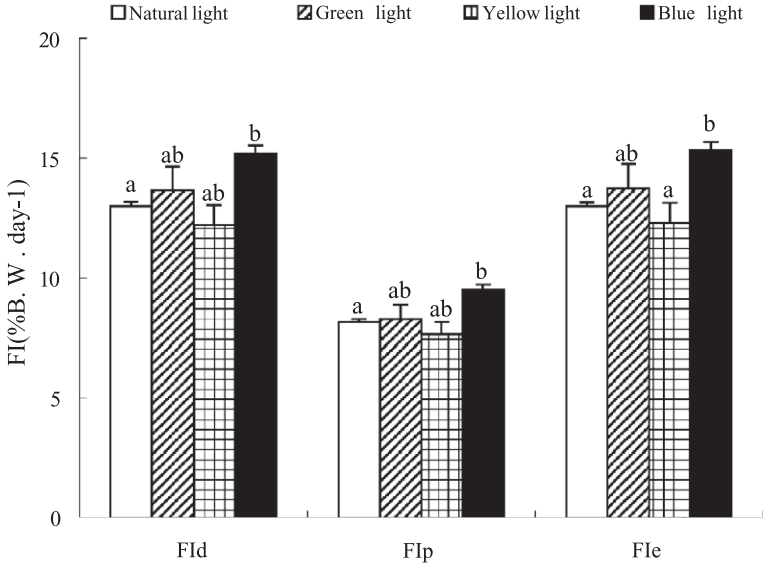

Fig. 2. Feed intakes (FI) of *F. chinensis* during the 45-day experiment. Means (n=4) with different letters indicate significant differences (P<0.05) and bars represent standard errors of the means. The indices FId, FIp and FIe indicate food intake in terms of dry matter, protein and energy, respectively.

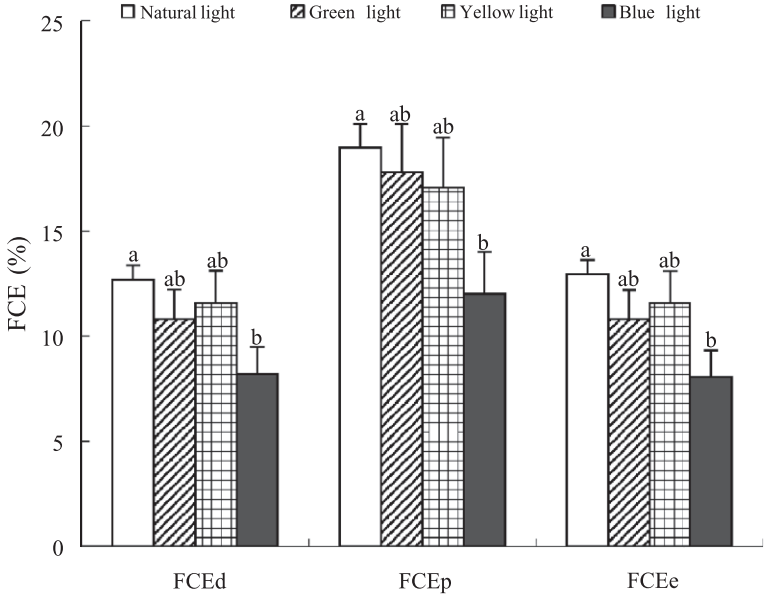

Fig. 3. Food conversion efficiencies (FCE) of *F. chinensis* during the 45-day experiment. Means (n=4) with different letters indicate significant differences (P<0.05) and bars represent standard errors of the means. The indices FCEd, FCEp and FCEe indicate food intake in terms of dry matter, protein and energy, respectively.

Table 2
Allocation of the consumed energy in Chinese shrimp at different treatments (mean±S.E.)[1]

Treatments	R/C[2]	G/C[3]	E/C[4]	U/C[5]	F/C[6]
Nature light	65.15±0.48[a]	12.94±0.70[a]	1.42±0.17[a]	5.76±0.08[a]	14.73±0.65[a]
Yellow light	68.43±2.19[ab]	11.56±1.54[ab]	1.72±0.16[a]	6.06±0.29[a]	12.24±0.87[b]
Green light	69.99±1.24[b]	10.81±1.39[ab]	1.36±0.24[a]	6.16±0.21[a]	11.69±0.79[b]
Blue light	76.11±1.22[c]	8.07±1.26[b]	1.52±0.13[a]	7.05±0.19[b]	7.25±0.33[c]

[1] Values (expressed as mean±S.E., n=4) with different letters in the same column significantly different from each other (P<0.05).
[2] R/C (%)=energy for respiration/ energy consumed in food.
[3] G/C (%)=energy for growth/ energy consumed in food.
[4] E/C (%)=energy for exuvia/ energy consumed in food.
[5] U/C (%)=energy for excretion/ energy consumed in food.
[6] F/C (%)=energy for feces/ energy consumed in food.

3.3. Food conversion efficiency

The maximal and minimal FCE values were gained under natural and blue light, respectively, and the differences between them were significant (P<0.05) (Fig. 3). The FCE differences between any other pair of treatments were not significant (P>0.05). Moreover, FCE in terms of protein and energy had similar variation. Under any one of the four light colors, the maximal food conversion efficiency was gained from FCE_p, and the values of FCE_e and FCE_d showed less difference.

3.4. Energy allocation

The patterns of energy allocation in the test shrimp presented significant differences among the groups under different light colors (Table 2). The test shrimp under blue light treatment spent much more energy in respiration and excretion, while depositing less energy for growth than those shrimp under any other light colors. In contrast, the shrimp under the natural light treatment deposited more energy for growth and spent less energy in respiration and excretion. The differences of energy allocation between these two treatment groups (blue and natural light) were significant (P<0.05).

4. Discussion

The physiological and ecological effect of different light colors on fish has been demonstrated for some time. For example, sensitive to yellow-green light, herring *Clupea harengus* larvae fed most actively under the light with a wavelength of 560 nm (Blaxter, 1968). Larvae of white salmon *Coregonus pollan*(Thompson) were sensitive to green light and insensitive to red light (Dabrowski and Jewson, 1984). The larvae of both silver perch *Bidyanus bidyanus* and golden perch *Macquaria ambigua* were attentive to yellow-orange light (Gehrke, 1994). No doubt, the abovementioned fish species were sensitive to different colors, which was the result for adaptations to their own habitat.

Zheng and Zhang (1985) showed that white shrimp (*F. penicillatus*) were relatively sensitive to the action spectrum of 490 and 570 nm. Anatomically, crayfish *Procambarus clarckii* possessed two photosensitive systems, one of which developed in the early life stage and was sensitive to blue light and another, developed later, was sensitive to red light. The photosensitivity of the crayfish changed in their different life stages (Fanjul-Moles and Fuentes-Pardo, 1988; Fanjul-Moles et al., 1992). *F. chinensis* have two types of photosensitive cells sensitive, respectively, to blue light (480 nm) and yellow light (580 nm) (Chen et al., 1996), and different light colors have an effect on ovarian maturation, growth and reproduction of crustaceans (Emmerson, 1980, Emmerson et al., 1983; Kelemec and Smith, 1980; Pudadera and Primavera, 1981; Primavera and Caballero, 1992). In the present experiment, the final wet body weight and SGRof the test declined in the order of natural>green>yellow>blue light. SGR under natural light and green light was 1.37 and 1.18 times of that under blue light, respectively. Le Reste (1970) reported that blue light was able to induce activity in *F. indicus*. In the present experiment, FI was greatest under blue light and the energy spent in respiration was as much as 1.17 in natural light, suggesting a similar effect in *F. chinensis*. In contrast, *F. chinensis* under the natural light treatment used more energy for growth and spent less energy in respiration and excretion.

Van Wormhoudt and Ceccaldi (1976) have also shown that different wavelengths affect the enzymatic activity in *Palaemon serratus* shrimp thus affecting digestibility, assimilation and the growth of shrimp. In our experiment, FCE under blue light only valued 64.5% than under natural light so also contributing to a lower SGR under blue light.

Blue light with a wavelength about 470 nm can transmit furthest in clean seawater, but red light and ultraviolet light may attenuate quickly when penetrating clean seawater (Jerlov, 1968). Coastal waters and those seawaters rich in plankton and dissolved organic substance may absorb or scatter blue light greatly to shift in the transmitted light from the blue-green region of the spectrum to the green-orange region of the spectrum (Blaxter, 1968; McFarland, 1986). High plankton density and high dissolved organic levels in the seawater of shrimp cultivation ponds result in decreased light transmittability, particularly for blue light. Consequently, the bottom of the organically poor ponds might have a greater level of blue light than organically rich pond waters, and this may explain the better growth of shrimp in organically rich pond waters. There are many confounding factors that might explain differences in growth between organically rich and organically poor ponds, for example, effects of chemicals and treatments used to clean the ponds and different food levels. However, the present experiment showed that the changing of light spectrum might be an additional factor that affects shrimp growth.

Acknowledgements

This work was supported by funds from the Chinese National Science Foundation for Talent Youths (Grant no. 39725023), the Project under the Major State Basic Research of China (Grant no. G1999012011) and the National Tenth Five-Year Scientific and

Technological Key Project (Grant no. 2001BA505B-04). We thank Fengcheng Shrimp Farm, Qingdao, PR China, for providing the shrimp used in this experiment.

References

Blaxter, J.H.S., 1968. Visual thresholds and spectral sensitivity of herring larvae. J. Exp. Biol. 48, 39–53.

Chen, S.Q., Li, A.J., Wang, C., 1996. The structure and physiological functions of eyes in shrimp (*Penaeus chinensis*). Marine Fisheries Research 17, 30–34.

Dabrowski, K.R., Jewson, D.H., 1984. The influence of light environment on depth of visual feeding by larvae and fry of *Coregonus pollan* (Thompson) in Lough Neagh. J. Fish Biol. 25, 173–181.

Emmerson, W.D., 1980. Induced maturation of prawn *Penaeus indicus*. Mar. Ecol., Prog. Ser. 2, 21–31.

Emmerson, W.D., Hayes, D.P., Ngonyame, M., 1983. Growth and maturation of *Peaneus indicus* under blue and green light. S. Afr. J. Zool. 18, 71–75.

Fanjul-Moles, M.L., Fuentes-Pardo, B., 1988. Spectral sensitivity in the course of the ontogeny of the crayfish *Procambarus clarckii*. Comp. Biochem. Physiol. 91A, 61–66.

Fanjul-Moles, M.L., Miranda-Anaya, M., Fuentes-Pardo, B., 1992. Effect of monochromatic light upon the ERG circadian rhythm during ontogeny in crayfish (*Procambarus clarckii*). Comp. Biochem. Physiol. 102A, 99–106.

Gehrke, P.C., 1994. Influence of light intensity and wavelengh on phototactic behaviour of larval silver perch *Bidynus bidyanus* and golden perch *Macquaria ambigua* and the effectiveness of light traps. J. Fish Biol. 44, 741–751.

Hillier, A.G., 1984. Artificial conditions influencing the maturation and spawning of subadult *Penaeus monodon* (Fabricius). Aquaculture 36, 179–184.

Jerlov, N.G., 1968. Optical Oceanography. Elsevier, Amsterdam.

Jones, D.A., Kamarudin, M.S., Le Vay, L., 1993. The potential for replacement of live feeds in larval culture. J. World Aquac. Soc. 19, 197–203.

Kelemec, J.A., Simth, I.R., 1980. Induced ovarian development and spawning of *Penaeus plebejus* in a recirculating laboratory tank after unilateral eyestalk enucleation. Aquaculture 21, 55–62.

Leber, K.M., Pruder, G.D., 1988. Using experimental microcosms in shrimp research: the growth-enchancing effect of shrimp pond water. J. World Aquac. Soc. 19, 197–203.

Lemos, D., Phan, V.N., 2001. Energy partitioning into growth, respiration, excretion and exuvia during larval development of the shrimp *Farfantepenaeus paulensis*. Aquaculture 199, 131–143.

Le Reste, L., 1970. Contribution a l'étude du rhythme d'activité nocture de *Penaeus indicus* en *Parapenaeopsis acclivirostris* (Crustacea: Decapoda: Natantia). Cah. Off. Rech. Sci. Tech. O.-M. (Oceanogr.) 8, 3–10.

Levine, D.M., Sulkin, S.D., 1979. Partitioning and utilization of energy during the larval development of the xanthid crab, *Rithropanopeus harrisii* (Gould). J. Exp. Mar. Biol. Ecol. 40, 247–257.

McFarland, W.N., 1986. Light in the sea-correlations with behaviours of fishes and invertebrates. Am. Zool. 26, 389–401.

Moss, S.M., 1990. Possible trophic links in penaeid shrimp aquaculture ponds. Pac. Sci. 44, 193.

Moss, S.M., 1995. Production of growth-enchancing particles in a plastic-lined shrimp pond. Aquaculture 132, 253–260.

Moss, S.M., Pruder, G.D., Leber, K.M., Wyban, J.A., 1992. The relative enhancement of *Penaeus vannamei* growth by selected fractions of shrimp pond water. Aquaculture 101, 229–239.

Moss, S., Divakaran, S., Kim, B., 2001. Stimulation effects of pond water on digestive enzyme activity in the Pacific white shrimp, *Litopenaeus vannamei* (Boone). Aquac. Res. 32, 125–131.

Petrusewicz, K., Macfadyen, A., 1970. Productivity of Terrestrial Animals: Principles and Methods. IBP Handbook, vol. 13. Blackwell, Oxford. 190 pp.

Primavera, J.H., Caballero, R.M.V., 1992. Light color and ovarian maturation in unablated and ablated giant tiger prawn *Penaeus monodon* (Fabricius). Aquaculture 108, 247–256.

Pudadera, R.A., Primavera, J.H., 1981. Effects of light quality and eyestalk ablation on ovarian maturation in *Penaeus monodon*. Kalikasan, Philipp. J. Biol. 10, 231–240.

Rodriguez, A., Le Vay, L., Mourente, G., Jones, D.A., 1994. Biochemical composition and digestive enzyme

activity in larvae and postlarvae of *Penaeus japonicus* during herbivorous and carnivorous feeding. Mar. Biol. 118, 45–51.

Van Wormhoudt, A., Ceccaldi, J.H., 1976. Influence de la qualité de la lumiére en élevage intensif de *Palaemon seratus* Pennant. In: Persoone, G., Jaspers, G. (Eds.), Proc. 10th Eur. Symp. Mar. Biol., vol. 1. Universa press, Belgium, pp. 505–521. Mariculture.

Zheng, W.Y., Zhang, L., 1985. The receptor system and adaptive characteristic of eyes in shrimp *Fenneropenaeus penicillatus*. J. Xia Men Univ. 24, 256–262.