

The Influence of *Artemia* and Algal Supplements during the Nursery Phase of Rearing Pacific White Shrimp, *Litopenaeus vannamei*

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Abstract

A 21-d nursery trial was conducted to evaluate various food supplements on growth and survival of postlarval (PL) *Litopenaeus vannamei*. Each of four treatments was provided with an equal quantity of a dried commercial feed throughout the study. Three treatments received algae paste (*Thalassiosira weissflogii*) supplemented every 3 d. These include F, commercial feed plus algae; FAR3, commercial feed plus algae plus *Artemia* every other day during the first 7 d; and FAR7, commercial feed plus algae plus *Artemia* every day during the first 7 d. The fourth treatment served as control (FNA); it relied only on the commercial feed plus naturally occurring algae. At the conclusion of the nursery period, there were no significant differences in survival or feed conversion ration for PL nursed in the various treatments. *Artemia* did have some effect in that PL receiving *Artemia* supplement for 3 d (FAR3) were significantly larger than those that did not. Algal paste in itself had no significant effect. Overall, results suggest an advantage to supplementing dried feed with *Artemia* for at least 3 d during the first week of nursery culture but little advantage to the use of a diatom paste as a food supplement.

As culture system intensity increases for marine shrimp, two-phase culture systems that include both a nursery stage and grow out are becoming more common (Samocha and Lawrence 1992, 1998). The quantity and nutritional quality of the diet offered to postlarvae (PL) is a large factor in growth and survival, and in the success of producing juveniles during grow out. It is well established that shrimp larvae require different feeds according to behavior, morphology, and nutritional needs throughout their developmental stages (New 1976; Wickins 1976; Colvin and Brand 1977; Treece and Yates 1990; Wyban and Sweeney 1991). In larval rearing systems, growers commonly use a combination of live feeds with prepared high-protein dried feeds (Fegan 1992). Currently, *Artemia* is the food most commonly chosen in shrimp larvae culture to fulfill nutritional needs (Fujita et al. 1980; Schauer et al. 1980; Sorgeloos 1980; Navarro et al. 1991; Wilkenfeld 1992; Dhert et al.

1993; Nelson et al. 2002; Shapawi and Purser 2003). *Artemia* provides a rich source of nutrients including essential amino acids and some essential polyunsaturated fatty acids such as 20:5n3 (Leger et al. 1985; Millamena et al. 1988). Although the commercial production of *Artemia* cysts has increased since its value as a food for larvae was first reported (Seale 1933; Hudinaga 1942), demand for cysts still exceeds commercial supplies (Sorgeloos et al. 1986). Because of the subsequent high price, recent studies have sought the optimum utilization of *Artemia* (Samocha et al. 1989; Liao et al. 1993). Although *Artemia* are commonly used in nursery systems, most research has emphasized its use during the hatchery phase; consequently, there is little information on the benefits for intensive nursery systems.

Another natural food of shrimp is algae, which is commonly offered to the early larval rearing stages of shrimp (Cockcroft and McLachlan 1986; Bailey-Brock and Moss 1992). In culture facilities, algae species are selected for cultivation based on ease of culture and cost of culture as well as dietary value (Treece and Yates 1990). Diatoms are advantageous because of their low

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fiber content (Mann and Pruder 1988) and high concentration of polyunsaturated fatty acids (Phillips 1984). Penaeid shrimp consume diatoms in their natural environment (Gleason and Zimmerman 1984; Gleason and Wellington, 1988) and in aquaculture ponds (Hunter et al. 1987; Bombeo-Tuburan et al. 1993; Moss and Pruder 1995). However, Boyd (1989) neither supported nor disputed the relevance of diatoms in shrimp culture.

Several products have been used with limited results as complete or partial replacements for live algae, including yeast; dry compounded feeds; and frozen, dried, and concentrated live algal pastes (Biedenbach et al. 1990; Coutteau et al. 1990). The advantages of algal pastes include stable nutritional composition, reduction in both the labor and expense of maintaining a large live algal production facility, ability to harvest excess algal biomass for use at a later date, maintenance of the nutritional profile without requiring nutrient additions, ease of achieving high concentrations (5.0×10^3 cells/mL), and ease of suspension in the water column with minimum circulation. However, improper harvest and extended storage of algal materials can lead to cell wall disruption and nutrient loss. Of those products composed exclusively of algal material, concentrated live algal pastes and dried algae appear to hold the most promise (Smith et al. 1993). In addition to their nutritional content, microalgae also play a role in conditioning rearing water, contributing to dissolved oxygen levels and to the removal of toxic metabolites (Leger and Sorgeloos 1992).

Because live food can be expensive and variable in production and nutritional quality (Sorgeloos et al. 1983; Kuban et al. 1985; Leger et al. 1986a), considerable work has gone toward developing dry diets to replace or supplement live feeds (Jones et al. 1987, 1993; Fegan 1992). Dry feeds are typically fortified with vitamins and minerals, and have 10–30% higher protein content than feeds used in grow out (Samocha and Lawrence 1992). Besides adequate nutritional content, artificial diets should meet certain minimum standards including correct particle size distribution, availability in the water at similar density to live feed, stability,

minimal leach loss, high digestibility, and long-term storage capacity (Langdon et al. 1985). Most diets are made from natural products such as fish meal, which has a composition similar to phytoplankton or zooplankton (Jones et al. 1993). As both ingredients and processing are costly, larval feed is expensive and may increase operational costs (Otoshi et al. 2001). Prepared compounded feeds can replace live feed (Jones et al. 1987) and algae (Kanazawa 1990), both in the laboratory and commercially, in most cases they are only used as partial (50–70%) replacement (Jones et al. 1993). Growth may be lower without live feed because the lack of water stability in most microparticulate diets causes leaching, bacterial development, and water pollution (Liao et al. 1988; Jones et al. 1989). Therefore, algae and *Artemia* continue to supplement larval diets (Wilkenfeld 1992).

As previously noted, there are a number of references that support the individual usage of diet components; there is limited research on shrimp growth under nursery conditions and using different combinations of diet supplements that are commercially available. Hence, this study was designed to evaluate the influence of dried feed combined with algae and newly hatched *Artemia* on PL shrimp survival, growth, and feed conversion ratio (FCR) under nursery conditions.

Materials and Methods

This research was conducted at the Claude Petet Mariculture Center, Gulf Shores, Alabama. The design included four treatments, with four replicates, each conducted for 21 d. All treatment tanks received equal quantities of the same dried feed, combined with an additional diet component that varied according to treatment. In three of the treatments, a concentrated algae paste (156×10^8 cells/mL) of the diatom, *Thalassiosira weissflogii* (Instant Algae; Reed Mariculture Inc., San Jose, CA, USA), supplemented the natural algae. The paste was added before stocking and by subsequent applications of 2.8×10^9 million cells every 3 d (after water exchanges) to each of the assigned tanks throughout the nursery period. Of these three treatments, the first (F) received only

commercial dried feed plus algae paste; the second (FAR7) received feed plus algae paste plus *Artemia* every day during the first 7 d; and the third (FAR3) received feed plus algae paste plus *Artemia* at a ratio of 100 *Artemia*/PL every other day during the first 7 d. The fourth treatment (FNA) was not supplemented but relied only on naturally occurring algae plus commercial feed. Cysts of *Artemia* from the Great Salt Lake, USA (INVE Americas Inc., Salt Lake City, UT, USA), were decapsulated with hypochlorite solution (Sorgeloos et al. 1977, 1983, 1986; Treece and Yates 1990) and hatched over a 24-h period before offerings.

Litopenaeus vannamei PL (8–9 d old) were obtained from GMSB Inc. (Key West, FL, USA) on April 29. PL were shipped at a density of about 1400 PL/L. Upon receipt, water samples were collected to evaluate water quality of the shipping bags. Initial weights and the CVs of individual weights were determined from samples by weighing at least 40 PL individually. Excess water was minimized by collecting PL with a strainer, depositing them on an absorbent paper cloth, and then weighing them individually (to the nearest 0.01 mg) on an analytical scale Model ER-182A (A&D Co., Milpitas, CA, USA).

Upon receipt, the PL were transferred into a 940-L acclimation tank filled with sea water that had been adjusted to the salinity of shipping for the PL. The bags containing the PL floated in the acclimation tank until temperatures between the water in the tank and the bags were within 0.5 C. Then, the PL were released in the reception tank and their size, coloration, and activity were evaluated as indicators of PL quality. During acclimation, decapsulated and hatched *Artemia* nauplii (52% protein, 200–300 μ m) (INVE Americas Inc.) were offered at a rate of 100 *Artemia*/PL (Treece and Yates 1990). *Artemia* offerings were calculated based on the assumption of 250,000 *Artemia* cysts in each gram of *Artemia* cysts (Wyban and Sweeney 1991). Salinity of the acclimation tank was gradually adjusted to the salinity of the nursery tanks (from 30.6 to 21 ppt) over 8 h. Once the PL warmed up and their activity increased, the PL were concentrated. The PL were quantified vol-

umetrically (Hardin et al. 1985; Juarez et al. 1996) and distributed. PL were concentrated in a 57-L tank, vigorously mixed by hand, and subsampled with a 60-mL beaker to obtain the density. Means, SD, and CVs were recorded. Replicate nursery tanks were stocked at a density of 22 PL/L (total of 12,429 PL/tank) and the shrimp were nursed for 21 d.

Nursery System

Sixteen circular, polyethylene, round nursery tanks (0.85 m height \times 1.22 m upper diameter, 1.04 m lower diameter, total volume of 795 L), located under a plastic cover, were used for the experiment. The nursery was set as a single-pass flow-through system, with a reservoir tank, a 3-kg canister charcoal filter (Ocean clear Model 320; Red Sea, Houston, TX, USA) and a 1/3-hp (45 gpm) pump (EBARA International Corp., Rock Hill, SC, USA.) for water distribution. Each tank had two air stones connected to a common air supply from a 1-hp regenerative blower (Sweetwater Aquaculture Inc., Lapwai, ID, USA). Tanks had center drainage with a standpipe of 3.2-cm diameter and 75 cm long, set to maintain water level at a height of 61 cm (570 L). Standpipes were surrounded by an external screened pipe (250- μ m mesh). One week prior to stocking, the nursery system was filled with brackish water (21 ppt) originating from the Intracostal Canal between Mobile Bay and Perdido Bay. Water was first pumped into a nearby raceway system for sand filtration for over 24 h for removal of undesirable organisms, organic materials, and other debris. Water was added into the nursery system through the reservoir and distributed into the nursing tanks, pumped at 10.6 L/tank/min. Once the system was filled, water and nursery tanks were disinfected using sodium hypochlorite (approximately 10 ppm chlorine). Dechlorination was ensured by bubble aeration for 4 d and then tested for chlorine residues. To maintain good water quality, 50% of the water in each tank was exchanged every 3 d. First water was drained from the bottom of the tank until reaching the water column height of half its volume and then new water was added.

Feeding

Daily rations were determined based on estimated biomass and feed rates ranging from 50 to 30% of the estimated biomass (Table 1). Biomass was determined every 3 d from a random sample collected from each tank. At least 40 PL were weighed collectively to determine average weight. Four feedings were scheduled each day. The weighed dry feed was divided into four containers. To facilitate feed immersion and distribution, feed in each container was mixed with tank water to form a slurry, which was then distributed evenly around the tank. During the first 6 d, PL were offered a 50% protein diet, PL Redi-Reserve (400–600 mm) (Zeigler Bross Inc., Gardners, PA, USA). Thereafter, PL were fed with a combination of two 45% protein commercial shrimp starter feeds, Rangen #0 (<0.6 mm) and #1 (0.6–1 mm) (Rangen Inc., Buhl, ID, USA).

Water Quality Analyses

Temperatures were recorded every 2 h on a 24-h basis with a temperature logger Boxcar version 3.7 (Onset Computer Corp., Bourne, MA, USA). Dissolved oxygen and temperature was monitored daily in the morning and afternoon hours using either a YSI 85 or YSI 556 dissolved oxygen meter (Yellow Spring Instruments, Yellow Springs, OH, USA). Water quality parameters were monitored every 3 d from samples collected from a randomly selected replicate from each treatment, including salinity, total ammonia-nitrogen (TAN), and pH. Salinity

was monitored using a YSI 30 salinity meter (Yellow Springs Instruments). TAN was monitored using a spectrophotometer Spectronic 20 Genesys (Spectronic Instrument Inc., Rochester, NY, USA) and the Nesslerization method (APHA, American Water Works Association, and Water Pollution Control Association 1989), and pH measurement was taken using a Accumet pH meter (Fisher Scientific, Pittsburgh, PA, USA).

Data Analyses

The data were analyzed by ANOVA for juvenile's final average weight, survival, FCR, biomass loading, and individual size CV. The Student–Newman–Keuls multiple comparison test was used to determine significant differences among treatment means ($P < 0.05$). Analyses were conducted using SAS program version 8.2 (SAS Institute Inc., Cary, NC, USA).

Results

Four feeding combinations were evaluated for this research that included (1) dry diet with algal paste (F), (2) dry diet with seven feedings of *Artemia* (FAR7), (3) dry diet with three feedings of *Artemia* (FAR3), and (4) dry diet with naturally occurring algae (FNA). At the end of the 21-d nursery trial, production results for the various treatments ranged as follows: final mean weight of juveniles, 27.1–47.0 mg/PL; FCR, 1.2–1.6; survival 74.7–87.1%; and biomass loading from 0.68 to 0.95 kg/m³ (Table 2).

No significant differences were found in FCR, survivals, and CV of individual weights among treatments. Average weight and biomass loadings were significantly greater in the treatment receiving three feedings of *Artemia* (FAR3) as compared to those receiving feed and algae (F and FNA). PL receiving *Artemia* for 7 d (FAR7) were intermediate between these two groups. There were no significant differences or notable trends in survival. It should be noted that one replicate tank from FAR7 (Tank 11) and one from FAR3 (Tank 13) treatments were excluded from analyses. In these tanks, excessive mortality was noted during a cold front that occurred during the last week of the nursery trial. Survivals in these replicates were 13.4

TABLE 1. Feeding rates as percent biomass and feed type utilized through the 21-d nursery period for *Litopenaeus vannamei* postlarvae (PL). Feed inputs were based on an assumed 100% survival and the mean shrimp weight.

Days	% biomass	Feed type
1–3	50	PL Ready ^a
4–6	50	PL Ready
7–9	35	PL Ready/Crumble #0
10–12	35	Crumble #0
13–15	30	Crumble #0 and Crumble #1 ^b
16–18	30	Crumble #1
19–21	30	Crumble #1

^a PL Ready 50% protein, Zeigler Bross Inc.

^b Rangen 45% protein, Rangen Inc.

TABLE 2. Production characteristics of *Litopenaeus vannamei* nursed for 21 d, stocked at 22 postlarvae/L and fed algae paste with a commercial feed (F), feed with algal paste plus 7 d of *Artemia* (FAR7), feed with algal paste and *Artemia* every other day for 7 d (FAR3), and feed with naturally developed algae (FNA).¹

Nursery phase	F	FAR7	FAR3	FNA	P > F
Final average weight (mg)	27.1 ^a	35.8 ^{ab}	47.0 ^b	29.4 ^a	0.019
Survival (%)	86.1 ^a	87.1 ^a	74.7 ^a	78.0 ^a	0.362
FCR ²	1.5 ^a	1.6 ^a	1.4 ^a	1.2 ^a	0.149
Final biomass (kg/m ³)	0.679 ^a	0.910 ^{ab}	0.947 ^b	0.688 ^a	0.019
CV (%) ³	61.25 ^a	76.81 ^a	61.46 ^a	64.33 ^a	0.477

¹ Means not sharing a common superscript within a row are significantly different ($P \leq 0.05$) based on Student–Newman–Keul’s multiple range test.

² FCR (feed conversion ratio) = total weight of feed given/biomass increase.

³ CV = SD/mean × 100.

and 38.9%, while the rest of the replicates averaged 87.9 and 74.7%, respectively.

The four treatments followed similar growth patterns; however, treatments supplemented with *Artemia* (FAR7 and FAR3) had higher weights than the other two treatments during sampling periods (Fig. 1). The gap between the supplemented group (FAR7 and FAR3) versus the non-supplemented group (F and FNA) increased throughout the nursing period. The CV for individual weights at stocking was 44%. After the nursery, CV ranged from 61 to 76.8%. Although no significant differences were found among treatments, the highest size variation was observed in FAR7 (CV = 76.8%).

Water temperatures throughout the nursery averaged 24.93 ± 2.86 C and 25.05 ± 2.89 C for day and night readings, respectively. On D 14 and D 18–21, two cold fronts caused low water temperatures in the range of 17.9–20 C and 18–19 C, respectively. Dissolved oxygen readings in all tanks were consistently from 7.2 to 8.3 mg/L. Salinity throughout the experimental period ranged from 21 to 16.7 ppt. During the last 3 d, salinity increased to 21 ppt because of salinity fluctuations in the water source. The pH generally stayed between 8.2 and 7.7. Highest detected TAN concentrations were 1.33, 2.25, 2.37, and 0.95 mg/L NH₃-N for F, FAR7, FAR3, and FNA treatments, respectively.

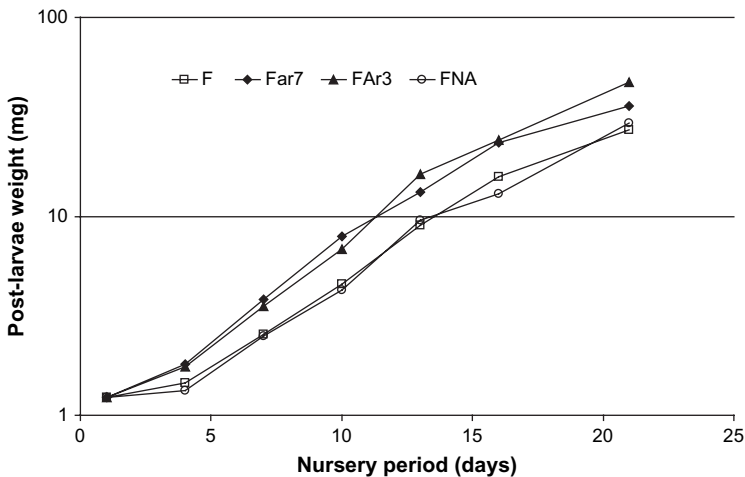


FIGURE 1. Growth curves of *Litopenaeus vannamei* postlarvae (PL) at various days during the indoor nursery phase stocked at 22 PL/L and fed algal paste with a commercial feed (F), feed with algal paste plus 7 d of *Artemia* (FAR7), feed with algal paste and *Artemia* every other day for 7 d (FAR3), and feed with naturally developed algae (FNA).

Treatments FAR7 and FAR3, which were supplemented with *Artemia*, had TAN concentrations that were twice as high as treatments that did not receive *Artemia* (Table 3). With the exception of the low water temperatures that occurred during cold fronts, temperatures, dissolved oxygen, salinities, pH, and TAN values were within recommended ranges for *L. vannamei* culture (Hanson and Goodwin 1977; Clifford 1985; Boyd 1989; Brock and Main 1994).

Discussion

The various feeding protocols did not have a significant effect on survival, FCR, and the variation of final individual weights; however, there were significant differences in final mean weights and final biomass. Survivals were higher than what is typical for this facility and may have been better if cold weather had not stressed the shrimp. Two tanks were excluded from the study because of visible mortalities during the cold front. Overall survivals and FCR were still good across all treatments and were similar to the results reported by Sturmer and Lawrence (1987), Sturmer et al. (1992), Samocha and Lawrence (1998), and Samocha et al. (1999).

Size variation is often used as a measure of PL quality (Fegan 1992). Wyban and Sweeney (1991) reported that during the nursery phase, the CV for individual weights declines. The initial CV of individual PL weights (CV = 44%) for this trial was relatively high as CVs greater than 30% are considered excessive (Wyban and Sweeney 1991; Brock and Main 1994). At the conclusion of the nursery period, CV increased in all the treatments ranging from 61.2 to 76.8%. This is typical for a number of

nursery trials that have been conducted at this facility. For example, CV found in two other nursery trials ranged from 66 to 156% and 54 to 71% for the various nursery treatments. In each of these trials, there has been an increase in the CV of weights at the conclusion of the nursery period, which could be because of genetic potential or some shrimp outcompeting others for food and thus being able to grow faster.

For this study, *Artemia* were decapsulated and then hatched over 24 h before being offered. Several advantages of *Artemia* decapsulation have been listed, including disinfection, facilitation of separating cyst shells from the hatched nauplii and the potential use of decapsulated cysts as a direct food source for fish and crustacean larvae (Liao et al. 1993; GomezGil et al. 1994), and hatching rate improvement without causing significant individual naupliar dry weight variation (Sorgeloos et al. 1977). The decapsulated cysts and nauplii of *Artemia* have similar biochemical composition for all the major nutrients (Garcia-Ortega et al. 1998). Garcia-Ortega and Huisman (2001) concluded that there is no difference in feeding *Artemia* cysts or nauplii to larvae based on the amount of nutrients.

Results indicate an advantage in supplementing dried feed with *Artemia* nauplii during the first week. Throughout the nursery period, the two treatments supplemented with *Artemia* had greater growth (Fig. 1). The two treatments receiving *Artemia* supplements had similar growth rates but those receiving three feedings were numerically larger at the end of the nursery trial. This shift in relative weights is assumed to be because of variations in growth that result from molting, that is, the FAR3 probably had just

TABLE 3. Water quality parameters over a 21-d nursery period for *Litopenaeus vannamei* stocked at 22 postlarvae/L and fed algal paste with a commercial feed (F), feed with algal paste plus 7 d of *Artemia* (FAR7), feed with algal paste and *Artemia* every other day for 7 d (FAR3), and feed with naturally developed algae (FNA). Figures are displayed as mean \pm SD and maximum/minimum values in parentheses.

Treatment	pH	Salinity (ppt)	Total ammonia-nitrogen (mg/L)
F	7.99 \pm 0.18 (8.22, 7.8)	19.3 \pm 2.33 (21.8, 16.4)	0.76 \pm 0.50 (1.33, 0.126)
FAR7	7.96 \pm 0.19 (8.22, 7.7)	19.4 \pm 2.31 (21.8, 16.5)	1.30 \pm 0.63 (2.25, 0.419)
FAR3	7.97 \pm 0.21 (8.24, 7.6)	19.4 \pm 2.31 (21.8, 16.5)	1.13 \pm 0.81 (2.52, 0.76)
FNA	8.01 \pm 0.17 (8.23, 7.7)	19.4 \pm 2.31 (21.8, 16.5)	0.57 \pm 0.35 (2.52, 0.76)

molted and thus were numerically larger at this point in time. Colvin and Brand (1977) and Akiyama et al. (1992) reported that the dietary protein requirement of early PL penaeid shrimp exceeds 40% crude protein but decreases to less than 30% in the later life cycle stages. Leger et al. (1985) suggest that highly unsaturated fatty acids contribute significantly in sustaining faster PL growth. Here, treatments without *Artemia* supplementation, although fed with a high-protein diet (50%), did not grow as well as those supplemented with *Artemia*. This probably suggests the need for highly unsaturated fatty acids and other essential nutrients that may not be present in compounded feeds.

Although *Artemia* provide a good nutrient source, when offered in excess they can cause problems by limiting the swimming and the prey capture efficiency of shrimp. Uneaten *Artemia* could grow quickly, become difficult to capture, and compete with larval shrimp for important resources such as feed, algae, and dissolved oxygen. They also excrete metabolites, thereby contributing to water quality deterioration, affecting growth, and complicating tank management (Samocha et al. 1989; Liao et al. 1993). It is important to determine optimal *Artemia* offerings for larval culture systems to avoid problems with overfeeding as well as those associated with costs. Given tank volume (570 L) and the estimated *Artemia* nauplii offered (1.2×10^5), offerings were about 100 *Artemia*/PL. This is similar to concentrations found to be efficient by Samocha et al. (1989). He demonstrated that by increasing *Artemia* nauplii density in the culture medium up to 9/mL (or 90 *Artemia*/PL in our trial conditions) and start offering as early as Z2, dry weight increased; but further increasing *Artemia* offerings to 15/mL (or 150 *Artemia*/PL) had no significant effect on growth. Probably for all these reasons, here there was no significant difference in our study by offering *Artemia* daily (FAR7) or every other day (FAR3). *Artemia* every other day (FAR3) is more advantageous as only half the amount was used to achieve the same results.

In addition to *Artemia*, algae may provide some advantage. However, results indicate that the use of diatoms in an algal paste provided

no advantage over algae that grew naturally in the nursery tanks. According to Liao et al. (1993), a minimum of 5×10^3 cells/mL is generally required for most shrimp larvae, but specific concentrations for *L. vannamei* are in the range of 30–100 $\times 10^3$. The algal paste used in this study was nonliving and was offered as fresh feed rather than to start a culture. The concentrations (based on milliliter of regular addition of algal paste and volumes in the tanks) were 4.9×10^3 cells/mL, below the minimum recommended for *L. vannamei* larviculture. Algal concentrations found in the FNA treatments were much lower than that, around 1.5 – 2.0×10^3 cells/mL, because tanks were kept under an opaque plastic cover that minimized exposure to sunlight that probably limited the natural development of algae. Water was exchanged every 3 d, which also limited the development of natural algae. Frequent water exchanges limited the opportunity to notice the water quality stabilization function of live algae (FNA) over nonlive algal paste. However, trends in water quality indicators (Table 3) and overall average TAN concentrations in particular were greater in treatments with *Artemia* even after the end of offerings. Overall averages for $\text{NH}_3\text{-N}$ concentrations (Table 3) of FAR7 and FAR3 were 1.30 ± 0.63 and 1.13 ± 0.81 , respectively; 1.5 and 2 times greater than average in F or FNA (0.76 ± 0.50 and 0.57 ± 0.35 , respectively).

In some commercial operations, tanks are exposed to sunlight, leading to abundant algae. Natural inoculation can easily take place from other species than the ones initially inoculated. As many as 30 diatom species have been identified from a single culture tank (Krom et al. 1985; Sturmer et al. 1992; Liao et al. 1993). On previous nursery trials conducted in the same location, experimental tanks were housed inside a greenhouse and only nonlive algal paste was added. A week after initiating the nursery, naturally developed algae concentrations were in the range of 5 – 6×10^4 cells/mL. Final average weight was similar to this study, from 19–21.5 mg/PL to 10.5–16.4 mg/PL.

Some advantages of algae over *Artemia* have been documented (Schauer et al. 1980; Leger

et al. 1986a, 1986b; Navarro et al. 1991) mostly because of deficiency in docosahexaenoic acid (22:6n-3) and low or variable eicosapentaenoic acid (20:5n-3) content (Watanabe et al. 1982; Rees et al. 1994; Narciso et al. 1999; Nelson et al. 2002). Here, decapsulated *Artemia* supplementation proved a nutritional advantage by sustaining greater growth than algae alone. Leger and Sorgeloos (1992) also pointed out the convenience in preparing *Artemia* instead of culturing algae. Still, it is important to keep in mind the large variation in the nutritional quality of *Artemia* nauplii; their fatty acid profile varies geographically and from year to year, between strains, and even among batches of the same strain (Leger and Sorgeloos 1984; Leger et al. 1985; Millamena et al. 1988; Shapawi and Purser 2003).

Despite studies on alternative diets such as inert microalgal diets (Cordero Esquivel and Voltolina 1996; Albentosa et al. 1997) or artificial diets (Langdon 1983), a complete substitution of live feed for larval rearing has not been achieved. Here, shrimp performance still remained behind natural nutrient-enriched environments although the dried feed diet, with or without *Artemia* and algae, did support growth and PL survival. Some of the shrimp that came in the same shipment were direct stocked in grow-out ponds at the same time the nursery tanks were stocked, and at 21 d their average weight (out of four replicate ponds) was 0.67 g, significantly greater ($P < 0.001$) by between 14 and 25 times than the PL that were nursed for 21 d. There still is a challenge in improving nursery technology, feeds, and feeding methods. Leger and Sorgeloos (1992) noted that a complete replacement for live food needs both the right nutritional composition and the proper physical performance, especially its suspension in the water column and its leaching characteristics. Sedgwick (1979) proposes greater feeding frequency to reduce leaching because penaeid shrimp grow more rapidly and use feed more efficiently when fed more than once a day.

Based on the presented results, the supplementation of commercial larval feeds with algae paste demonstrated no advantage in terms of growth or survival during the nursery phase,

whereas the use of *Artemia* nauplii as a live food supplement in conjunction with a commercial feed provided better growth than using the feed by itself. Hence, we recommend limited use of *Artemia* during the first week of the nursery period.

Acknowledgments

The authors thank those who critically reviewed the manuscript. This research was supported in part by institutional grant number NA86RG0039-4, project R/SP-3 from the Mississippi-Alabama Sea Grant Consortium Program from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce and collaboration from the Marine Resources Division of the Alabama Department of Conservation and Natural Resources. The mention of trademarks or proprietary products does not constitute an endorsement of the product by the Auburn University and does not imply its approval to the exclusion of other products that may also be suitable.

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