Consumption of Natural and Artificial Foods by Shrimp (*Litopenaeus vannamei*) Reared in Ponds with and without Enhancement of Natural Productivity

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Abstract

The consumption of natural and artificial foods by juvenile shrimp was evaluated in ponds with and without the enhancement of natural productivity by the addition of fertilizers, vitamins, minerals, carbohydrates, and artificial substrates. Shrimp in the enhanced ponds consumed 68% natural foods and 32% formulated feed, while shrimp in unenhanced ponds consumed 42% natural foods and 58% formulated feed. Shrimp from the enhanced ponds had a higher full stomach index than those from the unenhanced ponds. Stomach contents included formulated feed, diatoms, filamentous algae, macroalgae, protozoans, crustaceans, detritus, polychaetes, and rotifers. According to the frequency of each prey, the shrimp preferred diatoms, filamentous algae, crustaceans, rotifers, and detritus. Shrimp from the enhanced ponds had a better growth rate than those from the unenhanced. Not all types of natural food were commonly consumed; the shrimp tended to consume prey that improved growth performance.

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Introduction

Problems of shrimp aquaculture during the last 20 years include severe environmental impact and dependence on fishmeal and fish oil to improve the nutritional quality and protein content of formulated feeds (Taconn, 2002; De Schryver et al., 2008). However, the increasing proportion of fishmeal destined for human consumption may be responsible for the >200% increase of fishmeal prices during the last decade (FAO, 2010). Thus, it is important to seek alternatives to fishmeal in aquaculture feeds. The use and enhancement of natural foods can promote sustainable aquaculture, particularly in the shrimp farming industry (Avnimelech et al., 2008; Campos et al., 2009; Becerra-Dórame et al., 2011).

Zooplankton, phytoplankton, and bacteria are natural shrimp foods. Natural productivity can provide up to 50-70% of the nutritional requirements of shrimp (Jory, 2000; Taconn, 2002; Enríquez, 2003; Martínez-Córdoa and Enríquez-Ocaña, 2007). Because shrimp can obtain part of their nutritional requirements by feeding on these organisms, the formation of biotic communities in shrimp ponds may have positive impacts on production parameters and operation costs. Further, the formation of biotic communities in culture units helps to improve nutrient cycling, decrease toxic metabolites and anoxic zones, and alleviate nutrient loading in effluent-receiving ecosystems (Moore, 1986; Martínez-Porchas et al., 2010). In addition, the presence of zooplankton in culture units of aquatic organisms reduces cannibalism (Atencio-Garcia and Zaniboni-Filo, 2006).

Specific nutrients are added to ponds to promote the formation of biota (Moore, 1986; Molina-Poveda et al., 2006). As biota are formed and increase in biomass, cultured shrimp tend to consume the natural food. Promoted biota comprise a diversity of organisms but shrimp do not necessarily consume all the organisms thriving in a pond. Thus, it is important to learn which organisms are more frequently consumed by shrimp. Such knowledge could contribute to the development of new strategies regarding the use and enhancement of particular kinds of natural food. Such strategies could include the isolation and production of a particular food species, and improved proliferation of such species within culture units. The aim of this experiment is to analyze the stomach contents of white shrimp (Litopenaeus vannamei) cultured in ponds with and without enhancement of natural productivity.

Materials and Methods

The experimental trial consisted of two treatments, with four repetitions of each treatment, in 400 m² earthen ponds (1.5 m deep). In one treatment, natural productivity was enhanced; in the second treatment, shrimp were reared in similar ponds without enhancement. Shrimp in both treatments were fed a formulated feed (Camaronina, Purina®, Hermosillo, Mexico). In addition, natural productivity was enhanced in three ponds without shrimp (control) to verify the effectiveness of enhancement and estimate shrimp consumption of each type of organism.

Natural productivity was enhanced two weeks before the beginning of the trial. Phytoplankton biomass was enhanced by fertilization with urea and triple super phosphate, as proposed by Molina-Poveda et al. (2006). Zooplankton were enhanced by hitching bunches of alfalfa (5 kg), fermented with fish oil (50 ml/kg alfalfa), molasses (0.5 l/kg), and vitamins (vitamin premix + ascorbic acid; 0.5 g/kg) for 72 h, to nylon mesh submerged in 15 l marine water, as described by Martínez-Córdova and Porchas-Cornejo (2009); afterwards, two bunches per pond were placed in the ponds and left floating. Benthic fauna were enhanced by using enclosures fertilized with chicken manure (500 g/m²), as suggested by Molina-Poveda et al. (2006).

The experimental units were stocked with 8000 shrimp postlarvae (PL15) obtained from the commercial laboratory Maricultura del Pacífico in Bahía Kino, Sonora, Mexico. The shrimp were fed a formulated feed in two daily rations, using plastic trays, for 14 weeks. Rations were adjusted following the methodology of “apparent consumption” described by Salame (1993).

Temperature, dissolved oxygen, and pH were recorded twice a day (08:00, 15:00), salinity and chlorophyll a once a day (15:00) using a multiparameter sensor YSI 6600®.
(Yellow Springs, OH, USA). Total ammonium nitrogen (TAN; NH₃ + NH₄), nitrates (NO₂⁻), nitrites (NO₃⁻), and phosphates (PO₄³⁻) were evaluated weekly by spectrophotometry (HACH DR4000®, Loveland, CO, USA). Biotic communities were evaluated each week. Phytoplankton was indirectly estimated by measuring chlorophyll a by fluorescence, using a YSI 6600 chlorophyll sensor. Zooplankton density was measured by taking and filtering 10-l water samples from five locations in each pond, at three depths (0.1, 0.5, 1.0 m). Zooplankton were identified and counted in a Sedgwick-Rafter Chamber® (Wildlife Supply Co. Buffalo, NY, USA) using a stereoscope. Benthic organisms were sampled with a core sampler from four points in each pond; the smallest organisms were counted in a Petri chamber using a stereoscope.

To evaluate stomach contents, ten shrimp were sampled from each pond once a week and preserved in formalin buffer 10%. The stomachs were extracted and preserved in ethanol (70%) for later analysis. Stomachs were dissected longitudinally into two parts and observed with a microscope (4X). Stomach components were identified as individuals or fragments of crustaceans, insects, polychaetes, macroalgae, sand particles, formulated feed, diatoms, protozoans, and detritus or unidentified organic matter.

Fill index, an indicator of how full the stomach is with natural or formulated feed (%), was estimated following Lagardère (1972). Stomach contents were observed with a microscope at 4, 10, and 40X to identify components and estimate prey frequency (PF), empty stomach index (ESI), and full stomach index (FSI). Prey frequency indicates the recurrence of a particular prey within the stomachs, calculated as PF = 100(N/n′) where N is the number of stomachs containing a particular prey, and n′ is the number of stomachs with any food content. Empty stomach index indicates the proportion of stomachs without food content, calculated as ESI = 100(ES/N), where ES is the number of individuals with empty stomachs and N is the number of sampled individuals. Full stomach index indicates the proportion of completely full stomachs, calculated as FSI = 100(FS/N) where FS is the number of full stomachs.

Weight gain, feed conversion ratio, final biomass, specific growth, and survival were calculated at the end of the trial.

Water quality parameters, natural productivity, and stomach contents were evaluated by repeated measures analysis of variance. Stomach content data were analyzed by Chi-square test for comparisons among treatments within a single month. Shrimp production data were evaluated by one-way ANOVA with a significance level of α = 0.05.

Results

There were no differences among treatments in temperature (29-34°C), dissolved oxygen (5.5-7.1 mg/l), salinity (38-43 g/l), or pH (8.3-8.7). The treatment without enhancement had a higher concentration of TAN (0.10 mg/l) than the enhanced treatment (0.07 mg/l) and control (0.06 mg/l) ponds. There were no differences among treatments in nitrite (0.01-0.03 mg/l), nitrate (3.05-4.59 mg/l), or phosphate (0.15-0.26 mg/l) concentrations.

The strategy used to enhance natural productivity was successful (Fig. 1). Zooplankton density was highest in the control ponds (470-960 organisms/l), followed by the enhanced (133-540/l) and unenhanced (51-309/l) ponds. A similar trend was observed for the benthic community with 146-424, 118-290, and 38-205 organisms/m² for the control, enhanced, and unenhanced ponds, respectively. The density of zooplankton and benthos diminished around 70% during the first four weeks of the experiment in the ponds containing shrimp. Chlorophyll a levels were significantly higher in the enhanced treatment and control (20-30 mg/m³) than in the unenhanced (4-14 mg/m³).

Shrimp in the enhanced ponds consumed more food and had a higher stomach fill (40-60%) than those in the unenhanced ponds (20-40%; Fig. 2). Also, a higher proportion of shrimp with completely full stomachs was observed in the enhanced ponds (12-40%) than in the unenhanced (6-18%). Shrimp from the unenhanced ponds had a higher proportion of empty stomachs (0-18%) than those from the enhanced ponds (0-12%) while empty stomachs appeared in eight of the 14 experimental weeks for the
Fig 1. Natural productivity of (a) zooplankton, (b) benthos, and (c) chlorophyll a in shrimp ponds enhanced by biota induction, unenhanced by biota induction, or enhanced but containing no shrimp (control). Different letters to the right of lines within a graph indicate statistical differences ($p<0.05$).

...while stomachs for shrimp from the unenhanced ponds contained 42% natural foods (32%) and 58% formulated foods (Fig. 3).

Organisms in the shrimp stomachs were identified as diatoms, filamentous algae, macroalgae fractions, foraminifers, other protozoans, crustacean fractions, detritus, polychaetes, and rotifers. Shrimp reared in enhanced ponds consumed more natural food than formulated feed in shrimp ponds enhanced or (b) unenhanced ponds. Stomachs of shrimp from the enhanced ponds contained a higher proportion of natural food (68%) than formulated feed in shrimp from the unenhanced ponds but only four for the enhanced ponds. Stomachs of shrimp from the enhanced ponds contained a higher proportion of natural food (68%) than formulated feed in shrimp ponds enhanced or (b) unenhanced ponds. Asterisks above pairs of bars indicate significant differences between treatments within that month.

Table 1. Prey frequency (means and ranges) and production of shrimp reared in ponds with and without induction of biota.

<table>
<thead>
<tr>
<th>Stomach content (%)</th>
<th>With</th>
<th>Without</th>
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<tbody>
<tr>
<td>Formulated feed</td>
<td>47(26-79)</td>
<td>88(75-100)</td>
</tr>
<tr>
<td>Diatoms</td>
<td>86(74-100)</td>
<td>50(20-76)</td>
</tr>
<tr>
<td>Filamentous algae</td>
<td>59(33-90)</td>
<td>49(5-80)</td>
</tr>
<tr>
<td>Macroalgae fractions</td>
<td>30(10-55)</td>
<td>10(0-23)</td>
</tr>
<tr>
<td>Foraminifers</td>
<td>8(0-45)</td>
<td>4(0-50)</td>
</tr>
<tr>
<td>Other protozoans</td>
<td>37(0-55)</td>
<td>25(0-38)</td>
</tr>
<tr>
<td>Crustacean fractions</td>
<td>53(21-97)</td>
<td>27(0-51)</td>
</tr>
<tr>
<td>Detritus</td>
<td>91(83-100)</td>
<td>80(52-100)</td>
</tr>
<tr>
<td>Polychaetes</td>
<td>26(3-48)</td>
<td>8(0-21)</td>
</tr>
<tr>
<td>Rotifers</td>
<td>48(30-55)</td>
<td>15(0-39)</td>
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<tr>
<th>Production parameter</th>
<th>With</th>
<th>Without</th>
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<tr>
<td>Feed conversion ratio</td>
<td>1.8(1.6-1.9)</td>
<td>2.2(2.0-2.3)</td>
</tr>
<tr>
<td>Weight gain (g)</td>
<td>26.8(25.8-27.0)</td>
<td>21.7(20.0-23.4)</td>
</tr>
<tr>
<td>Final biomass (g/m²)</td>
<td>362(346-379)</td>
<td>284(261-308)</td>
</tr>
<tr>
<td>Survival</td>
<td>68(65-71)</td>
<td>66(62-69)</td>
</tr>
<tr>
<td>Specific growth rate</td>
<td>5.8(5.6-6.0)</td>
<td>5.4(5.2-5.6)</td>
</tr>
</tbody>
</table>

Different letters in a row indicate significant differences ($p<0.05$).
different among treatments. In addition, all the stomachs sampled (except those empty) from both treatments, contained natural food, whereas not all contained artificial feed. Production was significantly improved by the presence of enhanced natural productivity.

Discussion
The present study demonstrates the effectiveness of the protocol used to enhance natural productivity in shrimp ponds. Shrimp consumed zooplankton, benthos, and phytoplankton throughout the 14-week experiment.

The stocking density was 20 individuals/m², lower than the 50/m² specified for shrimp aquaculture on an intensive scale (Mena-Herrera et al., 2006), but similar to commercial farms working on a semi-intensive scale, where the enhancement of natural productivity before and during culture is possible. In addition and also similar to commercial farms, artificial feed was not limited. Shrimp in the enhanced ponds showed a marked preference for natural food. In the unenriched ponds, natural food was observed in the stomachs of all shrimp whereas not all stomachs contained artificial feed. The preference for natural food could indicate that artificial feed can be reduced if natural productivity is enhanced. The stomach contents indices suggest that high densities of natural food enhance the feeding activity of shrimp. A higher proportion of full stomachs and lower proportion of empty ones were observed in shrimp from the enhanced ponds where natural food was abundant. "At some point" in the growth process of white shrimp, a change in feeding preference can occur, during which growth is supported mainly by nutrients from natural productivity (Gamboa-Delgado et al., 2003). The higher amount of empty stomachs in shrimp from unenhanced ponds could be associated with the lower natural productivity and a change in feeding preference.

The frequencies of each type of prey in the stomachs suggest that shrimp are selective. Diatoms and filamentous algae were observed with relatively high frequency, indicating that they are essential for shrimp nutrition, even at adult stages. This contrasts with procedures in commercial farms, where microalgae are administered only at larval stages and artificial feed is provided during the rest of the culture cycle. In addition, we observed that shrimp grazed on macroalgae. Farmers usually try to halt macroalgae proliferation because of their oxygen demand and because eutrophication is induced when they die. However, shrimp grow better in “brown or green” water than in clear water, as long as aeration is adequate and pH is managed (Avnimelech, 2009); green algae (Caulerpa sertularioides) contribute to the improvement of production parameters for yellowleg shrimp (Porchas-Cornejo et al., 1999); and diatoms substantially contribute to the growth performance of white shrimp, even at adult stages (Moss, 1994). Amongst protozoans, some penaeid shrimp prefer aminifers (Al-Malsamani et al., 2007). In our study, the white shrimp had a considerable preference for other protozoans. Detritus is a conglomerate of live and dead organic matter. It is of high quality and has essential nutrients such as AA and EPA (González-Baró and Pollero, 1998). Apart from algae, the consumption of shrimp from the enhanced ponds was based on detritus, crustaceans, and rotifers. While shrimp in unenhanced ponds consumed these foods throughout the experiment, their lower consumption of these foods may be attributed to the lower densities in the unenriched ponds.

The better production from enhanced ponds supports the hypothesis that a major presence of natural food can positively effect shrimp growth. In particular, diatoms, filamentous algae, crustaceans, rotifers, and detritus seem to play a key role in the nutrition of white shrimp. However, artificial feed inputs are still essential. Artificial feed represented about one third of the food consumption of the shrimp in the enhanced ponds. Formulated feeds may contain nutrients that natural food do not always provide because the chemical proximate composition and nutritional quality of biota can be affected by a variety of factors. Natural productivity can be difficult to maintain in intensive and super-intensive shrimp units, although natural foods can be supplied exogenously (Campaña-Torres et al., 2009, 2010; Martínez-Córdova et al., 2011). Since diatoms, filamentous algae, crustaceans, rotifers and detritus, seem to play an important role in shrimp nutrition, it is important to study how to enhance the growth of particular
foods within culture units; for example, ponds could be inoculated with specific organisms. Further, it is important to elucidate which organisms contribute most to the growth of shrimp.

References


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