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Digestive physiology and metabolism of green abalone *Haliotis fulgens* from postlarvae to juvenile, fed three different diatoms

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Abstract

Growth, survival, digestive enzymes, ingestion rates, digestibility, fatty acid profile and energy budget were used to assess the nutritional quality of three diatoms as food for the first 3 months of age: *Navicula incerta* (NAV), *Amphiprora paludosa* (AMP), *Nitzschia thermalis* (NIT) and a combination of all three species (MIX). The highest growth was observed for postlarvae fed the MIX (51.37 μm day^{-1} and 0.578±0.1 mg day^{-1}), but was not significantly different from the NAV treatments (46.60±3.4 μm day^{-1} and 0.550±0.1 mg day^{-1}).

Abalone larvae, which are lecithotrophic organisms, seem to utilize proteins as a preferred energy substrate up to metamorphosis, since the relative lipid content increased from 15 to 30% from days 0 to 10. Thereafter, lipids are rapidly utilized and decreased to a level of 2% of the dry matter in the postlarvae whole soft tissue. Tissue fatty acid analysis indicated a similar trend among treatments, where relative fatty acid levels increased during the endogenous feeding period and started to decrease concomitant with the start of the exogenous feeding. Polyunsaturated fatty acids, reported on abalone tissue showed a similar trend, among treatments.

Based on the results reported here, it can be concluded that the type of diatom is an important factor for growth, where a high lipid and low ash content could be important to improve the performance in terms of growth and survival, in combination to stimulate protease activity and therefore better digestibility. Last but not the least important, the use of monoculture with NAV will be of importance when culturing abalone postlarvae. The estimated energy budget, back calculated from the digestibility figures, indicates that abalone requires from 25 to 38 cal day^{-1} g abalone^{-1} for adequate growth.

Keywords: Abalone postlarvae; *Haliotis fulgens*; Diatoms; Growth; Apparent digestibility

1. Introduction

Abalone aquaculture still faces the problem of low survival and poor performance during the culture of the postlarvae stage (Uriarte et al., 2006). In an attempt to overcome this problem, a number of studies have been

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performed addressing one of the various aspects associated with the culture of postlarvae under controlled conditions, such as: natural chemical inductors of settlement (Slattery, 1992), dietary value of diatoms using proximate composition (Brown, 1991; Brown et al., 1997), the effect of culture methodology on diatom chemical composition, diatom density (Daume et al., 2004; Watson et al., 2004) and cell size (Kawamura et al., 1998a,b). Kawamura et al. (1995) reported that the dietary value of diatoms was related to the ability of abalone to break down the diatom cells using their radula during grazing. This ability was related to the radula strength overcoming the high adhesive capacity or the weakly silicified cell walls, but not to the digestive enzymes present in the abalone gut. However, in later studies and practice, the polyculture of diatoms has been emphasized by means that abalone can select their appropriated food (Martínez-Ponce and Searcy-Bernal, 1998; Gordon et al., 2006). Kawamura et al. (1998a) reported that the fast growth rates obtained using two diatom strains were related to the capacity of postlarvae to efficiently digest the diatom by breaking down cells walls during the passage through the gut, possibly influenced by diatom morphology, attachment strength, frustula hardness and postlarval age/size. When larvae are ready to metamorphose and culture conditions are adequate, metamorphosis is completed without problems (Hahn, 1989). If their requirements are not met, metamorphosis can be delayed resulting in a negative impact on future development (Takami et al., 2002).

Diatoms are the main diet for abalone postlarvae, not only as a source of nutrients, but also to adequately induce metamorphosis and promote good settlement in combination with other natural stimulants, such as γ-aminobutyric acid (GABA) among others (Takami et al., 1997). It has been reported that during the first 12 to 18 days after hatching, diatoms are more important as metamorphosis inductors than as nutrient sources, since differences in growth can be observed only after two weeks among different diatom strains (Kawamura et al., 1998a; Daume et al., 2004). Another critical period for the postlarvae development is the change from feeding on diatoms to feeding on macroalgae. This crucial period can have a significant economic impact on abalone production systems, since high mortalities are usually obtained (Searcy-Bernal et al., 1992). Some authors have suggested that radula hardening is the most important factor (Johnston et al., 2005), whereas others have blamed the digestive capacity of the postlarvae (Kawamura et al., 1998a). While the chemical composition between diatoms for postlarvae and macroalgae for juveniles is very different, abalone does not suffer any metamorphosis to excuse these changes in nutrients.

Few studies to date evaluating abalone postlarvae feed utilization have combined information on growth, energy budgets, digestive enzyme activity and chemical composition of diatoms. Moran and Manahan (2003) studied the energy metabolism during larval development; however almost no information is given of the postlarvae stage. Combining these parameters can result in a more complete assessment of diatoms utilization, and under which conditions a beneficial effect is obtained on the overall performance under culture conditions.

Therefore, the objective of this study was to utilize a multidisciplinary approach to evaluate feed utilization by abalone (*Haliotis fulgens*) postlarvae, from fertilization to 3-month-old, using three species of diatoms and a mixture of the three.

2. Materials and methods

2.1. Experimental design

2.1.1. Dietary treatments

Three benthic diatom strains isolated from the coastal area of Baja California (BC) and Baja California Sur (BCS), Mexico (Correa-Reyes et al., 2001) (Table 1) were used for this study: *Amphiprora paludosa* var. *hyaline* (AMP), *Navicula incerta* (NAV), *Nitzschia thermalis* var. *minor* (NIT) and a mixture of all three species (MIX). The diatoms were fed to the abalone from settlement to three months of life. Proximate composition and caloric content of the dietary treatments are presented in Table 1.

2.1.2. Experimental units

A total of 2000 abalone postlarvae with an average shell length of 909.21 ± 130 μm and 0.558 mg (from one single batch) were selected for each bucket for use in the feeding trial that lasted a total of 90 days. Each experimental unit consisted of 20 L buckets in a batch-closed system (100% exchange per h) provided with supplemental air to maintain satisfactory oxygen (7.5 ± 0.5 mg O_2 L^{-1}). Temperature was maintained at 20 ± 1 °C throughout the experiment by submerging the buckets in a water-bath with a flow-through system connected to a heat pump. Each of the four treatments was run in triplicate for a total of 12 experimental units, and treatments were randomly assigned to buckets in the culture system. A photoperiod of 12L/12D was maintained throughout the experiment. Light was controlled using 75 W cool-white fluorescent lamps to provide 150 μE m^{-2} s^{-1}. Diatoms previously grown in separate tanks (see below), were added to each experimental unit, by