Comparative growth performance of early juvenile Haliotis asinina fed various artificial diets.

Print

Author: Sangpradub, S.
Date: Apr 1, 2004
Words: 6707
Publication: Journal of Shellfish Research
ISSN: 0730-8000

ABSTRACT The purpose of this study was to compare artificial diets for early juvenile abalone, Haliotis asinina, containing different sources of protein. Juvenile H. asinina with mean initial shell length of 5.3-5.6 mm were fed artificial diets for 90 days. Diets contained 30% crude protein from different sources: casein, fish meal, soybean meal, and rice bran. The diets were fed to abalone at 5-10% body weight once daily in the afternoon. Abalone fed Acanthophora sp. served as a control. The results showed that the abalone fed fresh Acanthophora sp. and those receiving the casein-based diet had the highest growth rates in shell length (96.7 [+ or -] 8.0 [micro]m/day and 96.3 [+ or -] 6.7 [micro]m/day, respectively). Those fed the casein-based diet showed the highest growth rate in weight (8.6 [+ or -] 0.3 [micro]g/day). The best survival rates were found in abalone fed Acanthophora sp., the soybean-based diet and the casein-based diet (88.9%, 81.1%, and 78.9%, respectively). The casein diet yielded the maximum rate of growth and survival.

KEY WORDS: comparative growth performance, early juvenile, artificial diets, Haliotis asinina

INTRODUCTION

The donkey's ear abalone, Haliotis asinina Linnaeus, a very promising commercial abalone in the Southeast Asia region, is a tropical species. It is distributed widely in coastal reef zones of Southeast Asia. In Thailand, research into abalone culturing techniques began in the early 1990s (Singhagraiwan 1989, Singhagraiwan & Doi 1993, Jarayabhand & Paphavasit 1996). Feeding, growth, and survival (Singhagraiwan 1991a, 1991b, Singhagraiwan & Sasaki 1991, Singhagraiwan 1993, Kunavongdate et al. 1995, Upatham et al. 1998, Kruatrachue et al. 2000) have been investigated for adult abalone, but little work has been done on juvenile H. asinina.

Culture of H. asinina in Thailand is divided into two phases. The first phase is the culture of newly settled spats on corrugated plastic plates coated with diatoms until a shell length of 5-10 mm is attained. The second phase is the culture of juveniles on corrugated cement plates with seaweed until they reach a marketable size (40-50 mm in shell length) (Singhagraiwan & Doi 1993). There are many problems, however, in using natural seaweed, such as seasonality and accessibility (Uki & Watanabe 1992). Artificial diets could solve these problems.

In recent years, there has been a rapid increase in the number of research groups developing artificial diets to supplement or replace seaweeds in abalone culture (Uki & Watanabe 1992, Viana et al. 1993, Fleming et al. 1996, Britz 1996a, 1996b, Capinpin & Corre 1996, Moss

1997, Corazani & Illanes 1998, Lopez et al. 1998, Chen & Lee 1999, Kruatrachue et al. 2000, Serviere-Zaragoza et al. 2001, Boarder & Shpigel 2001, Shipton & Britz 2001, Jackson et al. 2001). Growth of abalone feeding on macroalgae and artificial diets has been studied for H. discus Reeve (Ogino & Ohta 1963), H. discus hannai Ino (Uki et al. 1985, Nie et al. 1986, Uki et al. 1986a, 1986b, Corazani & Illanes 1998), H. fulgens Philippi (Viana et al. 1993, Serviere-Zaragoza et al. 2001), H. asinina (Capinpin & Corre, 1996, Upatham et al. 1998, Capinpin et al. 1999, Bautista-Teruel & Millamena 1999, Kruatrachue et al. 2000, Jackson et al. 2001), H. iris Gmelin (Stuart & Brown 1994), H. tuberculata Linnaeus (Koike et al. 1979, Mgaya & Mercer 1995, Lopez et al. 1998), H. luevigata Donovan (Morrison & Whittington 1991), H. rufescens Swainson (Corazani & Illanes 1998), H. australis Gmelin (Moss 1997), H. diversicolor supertexta Lischke (Chen & Lee 1999), and H. midae Linnaeus (Britz 1996a, Knauer et al. 1996, Shipton & Britz 2001). Among these extensive studies, only a few reported on early juvenile growth of abalone.

For commercial abalone culture, it is important to enhance the growth at all stages and therefore information is required on the dietary requirements of each size class. This study was carried out to investigate the growth and survival of early juvenile H. asinina fed four artificial diets with different sources of protein: casein, fish meal, soybean meal, and rice bran.

MATERIALS AND METHODS

Abalone

Three month old juvenile H. asinina (5.5 [+ or -] 0.2 mm in length. 45.3 [+ or -] 3.7 in weight) were obtained from the Coastal Aquaculture Development Center, Prachuap Khiri Khan Province, Thailand. They were placed in the rearing system for acclimatization and fed Acanthophora sp. seaweed for two weeks before collection of initial data.

Preparation of Diets

Diet formulations are presented in Table 1. The diets were prepared following Uki et al. (1986a), using different sources of protein-casein, fishmeal, soybean meal, and rice bran. The vitamin mix in Cetavit 1,000 g was obtained from the Eastern Marine Co., Ltd., Thailand, and mineral mix in Premix 1,000 g was obtained from Chanaphant Industry Co., Ltd., Thailand (Table 2). Equivalent amounts of vitamins and minerals were added to all diets (Table 1).

All dry ingredients were mixed together and then cod liver oil and vegetable oil added. The sodium alginate was heated in 60-80 mL distilled water at 60-80[degrees]C, until it melted, then poured into the mixed ingredients and kneaded immediately to obtain a homogeneous paste. The paste was flattened with a kitchen roller to a thickness of 0.5 cm. Pieces 1.5 x 1.5 cm in dimension were cut and stored in the freezer until feeding.

Experimental Procedure

There were four dietary treatments: (1) casein-based diet; (2) fish meal-based diet; (3) soybean meal-based diet; and (4) rice bran-based diet. Fresh seaweed (Acanthophora sp.) was fed to the control group. Early juvenile abalone (5.3-5.6 mm in shell length, 40-50 mg in weight) were kept in rectangular 5-L plastic aquaria. Thirty abalone were allocated to each trial aquarium (three replicates per diet), and all 12 aquaria were floated in 700-L fiberglass tanks under a close system with aeration and filter system. The tanks were covered to prevent animals from escaping. UV-sterilized and filtered seawater (salinity 32-34 ppt, pH 8.4-8.5) was changed every morning for 90 days. The abalone were fed every afternoon with artificial diets and macroalgae at 5-10% of their body weights. Any uneaten food was collected the following morning to estimate the feed consumed and the food conversion rate (FCR). The light/dark sequence was 12h/12h and the temperature was 29-32[degrees]C. Water quality parameters (DO, pH, and temperature) were randomly measured weekly. The total ammonia and the total nitrite were within the standard ranges (0.013-0.191 ppm and 0.016-0.053 ppm, respectively). The dry weight of artificial diets and algae were determined by drying in a hot air oven at 80[degrees]C until a constant weight was reached. Growth was measured biweekly as gain in weight and shell length and expressed in terms of shell length ([micro]m/day) and body weight (mg/day). Mortality was also recorded every two weeks.

The FCR was calculated on the basis of the total dry weight gain of abalone and the dry weight of teed consumed as follows (Leighton & Boolootian 1963):

FCR = Dry weight feed consumed (g)/Dry weight gain (g)

At the beginning of the experiment, 15 animals were sampled out to determine their total dry weight. Similarly, at the end of the experiment (90 days), the total dry weight of those animals that survived from each treatment was determined. These animals were weighed and dried at 80[degrees]C until a constant weight was reached.

Statistical Analysis

Differences in growth and survival rates, and FCR among the different dietary treatments were determined by one-way ANOVA. The multiple comparisons, Duncan's multiple range test, was further used to determine significant differences between treatments. SPSS for Windows (Version 6,0) was the statistical software used for all statistical analysis. $P < 0.05$ was used as the significance level.

RESULTS

Growth Rate

The results obtained from each artificial diet and the control diet are shown in Table 3 and Figures 1 and 2. Growth rates (shell length and body weight increase/day) of H. asinina were significantly different ($P < 0.05$) among feed treatments. In terms of shell length, three statistically different groups could be recognized ($P < 0.05$): (1) control and casein-based diet; (2) fish meal-based and soybean meal-based diets; and (3) rice bran-based diet (Table 3). Four statistically different groups ($P < 0.05$) could be differentiated on weight increase: (1) casein based diet: (2) control; (3) fish meal-based and soybean meal based diets; and (4) rice bran based diet (Table 3).

[FIGURES 1-2 OMITTED]

Shell Length

The maximum cumulative increases in shell length were 161.2% and 164.7% for the control and casein-based diet, respectively (Fig. 1). These equated to growth rates of 96.7 and 96.3 [micro]m/day, respectively (Table 3). Lower cumulative increases of shell length were obtained with abalone fed fish meal-based (111.2%) and soybean meal-based diets

(107.8%) (Fig. 1). These gains corresponded to growth rates of 68.1 and 67.0 [micro]m/day, respectively (Table 3). The lowest cumulative increase in shell length was found in abalone fed the rice bran-based diet (81.5%), which equated to a growth rate of 48.5 [micro]m/day (Fig. 1, Table 3).

Body Weight

The maximum cumulative weight increase (1683.6%) was found in the casein-based diet group that gave a growth rate of 8.6 rag/day (Fig. 2, Table 3). The control also had a high cumulative weight increase (1283.7%) and growth rate of 6.3 mg/day. Abalone fed soybean meal- and fish meal-based diets had lower cumulative increases in weight (621% and 569.6%, respectively) (Fig. 2, Table 3). These equated to growth rates of 3.2 and 2.9 rag/day, respectively (Table 3). The lowest cumulative increase in weight was found in abalone fed the rice bran-based diet (327.4%) that resulted in a growth rate of 1.6 mg/day.

Survival Rate

The survival rates of H. asinina fed different artificial diets and on algal control diet were significantly different (P < 0.05) (Fig. 3, Table 3). Two different groups could he recognized: (1) control (88.9%), soybean meal-based diet (81.1%), and casein-based diet (78.9%/; (2) rice bran-based diet (74.4%) and fish meal-based diet (71.1%) groups.

[FIGURE 3 OMITTED]

Food Conversion Rate

The dry weight FCR was significantly different (P < 0.05) among tour dietary groups (Table 4): (l) control (0.3): (2) casein-based diet (1.5); (3) soybean meal based diet (4.0); (4) fish meal-based diet (6.1); and rice bran-based diet (6.4).

DISCUSSION

Early juvenile H. asinina provided Acanthophora sp. and a casein-based diet (as a main source of protein) produced superior growth rates (for shell length and body weight) and survival rates compared with juveniles fed fish meal-based, soybean meal-based, and rice bran-based diets. The growth and survival rates of the casein-based diet group were not significantly different from those fed macroalgae (control). The dietary value of casein-based diet was comparable to that of the macroalgae. The growth rates in shell length (96.8 [micro]m/day in the macroalgae group and 96.3 [micro]m/ day in the casein-based diet group) are comparable with that reported by Kunavongdate et al. (1995), who found that juvenile H. asinina (31 mm in shell length) fed Laurencia sp. yielded a growth rate of 98 [micro]m/day (Table 5). Upatham et al. (1998) reported a lower growth rate (70 [micro]m/day) in juvenile H. asinina (13 mm in shell length) fed Gracilaria tenuistipitata. In comparison, Kruatrachue et al. (2000) reported very low growth rates (29-36 [micro]m/ day) for juvenile H. asinina (13 mm in shell length) fed casein-based diets containing various species of red algae (Table 5). They suggested that these formulated diets were unsuitable and significant leaching of some trace nutrients might occur, resulting in poor growth rates (Kruatrachue et al. 2000). Jackson et al. (2001) studied the suitability of Australian formulated diets for aquaculture of H. asinina and found that a natural diet of G. edulis still produced the highest growth rate (56 [micro]m/day; Table 5), while four formulated diets from two Australian abalone feed companies produced lower growth rates of 19-54 [micro]m/day (Table 5). However, the growth rates of H. asinina of our study were low when compared with the study of Capinpin & Corre (1996) who reported that the growth rates of juvenile H. asinina fed G. heteroclada and a commercial artificial diet were 193 and 192 [micro]m/day, respectively (Table 5). Capinpin et al. (1999) also recorded a shell length growth rate of 164 [micro]m/day for H. asinina reared in sea cages and fed G. bailinae. Bautista-Teruel & Millamena (1999) achieved growth rates ranging from 222 to 247 [micro]m/day over 90 days when 20 juvenile H. asinina (18.3 mm in shell length) were housed in large 60-L containers and fed either of three formulated diets. These are the highest growth rates ever reported for Haliotis species (Table 5). In this study, H. asinina were reared in small (5-L) enclosures, which may have contributed significantly to the lower growth rates (49-96 [micro]m/day) compared to other studies. The results are not directly comparable because of differing experimental conditions and the smaller size of juvenile H. asinina used in this study. In general, certain species of red algae seemed to produce higher growth rates in H. asinina than artificial diets.

Table 5 also summarizes the reported data on growth rates of abalone fed artificial diets. Most studies evaluated the quality of several protein sources in diets such as casein, fishmeal, and soybean meal. A casein-based diet produced a higher growth rate (133 [micro]m/day) in juvenile H. discus hannai (34 mm), compared with those fed either a soybean-based diet (106 [micro]m/day) or a fishmeal-based diet (74 [micro]m/day) for 40 days (Uki et al. 1985). Uki et al. (1986b) also reported a higher growth rate (82 [micro]m/day) in juvenile H. discus hannai fed a casein-based diet than in those fed a fishmeal-based diet (47 [micro]m/day), for 50 days. These reported results were in agreement with the results of this study on juvenile H. asinina (5-6 mm).

In comparison Britz (1996a, 1996b) reported that a fish meal-based diet produced a higher growth rate (65, 83-96 [micro]m/day) than a casein-based diet (45 [micro]m/day) in juvenile H. midae (20-21 mm) (Table 5). Similarly, Lopez et al. (1998) also reported that a fish meal-based diet resulted in a higher growth rate (135 [micro]m/day) than a casein-based diet (119 [micro]m/day) (Table 5) in H. tuberculata (3.2 ram). However, Viana et al. (1993) reported that a casein-based diet and a fish meal-based diet produced similar growth rates (98 [micro]m/day and 101 [micro]m/day, respectively) in H. fulgens (13 mm) (Table 5). In H. asinina of this study, fish meal-based and soybean meal-based diets produced the second highest growth rates (68 [micro]m/day and 67 [micro]m/day, respectively). The source and the processing of the fishmeal used in these studies may account for these differences. A soybean meal-based diet was also reported to produce high growth rates in H. discus hannai (106 [micro]m/day) (Uki et al. 1985) and H. diversicolor supertexta (105-163 [micro]m/day) (Chert & Lee 1999) (Table 5).

The most appropriate diet for H. asinina culture depends on the availability and cost of various protein sources and the growth rates produced. Although a casein-based diet produced the highest growth rate in this study, casein is unlikely to be widely used as a primary protein source in practical diets because of its high cost. Fishmeal is more appropriate since it is readily available and less expensive than casein. Even though a fish meal-based diet produced a lower growth rate than casein-based diet in H. asinina, in other Haliotis species it produced higher growth rates. There is, however, an increasing concern about the future supply and demand for fish meal, and this concern has led to efforts to reduce its use as the major protein source in commercial aquaculture feed formulations (Barlow 1989, Ramsey 1993). Because Haliotis are naturally herbivorous animals with a digestive and enzymatic physiology equipped for processing plant materials, Shipton and Britz (2001) studied the partial and total replacement of fishmeal with selected plant protein sources (soy meal, sunflower meal, torula yeast, corn gluten, and Spirulinu) in diets for H.

midae, a

South African species. No significant differences were found in the growth rates between the control diet (100% fishmeal; 83 [micro]m/day) and diets in which 30% of the fishmeal component was replaced by plant proteins (Table 5). Among the plant protein sources, fishmeal with torula yeast produced the highest growth rate (91 [micro]m/day) (Table 5). The lowest growth rate was found in fishmeal and corn gluten (70 [micro]m/day) (Table 5). Substitution of 50% fishmeal with either soy meal or Spirulina did not affect growth rates. Replacement of either 75% or 100% fishmeal with plant protein sources (sunflower meal, soy meal, and Spirulina) produced growth rates comparable to that of the control. Shipton and Britz (2001) concluded that there was a potential to replace fish meal with plant protein sources in commercial diets for Haliotis, especially considering the low raw material costs associated with soybean meal and sunflower meal. This study shows that for H. asinina, the soybean meal-based diet, yielded similar growth rates to fishmeal-based diet, and the survival rate was higher. Other factors also affect the growth rate of abalone, including water temperature, (Leighton 1974, Leighton et al. 1981, Uki et al. 1981, Hahn 1989, Lopez et al. 1998), the species of abalone (Uki & Kikuchi 1979), the rearing system (Moss 1997, Chen & Lee 1999) changing the diet of juveniles from diatoms to seaweeds, or artificial diets at the appropriate size. These factors will also affect the early growth of juvenile H. asinina and need to be investigated.

In general, abalone fed artificial diets have displayed higher rates of weight gain and length increase, and lower FCR compared with those fed macroalgae (Table 5). FCRs obtained for macroalgae have also differed among species (Table 5). H. asinina fed G. tenuistipitata and Acanthophora spicifera showed lower FCRs (3.3 and 5.7, respectively) while those fed G. salicornia. G. fisheri, and Laurencia sp. showed higher FCRs (15.5 and 20.4, 7.4 and 29.5. and 18.0, respectively) (Singhagraiwan 1991b, Kunavongdate et al. 1995, Upatham et al. 1998; Table 5). The FCRs of H. asinina fed casein-based diets containing various species of macroalgae were higher than those of macroalgae (Upatham et al. 1998, Kruatrachue et al. 2000; Table 5). In contrast, abalone fed artificial diets showed lower FCRs, for example, H. tuberculata (0.8-0.9: Lopez et al. 1998), H. midae (0.7-1.0; Britz 1996b, Shipton & Britz 2001), H. diversicolor supertexta (3.0; Chen & Lee 1999), H. asinina (1.4-1.8; Bautista-Teruel & Millamena 1999, Jackson et al. 2001; Table 5). In this study, other than the control (Acanthophora sp.), the FCR of the casein-based diet was low (1.5) and similar to those reported by Bautista-Teruel and Millamena (1999) and Jackson et al. (2001). Fleming et al. (1996) reviewed the formulated diets of temperate abalone offered by various feed manufacturers around the world and reported an FCR range of 0.77 to 3.33. The FCR value for the casein-based diet of this study compares favorably.

TABLE 1.
Composition of four artificial diets for juvenile abalone H. asinina (% inclusion).

	Protein Based Diet (%)			
Ingredients	Casein	Fish Meal	Soybean Meal	Rice Bran
Casein	25			
Fish meal		39		
Soybean meal			68	
Rice bran				68
Sodium alginate	16	16	16	16
Dextrin	21.5	14.5	0	0
Cellulose	21.5	14.5	0	0

Vitamins	5	5	5	5
Minerals	5	5	5	5
Cod liver oil	2.5	2.5	2.5	2.5
Vegetable oil	2.5	2.5	2.5	2.5
Calcium chloride	1	1	1	1

TABLE 2.
Composition of vitamins and minerals mixes.

Composition	Weight
Vitamins	
Vitamin A	15,000,000 units
Vitamin D_3	3,000,000 units
Vitamin C	83.0 g
Vitamin E	27.5 g
Vitamin K	4.67 g
Vitamin B_1	25.0 g
Vitamin B_2	25.0 g
Vitamin B_6	5.0 g
Vitamin B_{12}	0.05 g
Nicotinamide	20.0 g
Calcium-D-Panthothenate	5.0 g
Folic acid	0.4 g
Minerals	
Manganese	5,400 g
Iron	14,200 g
Copper	1,000 g
Zinc	2,900 g
Sodium	3,300 g
Iodine	0.019 mg
Potassium	0.9 g
Cobalt	1.1 g
Medium	971.18 g

TABLE 3.
Growth and survival rates of H. asinina fed different artificial diets over a period of 90 days.

Diet	Survival Rate (%)
Control	88.9 [+ or -] 3.8[a]
Casein-based	78.9 [+ or -] 7.7[a,b]
Fish meal-based	71.1 [+ or -] 8.4[b]
Soybean meal-based	81.1 [+ or -] 3.8[a,b]
Rice bran-based	74.4 [+ or -] 8.4[b]

Diet	Shell Length (mm) Initial	Shell Length (mm) Final
Control	5.4 [+ or -] 0.2	14.1 [+ or -] 0.8[a]
Casein-based	5.3 [+ or -] 0.1	13.9 [+ or -] 0.5[a]
Fish meal-based	5.5 [+ or -] 0.2	11.7 [+ or -] 0.3[b]
Soybean meal-based	5.6 [+ or -] 0.2	11.6 [+ or -] 0.6[b]
Rice bran-based	5.4 [+ or -] 0.4	9.8 [+ or -] 0.1[c]

Body Wet Weight
(mg)

Diet	Initial	Final
Control	44.7 [+ or -] 4.2	615.0 [+ or -] [79.7.sup.b]
Casein-based	46.0 [+ or -] 2.0	820.0 [+ or -] [26.5.sup.a]
Fish meal-based	46.0 [+ or -] 3.5	307.0 [+ or -] [6.1.sup.c]
Soybean meal-based	46.0 [+ or -] 3.5	332.3 [+ or -] [38.1.sup.c]
Rice bran-based	44.0 [+ or -] 5.3	186.7 [+ or -] [10.2.sup.d]

	% Cumulative Increase
Diet	Length
Control	161.2 [+ or -] [13.1.sup.a]
Casein-based	164.7 [+ or -] [14.4.sup.a]
Fish meal-based	111.2 [+ or -] [12.1.sup.b]
Soybean meal-based	107.8 [+ or -] [8.6.sup.b]
Rice bran-based	81.5 [+ or -] [13.6.sup.c]

	% Cumulative Increase
Diet	Weight
Control	1,283.7 [+ or -] [205.0.sup.b]
Casein-based	1,683.6 [+ or -] [52.1.sup.a]
Fish meal-based	569.6 [+ or -] [46.0.sup.c]
Soybean meal-based	621.1 [+ or -] [28.6.sup.c]
Rice bran-based	327.4 [+ or -] [45.7.sup.d]

	Growth
Diet	Length ([micro]m/day)
Control	96.7 [+ or -] [8.0.sup.a]
Casein-based	96.3 [+ or -] [6.7.sup.a]
Fish meal-based	68.1 [+ or -] [5.0.sup.b]
Soybean meal-based	67.0 [+ or -] [5.3.sup.b]
Rice bran-based	48.5 [+ or -] [4.5.sup.c]

	Growth
Diet	Weight (mg/day)
Control	6.3 [+ or -] [0.9.sup.b]
Casein-based	8.6 [+ or -] [0.3.sup.a]
Fish meal-based	2.9 [+ or -] [0.1.sup.c]
Soybean meal-based	3.2 [+ or -] [0.4.sup.c]
Rice bran-based	1.6 [+ or -] [0.1.sup.d]

Means and standard deviations are presented (n = 90). Analysis of variance and Duncan's multiple range test were performed on the means of shell length and body weight increases; the same letter identities the values that are not significantly different (P < 0.05).

TABLE 4.
Food conversion rate of H. asinina fed different diets

over a period of 90 days.

Diet	Initial Number	Initial Total Wet Weight * (g)	Final Number	Final Total Wet Weight * (g)
Control	90	4.1 [+ or -] 0.4	80	49.6 [+ or -] 2.3
Casein-based	90	4.1 [+ or -] 0.2	71	58.2 [+ or -] 3.5
Fish meal-based	90	4.1 [+ or -] 0.3	64	19.8 [+ or -] 1.4
Soybean meal-based	90	4.1 [+ or -] 0.6	73	24.1 [+ or -] 2.8
Rice bran-based	90	3.9 [+ or -] 0.5	67	12.7 [+ or -] 0.5

Diet	Total Wet Weight Gain (g)	Total Dry Weight Gain (g)	Dry Weight of Food Intake (g)	FCR
Control	45.5 [+ or -] 2.7	28.9 [+ or -] 1.7	8.7 [+ or -] 0.0	0.3 [+ or -] [0.1.sup.a]
Casein-based	54.1 [+ or -] 1.4	35.2 [+ or -] 0.3	56.3 [+ or -] 0.2	1.5 [+ or -] [0.1.sup.b]
Fish meal-based	15.7 [+ or -] 0.5	9.9 [+ or -] 0.1	60.4 [+ or -] 0.6	6.1 [+ or -] [0.4.sup.d]
Soybean meal-based	20.0 [+ or -] 1.1	14.1 [+ or -] 0.7	56.4 [+ or -] 0.5	4.0 [+ or -] [0.4.sup.c]
Rice bran-based	8.8 [+ or -] 0.4	6.0 [+ or -] 0.3	38.4 [+ or -] 0.2	6.4 [+ or -] [1.1.sup.d]

Means and standard deviations are presented (n = 90). Analysis of variance and Duncan's multiple range test were performed on the means of growth rate; the same letter identifies the values that are not significantly different (P < 0.05); * three replicates.

TABLE 5.
Comparative growth of different species of Haliotis fed artificial diets and macroalgae.

Species	Size (mm)	Diet	Duration (day)
H. discus hannai	34	Casein-based (30% protein)	40

	24	Fish meal-based (32% protein)	40
	34	Soybean meal-based (31% protein)	40
	31	Casein-based (4.8-43.1% protein)	50
	31	Fish meal-based (5.6-43.1% protein)	50
	7	Artificial diet	70
	13	Artificial diet	70
	21	Artificial diet	270
H. fulgens	13	Casein-based (44% protein)	90
	13	Fish meal-based (35% protein)	90
	17	Artificial diet	106
H. midae	7.9	Artificial diet (35.5% protein)	30
	20	Fish meal-based (27-47% protein)	95
	21	Casein-based (31% protein)	124
	21	Fish meal-based (29% protein)	124
	10.6	Fish meal-based (34% protein)	180
	10.6	Fish meal/torula yeast	180
	10.6	Fish meal/soy meal	180
	10.6	Fish meal/sunflower meal	180
	10.6	Fish meal/Spirulina	180
	10.6	Fish meal/corn gluten	180
H. diversicolor supertexta	26	Soybean-based (30% protein)	33
	26	Soybean-based (30% protein)	395
H. tuberculata	3.2	Casein-based (36% protein)	105
	3.2	Fish meal-based	105
H. rufescens	21	Artificial diet	270
H. australis	3-6	Artificial diet	365
H. asinina	28	Gracilaria salicornia	120
	31	G. fisheri	120
	31	Laurencia sp.	120
	15	G. heteroclada	90
	15	Kappaphycus alvarezii	90
	15	Artificial diet (32% protein)	90
	13	G. tenuistipitata	184
	13	G. fisheri	184
	13	G. salicornia	184
	13	Acanthophora spicifera	184
	15	G. bailinae	90
	13	Formulated diets	90
	13	Casein + G. tenuistipitata	140
	13	Casein + G. fisheti	140
	13	Casein + G. salicornia	140
	18	Artificial diets	168
	5.3-5.6	Casein-based (30% protein)	90
	5.3-5.6	Fish meal-based (30% protein)	90
	5.3-5.6	Soybean meal-based (30% protein)	90
	5.3-	Rice bran-based	90

	5.6	(30% protein)	
	5.3-5.6	Acanthophora sp.	90

Species	Size (mm)	Diet	Growth Rate ([micro]m/day)
H. discus hannai	34	Casein-based (30% protein)	133
	24	Fish meal-based (32% protein)	74
	34	Soybean meal-based (31% protein)	106
	31	Casein-based (4.8-43.1% protein)	32-82
	31	Fish meal-based (5.6-43.1% protein)	32-47
	7	Artificial diet	135
	13	Artificial diet	101
	21	Artificial diet	62
H. fulgens	13	Casein-based (44% protein)	98
	13	Fish meal-based (35% protein)	101
	17	Artificial diet	42
H. midae	7.9	Artificial diet (35.5% protein)	59
	20	Fish meal-based (27-47% protein)	83-96
	21	Casein-based (31% protein)	45
	21	Fish meal-based (29% protein)	65
	10.6	Fish meal-based (34% protein)	83
	10.6	Fish meal/torula yeast	91
	10.6	Fish meal/soy meal	85
	10.6	Fish meal/sunflower meal	87
	10.6	Fish meal/Spirulina	92
	10.6	Fish meal/corn gluten	70
H. diversicolor supertexta	26	Soybean-based (30% protein)	105-163
	26	Soybean-based (30% protein)	42-68
H. tuberculata	3.2	Casein-based (36% protein)	119
	3.2	Fish meal-based	135
H. rufescens	21	Artificial diet	45
H. australis	3-6	Artificial diet	40-47
H. asinina	28	Gracilaria salicornia	51
	31	G. fisheri	21
	31	Laurencia sp.	98
	15	G. heteroclada	193
	15	Kappaphycus alvarezii	59
	15	Artificial diet (32% protein)	192
	13	G. tenuistipitata	70
	13	G. fisheri	48
	13	G. salicornia	59
	13	Acanthophora spicifera	62
	15	G. bailinae	164
	13	Formulated diets	222-247
	13	Casein + G. tenuistipitata	36
	13	Casein + G. fisheti	36

	13	Casein + G. salicornia	29
	18	Artificial diets	19-54
	5.3-5.6	Casein-based (30% protein)	96
	5.3-5.6	Fish meal-based (30% protein)	68
	5.3-5.6	Soybean meal-based (30% protein)	67
	5.3-5.6	Rice bran-based (30% protein)	49
	5.3-5.6	Acanthophora sp.	97

Species	Size (mm)	Diet	FCR
H. discus hannai	34	Casein-based (30% protein)	
	24	Fish meal-based (32% protein)	
	34	Soybean meal-based (31% protein)	
	31	Casein-based (4.8-43.1% protein)	
	31	Fish meal-based (5.6-43.1% protein)	
	7	Artificial diet	
	13	Artificial diet	
	21	Artificial diet	
H. fulgens	13	Casein-based (44% protein)	
	13	Fish meal-based (35% protein)	
	17	Artificial diet	0.02
H. midae	7.9	Artificial diet (35.5% protein)	
	20	Fish meal-based (27-47% protein)	
	21	Casein-based (31% protein)	0.7
	21	Fish meal-based (29% protein)	0.8
	10.6	Fish meal-based (34% protein)	0.92
	10.6	Fish meal/torula yeast	0.8
	10.6	Fish meal/soy meal	0.82
	10.6	Fish meal/sunflower meal	1.0
	10.6	Fish meal/Spirulina	0.97
	10.6	Fish meal/corn gluten	0.98
H. diversicolor supertexta	26	Soybean-based (30% protein)	
	26	Soybean-based (30% protein)	3.0
H. tuberculata	3.2	Casein-based (36% protein)	0.8
	3.2	Fish meal-based	0.9
H. rufescens	21	Artificial diet	
H. australis	3-6	Artificial diet	
H. asinina	28	Gracilaria salicornia	20.4
	31	G. fisheri	29.5
	31	Laurencia sp.	18
	15	G. heteroclada	
	15	Kappaphycus alvarezii	
	15	Artificial diet (32% protein)	

13	G. tenuistipitata	3.3
13	G. fisheri	7.4
13	G. salicornia	15.5
13	Acanthophora spicifera	5.7
15	G. bailinae	
13	Formulated diets	1.4-1.8
13	Casein + G. tenuistipitata	27.5
13	Casein + G. fisheti	29.8
13	Casein + G. salicornia	19.2
18	Artificial diets	1.4-1.8
5.3-5.6	Casein-based (30% protein)	1.5
5.3-5.6	Fish meal-based (30% protein)	6.1
5.3-5.6	Soybean meal-based (30% protein)	4.0
5.3-5.6	Rice bran-based (30% protein)	6.4
5.3-5.6	Acanthophora sp.	0.3

Species	Size (mm)	Diet	Reference
H. discus hannai	34	Casein-based (30% protein)	Uki et al. (1985)
	24	Fish meal-based (32% protein)	
	34	Soybean meal-based (31% protein)	
	31	Casein-based (4.8-43.1% protein)	Uki et al. (1986b)
	31	Fish meal-based (5.6-43.1% protein)	
	7	Artificial diet	Nie et al. (1986)
	13	Artificial diet	
	21	Artificial diet	Corazani & Illanes (1998)
H. fulgens	13	Casein-based (44% protein)	Viana et al. (1993)
	13	Fish meal-based (35% protein)	
	17	Artificial diet	Set viere-Zaragoza et al. (2001)
H. midae	7.9	Artificial diet (35.5% protein)	Knauer et al. (1996)
	20	Fish meal-based (27-47% protein)	Britz (1996a)
	21	Casein-based (31% protein)	Britz (1996b)
	21	Fish meal-based (29% protein)	
	10.6	Fish meal-based (34% protein)	Shipton & Britz (2001)
	10.6	Fish meal/torula yeast	
	10.6	Fish meal/soy meal	
	10.6	Fish meal/sunflower meal	

	10.6	Fish meal/Spirulina	
	10.6	Fish meal/corn gluten	
H. diversicolor supertexta	26	Soybean-based (30% protein)	Chen & Lee (1999)
	26	Soybean-based (30% protein)	
H. tuberculata	3.2	Casein-based (36% protein)	Lopez et al. (1998)
	3.2	Fish meal-based	
H. rufescens	21	Artificial diet	Corazani & Illanes (1998)
H. australis	3-6	Artificial diet	Moss (1997)
H. asinina	28	Gracilaria salicornia	Singhagraiwan (1996b)
	31	G. fisheri	Kunavongdate et al. (1995)
	31	Laurencia sp.	
	15	G. heteroclada	Capinpin & Corre (1996)
	15	Kappaphycus alvarezii	
	15	Artificial diet (32% protein)	
	13	G. tenuistipitata	Upatham et al. (1998)
	13	G. fisheri	
	13	G. salicornia	
	13	Acanthophora spicifera	
	15	G. bailinae	Capinpin et al. (1999)
	13	Formulated diets	Bautista-Teruel & Millamena (1999)
	13	Casein + G. tenuistipitata	Kruatrachue et al. (2000)
	13	Casein + G. fisheti	
	13	Casein + G. salicornia	
	18	Artificial diets	Jackson et al. (2001)
	5.3-5.6	Casein-based (30% protein)	Present study
	5.3-5.6	Fish meal-based (30% protein)	
	5.3-5.6	Soybean meal-based (30% protein)	
	5.3-5.6	Rice bran-based (30% protein)	
	5.3-5.6	Acanthophora sp.	

ACKNOWLEDGMENTS

This study was supported by the Thailand Research Fund BRG/ 04/2543.

LITERATURE CITED

Barlow, S, 1989. Fishmeal-world outlook to the year 2000. Fish Farmer October: 40-43.

Bautista-Teruel, M. N. & O. H. Millamena. 1999. Diet development and evaluation for juvenile abalone, Haliotis asinina : protein/energy level. Aquaculture 178:117-126.

Boarder, S. J. & M. Shpigel. 2001, Comparative performances of juvenile Haliotis roei fed on enriched Ulva rigida and various artificial diets. J. Shellfish Res. 20:653-657.

Britz. P. J. 1996a, Effect of dietary protein level on growth performance of South African abalone, Haliotis midae, fed fishmeal-based semi-purified diets. Aquaculture 140:55-61.

Britz. P. J. 1996b. The suitability of selected protein sources for inclusion in formulated diets for the South African abalone, Haliotis midae. Aquaculture 140:63-73.

Capinpin. E. C, & K. G. Corre. 1996. Growth rate of the Philippines abalone, Haliotis asinina fed an artificial diet and macroalgae. Aqua culture 144:81-89.

Capinpin, E. C., J. D. Toledo. V. C. I. Encena & M. Dot. 1999. Density dependent growth of the tropical abalone Haliotis asinina in cage culture. Aquaculture 171:227-235.

Chen, J-C. & W-C Lee. 1999. Growth of Taiwan abalone Haliotis diversicolor supertexta fed on Gracilaria tenuistipitata and artificial diet in a multiple-tier basket system. J. Shellfish Res. 18:627-635.

Corazani, D. & J. E. Illanes. 1998. Growth of juvenile abalone, Haliotis discus hannai Ino 1953 and Haliotis rufescens Swainson 1822, fed with different diets. J. Shellfish Res. 17:663-666.

Fleming, A. E. R., R. J. Van Barneveld & P. W. Hone. 1996. The development of artificial diets for abalone: a review and future directions. Aquaculture 140:5-53.

Hahn, K. O. 1989. A handbook of the culture of abalone and other gastropods. Boca Raton: CRC Press. 348 pp.

Jackson. D., K. C. Williams & B. M. Degnan. 2001. Suitability of Australian formulated diets for aquaculture of the tropical abalone Haliotis asinina Linnaeus. J. Shellfish Res. 20:627-636.

Jarayabhand, P. & N. Paphavasit. 1996. A review of the culture of tropical abalone with special reference to Thailand. Aquaculture 140:159-168.

Knauer, J., P. J. Britz & T. Hecht. 1996. Comparative growth performance and digestive enzymes activity of juvenile South African abalone. Haliotis midae, fed on diatoms and a practical diet. Aquaculture 140:75-85.

Koike, Y., J. Flassch & J. Mazurier. 1979. Biological and ecological studies on the propagation of the ormer Haliotis tuberculata Linnaeus. II. Influence of food and density on the growth of juveniles. La Mer 17:43-45.

Kruatrachue, M., S. Sawatpeera, E. S. Upahtam, T. Singhagraiwan & Y. P. Chitramvong.

2000. The utilization of artificial diets by Haliotis asinina Linnaeus. J. Med. & Appl. Malacol. 10:77-86.

Kunavongdate, P., W. Sakares & S. Muangsakorn. 1995. Experimental rearing on abalone, Haliotis asinina Linne with three species of seaweed. Technical Paper No. 39/1995. Coastal Aquaculture Division, Department of Fisheries. Ministry of Agriculture and Cooperatives, Thailand. (in Thai, with English abstract).

Leighton, D. L. 1974. The influence of temperature on larval and juvenile growth in three species of Southern California abalones. Fish. Bull. 72:1137-1145.

Leighton, D. L. & R. A. Boolootian. 1963. Diet and growth in the black abalone, Haliotis cracherodii. Ecology 44:227-238.

Leighton, D. L., M. J. Byhower, J. C. Kelly. G. N. Hooker & D. E. Morse. 1981. Acceleration of development and growth in young green abalone (Haliotis fulgens) using warmed effluent seawater. J. World Maricult. Soc. 12:170-180.

Lopez, L. M., P. A. Tyler & M. T. Viana. 1998. The effect of temperature and artificial diets on growth rates of juvenile Haliotis tuberculata (Linnaeus, 1758). J. Shellfish Res. 17:657-662.

Mgaya. Y. D. & J. P. Mercer. 1995. The effects of size grading and stocking density on growth performance of juvenile abalone, Haliotis tuberculata Linnaeus. Aquaculture 136:297-312.

Morrison, J. & J. Whittington. 1991. Development of an artificial feed for abalone. Australia Aquaculture 5:53-54.

Moss, G. A. 1997. Early juvenile growth of the abalone Haliotis australis in culture. Moll. Res. 18:153-159.

Nie, Z. Q., P. Wang, Z. Q. Wang & J-P. Yan. 1986. Experiments on preparing of formulated feed and feeding efficiency of young abalone, Haliotis discus hannai Ino. Mar. Fish. Res. 7:53-64.

Ogino, C. & E. Ohta. 1963. Studies on the nutrition of abalone 1. Feeding trials of abalone, Haliotis discus Reeve with artificial diets. Bull. Jpn. Soc. Sci. Fish. 29:691-694.

Ramsey, G. L. 1993. Fish meal and alternative sources of protein in fish feeds, update 1993. Fisheries 18:14-19.

Serviere-Zaragoza. E., A. Mazariegos-Villareal, G. Ponce-Diaz & S. M. Magallon, 2001. Growth of juvenile abalone, Haliotis fulgens Philippe, fed different diets. J. Shellfish Res. 20:689-693.

Shipton, T. A. & P. J. Britz. 2001. The practical and total replacement of fishmeal with selected plant protein sources in diets for the South African abalone. Haliotis midae L. J. Shellfish Res. 20:637-645.

Singhagraiwan, T. 1989. Some techniques for donkey's ear abalone culture (Haliotis asinina Linne). Extension Paper No. 1. Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. (in Thai, with English abstract).

Singhagraiwan, T. 1991a. Study on growth rate of donkey's ear abalone (Haliotis asinina Linne). Technical Paper No. 28. Department of Fisheries. Ministry of Agriculture and Cooperatives, Thailand. (in Thai, with English abstract).

Singhagraiwan, T. 1991b. An experiment on feeding of donkey's ear abalone (Haliotis asinina Linne). Technical Paper No. 29. Department of Fisheries, Ministry of Agriculture and Cooperatives. Thailand. (in Thai, with English abstract).

Singhagraiwan, T. 1993. Comparative study on the growth and survival of juvenile donkey's ear abalone (Haliotis asinina) in different rearing system. Technical Paper No.37. Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. (in Thai, with English abstract).

Singhagraiwan. T. & M. Doi. 1993. Seed production and culture of a tropical abalone, Haliotis asinina Linne. The Research Project of Fishery Resource Development in the Kingdom of Thailand, Department of Fisheries, Ministry of Agriculture and Cooperatives, Thailand. 32 pp.

Singhagraiwan, T. & M. Sasaki. 1991. Breeding and early development of the donkey's ear abalone, Haliotis asinina Linne. Thai. Mar. Fish. Res. Bull. 2:95-100.

Stuart, M. D. & M. T. Brown. 1994. Growth and diet of cultivated black-footed abalone. Haliotis iris (Martyn). Aquaculture 127:329-337.

Uki, N. & S. Kikuchi. 1979. Food value of six benthic microalgae on growth of juvenile abalone, Haliotis discus hannai. Bull. Tohoku Reg. Fish. Res. Lab. 40:47-52.

Uki, N. & T. Watanabe. 1992. Review of the nutritional requirements of abalone (Haliotis spp.) and development of more efficient artifical diets. In: S. A. Shepherd, M. J. Tegner & S. A, Guzman del Proo. editors. Abalone of the world, biology, fisheries and culture. Oxford: Fishing News Books. pp. 504-517.

Uki, N., J. F. Grant & S. Kikuchi. 1981. Juvenile growth of the abalone, Haliotis discus hannai, fed certain benthic miicroalgae related to temperature. Bull. Tohoku Reg. Fish. Res. Lab. 43:59-63.

Uki, N., A. Kemuyama & T. Watanabe. 1985. Nutritional evaluation of several protein sources in diets for abalone Haliotis discus hannai. Bull. Jpn. Soc. Sci. Fish. 51:1835-1837.

Uki, N., A. Kemuyama & T. Watanabe. 1986a. Optimum protein level in diets for abalone. Bull. Jpn. Soc. Sci. Fish. 52:1005-1012.

Uki, N., M. Sugiura & T. Watanabe. 1986b. Dietary value of sea-weeds occurring on the Pacific coast of Tohoku for growth of the abalone Haliotis discus hannai. Bull. Jpn. Soc. Sci. Fish. 52:257-266.

Viana. M. T., L. M. Lopez & A. Salas. 1993. Diet development for juvenile abalone Haliotis fulgens--evaluation of two artificial diets and macroalgae. Aquaculture 117:149-156.

Upatham, E. S., S. Sawatpeera, M. Kruatrachue, Y. P. Chitramvong, T. Singhagraiwan. T. Pumthong & P. Jarayabhand. 1998. Food utilization by Haliotis asinina Linnaeus. J. Shellfish

Res. 17:771-776.

M. KRUATRACHUE, (1), * S. SAWATPEERA, (2) Y. CHITRAMVONG, (1) P. SONCHAENG, (2) E. S. UPATHAM, (3) AND S. SANGPRADUB (4)

(1) Department of Biology, Faculty of Science, Mahidol University, Bangkok 10400 Thailand; (2) Institute of Marine Science, Burapha University Chonburi 20131, Thailand; (3) Faculty of Science, Burapha University, Chonburi 20131, Thailand; (4) Coastal Aquaculture Development Center, Prachuap Khiri Khan 77000, Thailand

* Corresponding author. E-mail: scmkt@mahidol.ac.th