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Suitability of two seaweeds, *Gracilaria lemaneiformis* and *Sargassum pallidum*, as feed for the abalone *Haliotis discus hannai Ino*

Zhanhui Qi [a,b], Hongmei Liu [c], Bin Li [b], Yuze Mao [b], Zengjie Jiang [b], Jihong Zhang [b], Jianguang Fang [b,*]

[a] South China Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Guangzhou 510300, China
[b] Yellow Sea Fisheries Research Institute, Chinese Academy of Fisheries Sciences, Qingdao 266071, China
[c] Yantai Institute of Coastal Zone Research Chinese Academy of Sciences, Yantai 264003, China

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ABSTRACT

The suitability of two algae species, *Gracilaria lemaneiformis* and *Sargassum pallidum*, for use as food sources for the abalone *Haliotis discus hannai Ino* was evaluated. Abalones were fed one of five experimental diets: 1) kelp *Laminari japonica*; 2) *G. lemaneiformis*; 3) *S. pallidum*; 4) a mixed diet of *L. japonica* and *G. lemaneiformis* (1:1); and 5) a mixed diet of *L. japonica* and *S. pallidum* (1:1) for a period of 4 months. The survival, growth (shell length and body weight), condition index (body weight/shell length), and feed utilization were measured. Survival was excellent (100%) in all groups. Growth rate (body weight) was highest in the abalone fed kelp exclusively, followed by the mixed diet of kelp and *G. lemaneiformis*. The abalone fed *S. pallidum* had the lowest increase in body weight and the lowest feed intake. The mixed diet of kelp and *G. lemaneiformis* yielded the biggest increase in shell length. There were no significant differences in the condition index among all the treatment groups. The mean daily feed intake of *L. japonica* was highest, followed by the mixed diets of kelp and *G. lemaneiformis*, and was lowest for *S. pallidum*. Abalone exhibited a preference for *L. japonica*. The feed conversion efficiency was highest for *G. lemaneiformis*. Results suggest that *G. lemaneiformis* can be used as a partial substitute for kelp in the diet of cultured abalone.

1. Introduction

Abalone is one of the most highly valued seafoods throughout the world. Until recently, they were harvested exclusively from the wild. Because of high demand, the wild populations in many regions have been over-exploited, resulting in serious declines in natural production (Guzmán del Proó, 1992; Parker et al., 1992; Shpigel et al., 1999; Tegner et al., 1992). Decreased wild catches combined with increasing global demand for abalone have resulted in market opportunities for cultured abalone (Oakes and Ponte, 1996). This has accelerated the development of intensive abalone aquaculture (Coote et al., 1996; Gordon and Cook, 2001; Shpigel et al., 1999).

Abalones are cultured extensively in China. In north China, particularly the Shandong and Liaoning provinces, *Haliotis discus hannai* is the most commonly cultured species. The successful culture of this species depends on proper nutrition and rapid growth. Developing a sustainable, cost-effective food supply for the long grow-out period is one of the key problems facing the abalone culture industry (Shpigel et al., 1999).

Artificial diets are generally expensive and their use is often not feasible (e.g., rapid leaching) for the ocean based long-line culture of abalone. Because of this, formulated diets are only used during the nursery stage, when the juvenile abalones are reared in land-based hatchery facilities. During the ocean-rearing period, abalones are primarily fed seaweed. A variety of seaweeds, including *Ecklonia maxima*, *Laminaria japonica*, *Ulva rigida*, *Carpoblepharis flaccida*, *Gracilaria gracilis*, *Ulva lactuca* are used for abalone culture (Alcantara and Noro, 2006; Demetropoulos and Langdon, 2004; Mai et al., 1996; Naidoo et al., 2006; Nie and Yan, 1985; Taylor and Tsvetnenko, 2004; Troell et al., 2006).

In north China, the majority of *H. discus hannai* is cultured on suspended long lines, and are often co-cultured with kelp (*L. japonica*). In this region, *L. japonica* is the most common, and often the only, food source for abalone. Sanggou Bay, located on the eastern side of the Shandong Peninsula, is one of the largest mariculture sites along the northern China coast (Guo et al., 1999). The entire bay is used for the culture of invertebrates and microalgae (Fang et al., 1996). In recent years, the culture of *H. discus hannai* has expanded rapidly in the bay, mostly co-cultured with kelp on long lines that are suspended in the water column.

Abalone can consume up to 35% of their body weight per day of seaweed (Tahil and Juinio-Menez, 1999). Typically, it takes about 3 years for *H. discus hannai* to reach commercial size in north China. Because of the long culturing period and high feeding rate, feed consumption and costs are considerable. In the last decade, the price of kelp has more than doubled, from 0.5 to 1.2 RMB/kg (based on fresh

* Corresponding author. Tel.: +86 532 85822957.
E-mail addresses: qizhanhui006@163.com (Z. Qi), Fangjg@ysfri.ac.cn (J. Fang).

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weight). Concurrently, the price of abalone has decreased from 300 RMB/kg in the late 1990s to 160 RMB/kg (based on fresh weight). The decrease in price is due to improvements in culture technology and increased production. The increase in food costs has led to a decline in net profit for abalone farmers. Given this, there is considerable demand for developing alternative, cheaper food sources.

A number of studies have evaluated the feasibility of using other red macroalgae, including *G. gracilis*, *Gracilaria cornea*, and *Gracilaria tenuistipitata* (Li et al., 2007; Naidoo et al., 2006; Viera et al., 2005). Different diets result in differential survival (Daume et al., 2003) and growth rate (Bautista-Teruel et al., 2003; Boarder and Shpigel, 2001; Britz, 1996; Guzmán and Viana, 1998; Leighton, 1974; Shpigel et al., 1999). Furthermore, the rate of growth is highly variable among species, even when fed identical diets. This is likely due to differences in nutrition requirements (Taylor and Tsvetnenko, 2004). Negative growth may even occur if the diet does not provide adequate nutrition.

Wild *Gracilaria lemaneiformis* and *Sargassum pallidum* often grow abundantly on structures that are used for kelp cultivation. *Gracilaria lemaneiformis* is also commercially cultured during the summer and autumn seasons in north China (Yang et al., 2005). The cost of abalone production may be lowered by using these seaweeds as a substitute (full or partial) for kelp. However, there is no information on the suitability of *G. lemaneiformis* and *S. pallidum* as feed for abalone.

The objective of this study was to evaluate growth and feed utilization of *H. discus hannai* fed *G. lemaneiformis* and *S. pallidum*, aimed to decrease the production costs.

2. Materials and methods

2.1. Experimental area

The study was conducted between May 20 and September 20, 2008, in Sanggou Bay, a 140-km^2 coastal embayment in north China (37°01′–37°09′N, 122°24′–122°35′E). Water exchange between the bay and the Yellow Sea is driven by semi-diurnal tidal exchange (tidal range 2 m). The average depth of the bay is 8.0 m. The experimental farm is located in a polyculture area of kelp and abalone. During the experiment, the water temperature ranged from 10.4 to 22.8 °C.

2.2. Experimental diets

The effects of three seaweeds *L. japonica*, *G. lemaneiformis*, *S. pallidum* on abalone were evaluated. The abalone were fed one of five experimental diets consisting of: 1) *L. japonica*, 2) *G. lemaneiformis*, 3) *S. pallidum*, 4) a mixture of *L. japonica* and *G. lemaneiformis*, and 5) a mixture of *L. japonica* and *S. pallidum* (D_L, D_G, D_S, D_{L+G}, and D_{L+S}, respectively). The two algae were combined at a ratio of 1:1 in the mixed diets. All the algae were collected fresh from suspended long lines.

2.3. Experimental animals and culturing condition

Hatchery-reared abalone (≈2 years old) that had an initial shell length (SL) of 75.78 ± 2.62 mm and an initial body weight (BW) of 62.31 ± 2.68 g were used in the experiment. The abalone were cultured in cylindrical plastic cages (diameter: 40 cm, height: 50 cm, N = 20 per cage). The abalone were distributed randomly among 15 cultivation cages. The cages were aligned in a single row and were suspended from long lines at a depth of 4.5 m.

2.4. Experimental procedures

The cages were identified using a numbered (1–15) tag. The cages were randomly assigned one of the five diet treatments to each cage (n = 3 cages per treatment). The abalone were acclimated for 1 month (April to May) to minimize the effects of switching diets. During the acclimation period, abalone from each treatment group were fed one of the five diets at a satiation level. BW and SL of each abalone were weighed and measured at the end of the acclimation period. There was no significant difference in SL and BW among the groups at the end of acclimation (P>0.05).

The experiment was carried out between May 20 and September 20, 2008. The abalone were fed with the appropriate diet once every 5 days. The wet weight of algae prior to feeding wase recorded and any uneaten algae were collected and weighed. Prior to weighing the excess water was removed by blotting with tissue paper. For the mixed diets, the two algae species were weighed separately. Consumption for each species of seaweed was calculated.

At monthly intervals, all the abalone cages were briefly brought to the surface for cleaning. All fouling organisms on the cages and the shells of the abalone were removed. BW and SL of all the abalone at the end of the experiment were measured.

2.5. Calculations and statistical analysis

The following variables were calculated:

Daily increase in body weight (DIBW) = $(W_t - W_0)/t$
Daily increase in shell length (DISL) = $(L_t - L_0)/t$
Feeding rate (FR % body weight day^{-1}) = $100 \times D/[t \times N \times (W_t + W_0)/2]$
Mean total feed intake (MTFI) = D/N
Feed conversion efficiency (FCE: %) = $100 \times (W_t - W_0) \times N/D$
Condition index (CI) = W_t/L_t

Where n: number of abalone in each cultivation tank, W_0: mean initial body weight, W_t: mean final body weight, L_0: mean initial shell length, L_t: mean shell final length, t: experimental duration (d), D: diet intake (g).

Differences in DIBW, DISL, FR, CI, FCE and MTFI among the treatment groups were analyzed using one-way analysis of variance (ANOVA). When overall differences were significant at the 0.05 level, Duncan's multiple range test was used to compare the mean values of individual groups. Data are reported as the mean ± standard deviation (S.D.). All statistical analysis was performed using Statistica 6.0 (Statsoft, Tulsa, OK, USA).

3. Results

3.1. Survival, growth performance and condition index

The survival rate was 100% for all treatment groups (Table 1). The growth rate (DIBW) of the abalone fed *L. japonica* was significantly higher than the other treatment groups, except D_{L+G}. The body weight of abalone fed *S. pallidum* was significantly lower than the other groups (P<0.05) (Table 1).

Abalone that were fed a mixed diet of *L. japonica* and *G. lemaneiformis* had the highest DISL (26.25 μm day^{-1}). This was significantly

Table 1
Mean body weight, daily increase in body weight (DIBW), and survival of *H. discus hannai* fed one of five experimental diets over a 4-month period.

Diet treatment	Mean initial body weight (g)	Mean final body weight (g)	DIBW (g·day^{-1})	Survival (%)
D_L	64.19 ± 3.21	76.82 ± 8.86^a	0.105 ± 0.005^a	100
D_G	66.02 ± 4.40	76.00 ± 9.04^a	0.083 ± 0.002^b	100
D_S	65.60 ± 2.11	74.94 ± 8.49^{bc}	0.078 ± 0.009^{bc}	100
D_{L+G}	63.94 ± 5.09	75.62 ± 7.32^{ab}	0.097 ± 0.002^a	100
D_{L+S}	64.20 ± 4.67	73.93 ± 7.82^c	0.081 ± 0.006^b	100

Values represent the mean of triplicate groups. Values in the same row with the same letters are not significantly different (P>0.05, Duncan's test).