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The effect of macroalgal, formulated and combination diets on growth, survival and feed utilisation in the red abalone *Haliotis rufescens*

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ABSTRACT

Abalone aquaculture in Chile is dominated by production of the red abalone *Haliotis rufescens* using a diet comprised predominantly of fresh, wild-harvested macroalgae. Concerns over the long-term supply of macroalgae have led farmers to investigate the suitability of various formulated feeds, however there has been limited commercial adoption. Combination diets of macroalgal and formulated feed fed together provide a mechanism to explore and adapt to formulated feed use without entirely abandoning macroalgal feed. The current study evaluated the use of formulated, macroalgal and two combination diets (low and high macroalgal supplementation) on production indicators and canning yields of juvenile abalone *H. rufescens* in a culture system modified for formulated feed. The macroalgal diet and the high macroalgal-formulated pellet combination diet (76.1% macroalgae: 23.9% pelleted diet as dry weight) produced significantly higher growth indicators (SGR and LGR) than the low macroalgal-formulated pellet combination diet (31.6% macroalgae: 68.4% pelleted diet as dry weight) and the formulated pellet diet. The protein efficiency ratio of the experimental treatments was positively related to the proportional contribution of fresh macroalgae in the diet. Furthermore, calculation of the protein efficiency ratio of the formulated component in combination diets (PER^f) revealed a significant positive relationship between macroalgae contribution and PER^f. This suggests that the increase in total PER is driven by the increased utilisation of protein in the formulated component of combination diets associated with increasing levels of fresh macroalgal supplementation. We suggest possible reasons why the presence of seaweed increased the availability of the formulated feed protein to the abalone. A simulated canning trial highlighted a significant positive linear relationship between meat canning yield and the proportional contribution of formulated feed. This study highlights the value of combination diets as a tool for abalone producers to harness the potential production advantages of macroalgae while still accessing the processing benefits associated with nutrient dense formulated feed.

Statement of relevance: We believe that this manuscript describes novel insights into the efficiency of protein utilisation in juvenile red abalone fed combination diets as well as the effect of diet, particularly formulated feed inclusion level, on canned meat yields. This provides empirical information to inform commercial abalone farmers of *H. rufescens* when exploring dietary options for optimal culture.

1. Introduction

Fresh macroalgae is the primary feed source used on abalone farms in Chile. Farms in the North (Regions III–V) generally use four wild-harvested species namely *Lessonia trabeculata*, *Lessonia berteroana*, *Lessonia spicata* and *Macrocystis pyrifera* while those in the South in the vicinity of Chiloé rely predominantly on wild-harvested *M. pyrifera*, but utilise cultured *Gracilaria chilensis* during winter months (Flores-Aguilar et al., 2007) (Fig. 1). When surveyed in 2006, land-based farmers considered feed to be the dominant constraint to the development of the industry, expressing concerns over the medium to long-term supply of macroalgae (Flores-Aguilar et al., 2007). Following from this concern the majority of farmers, both land and sea-based, listed feed as the most pressing research requirement. In addition, despite the industry testing various formulated diets, both locally produced and imported, concerns over poor growth rates and price had resulted in limited commercial adoption (Enríquez and Villagrán, 2008; Flores-Aguilar et al., 2007).

The experience of Chilean abalone farms in substituting macroalgal feeds with a formulated feed has been mixed, with the nutritional quality of the formulated diets, water stability and culture system design influencing performance. Culture systems designed for macroalgal diets are generally not suited to formulated diets, and require modifications to facilitate feed presentation and associated alterations to husbandry practices. As Chilean farmers were reluctant to convert to

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Fig. 1. Map of Chile with shading depicting the two major regions for abalone culture. Farms in the North (Regions III–V) are predominantly land-based operations while those in the South (Region X) undertake in-water growout.

pelleted diets, the option of combination diets (i.e., macroalgae and formulated feed fed together) thus provided a pathway for abalone farmers to explore the use of formulated feeds without abandoning macroalgal dietary options entirely. Combination diets allow for an extended weaning period to facilitate dietary switch and there is a growing body of literature to suggest that combination diets provide superior production outcomes when compared to single diets, either macroalgal or formulated (Dlaza et al., 2008; Durazo-Beltrán et al., 2003; Naidoo et al., 2006). The effect of diet on the growth of abalone in commercial culture must however always be balanced against its effect on the quality and yield of the final product. Diet has been shown to affect the taste, texture, chemical composition and colour of abalone meat (Allen et al., 2006; Bewick et al., 2008; Chiou and Lai, 2002; Smit et al., 2007, 2010). While some Chilean abalone farmers have been using combination diets since as early as 2006 (Flores-Aguilar et al., 2007), there is a paucity of information regarding the performance of these diets and their subsequent effect on yields of the dominant Chilean abalone export product, namely canned abalone.

Therefore, the aim of this study was to evaluate the effect of fresh macroalgal, formulated pellet and two combination diets (low and high macroalgae supplementation with formulated diet) on production performance indicators and canning yields of juvenile abalone *Haliotis rufescens* in a culture system modified for the use of formulated feeds.

2. Materials and methods

2.1. Culture system and experimental animals

The experimental culture system consisted of a 5000 l fiberglass raceway (10 m × 1 m × 0.5 m) with a single inflow of seawater (2500 $l \cdot h^{-1}$) and formed part of the production infrastructure at the AWABI Abalone Production Centre, Universidad Católica del Norte, Coquimbo, Chile (29°57′S; 71°21′W). Mean incoming water temperature at the facility over the experimental period was 13.3 ± 0.3 °C (range: 12.7–14.5 °C). Eight plastic mesh baskets (800 mm × 300 mm × 450 mm) were suspended in the raceway, with each divided by a double mesh wall (40 mm gap) to form two mesh compartments (380 mm × 300 mm × 450 mm) resulting in 16 experimental units. A double wall was used to prevent animals accessing food from an adjacent basket through the mesh spaces. Each compartment housed a vertical rack system of four high density polyethylene (HDPE) plates (300 mm × 300 mm) separated at 70 mm intervals by PVC spacers. A corrugated fibre–cement feeding plate rested on the vertical rack system with a distance of 100 mm between the submerged feeder plate and water surface. Dual parallel airlines ensured direct aeration to each mesh compartment. The experimental animals were hatchery-reared juvenile abalone *H. rufescens* (20.55 ± 1.69 mm shell length (SL); 1.1 ± 0.3 g, 431 ± 23 days post-spawning) sourced from production stock at AWABI Abalone Production Centre. The nutritional history of these animals consisted of post settlement rearing on diatom covered polycarbonate sheets followed by a diet of fresh macroalgae (*M. pyrifera*, *L. berteroana*/*L. spicata* and *Gracilaria* spp.).

2.2. Diets

Four dietary treatments with four replicates were allocated to basket compartments according to a randomised block design to ensure the even distribution of treatments along the length of the raceway. Dietary treatments consisted of a formulated pelleted diet (FD — ad libitum), two combination diet regimes consisting of the pelleted feed fed ad libitum and a fresh macroalgae supplement fed in conjunction (CMH — high macroalgae at 7.5% $bw \cdot day^{-1}$; CML — low macroalgae at 1.5% $bw \cdot day^{-1}$), and a fresh macroalgae only diet (MD — macroalgae at 15% $bw \cdot day^{-1}$). The pelleted diet was formulated from two sources namely steam dried, formaldehyde free, mackerel fishmeal (Oceana (Pty) Ltd., South Africa) and soya-oil cake. Starch carbohydrates and a vitamin/mineral mix were included according to a proprietary commercial formulation (Marifeed (Pty) Ltd., South Africa). Rehydrated, minced *M. pyrifera* was included at low levels to replace the macroalgae normally included in the commercial formulation (*Ecklonia maxima*) with a member of the Laminariales commonly used in the commercial culture of abalone in Chile. Proximate analysis of the diet indicated a composition of 26.2% crude protein (semi-micro Kjeldahl; N × 6.25), 3.4% total lipid (Soxhlet solvent extraction using chloroform and methanol at 2:1), 9.9% moisture (oven drying at 95 °C), 4.8% ash (residue after combustion at 550 °C), 55.7% non-nitrogenated extract (calculation by difference) and 17.1 $kJ \cdot g^{-1}$ digestible energy (Protein: 23.6 $kJ \cdot g^{-1}$,