Available online at www.sciencedirect.com

SCIENCE DIRECT®

Aquaculture 246 (2005) 331–345

Aquaculture

www.elsevier.com/locate/aqua-online

Lactic acid fermentation eliminates indigestible carbohydrates and antinutritional factors in soybean meal for Atlantic salmon (*Salmo salar*)

Ståle Refstie[a,b,*], Stefan Sahlström[c], Erland Bråthen[c], Grete Baeverfjord[a], Per Krogedal[d]

[a]*AKVAFORSK (Institute of Aquaculture Research AS), N-6600 Sunndalsøra, Norway*
[b]*APC (Aquaculture Protein Centre, Centre of Excellence), N-6600 Sunndalsøra, Norway*
[c]*MATFORSK (Norwegian Food Research Institute), N-1432 Ås, Norway*
[d]*EWOS Innovation AS, N-4335 Dirdal, Norway*

Received 26 November 2004; received in revised form 5 January 2005; accepted 5 January 2005

Abstract

This study investigated how lactic acid fermentation of extracted (de-oiled) soybean white flakes (WF) affected the nutritional value of the WF when fed to Atlantic salmon. WF and fermented WF (FWF) were compared with a commercial extracted (SBM) and a commercial biotechnologically processed (BPSBM) soybean meal. Lactic acid fermentation eliminated sucrose, reduced the level of raffinose, and lowered trypsin inhibitor activity in the FWF. Eight extruded diets were produced in which the soy products substituted LT-fish meal (FM) on a crude protein (CP) basis: No soy (LT-FM); 20% SBM; 20% WF; 20% FWF; 20% BPSBM; 40% WF; 40% FWF; and 40% BPSBM. Each diet was fed to triplicate groups of 188 g salmon maintained in 8.4 °C seawater for 68 days. The groups fed 40% FWF consumed slightly less feed than the other groups. The groups fed LT-FM and 20% BPSBM grew fastest, while those fed 40% WF and 40% FWF grew slowest and at similar rates. All soy products reduced the digestibility of lipid, but this effect was less severe when feeding the diets with FWF and BPSBM. Soybean meal-induced pathological changes in the intestine were less pronounced in fish fed FWF and BPSBM than in fish fed WF and SBM. The similar growth in the groups fed 40% WF and 40% FWF was attributed to higher digestibility of lipid and energy when feeding FWF. The intestinal microflora of the salmon appeared to utilise soy oligosaccharides, and also some pectin and mannan. To conclude, lactic acid fermentation improved the nutritional value of WF by partly eliminating feed allergen(s) and soy factor(s) that restrict the absorption of lipid by Atlantic salmon.

Keywords: Feedstuffs; Soy-white flakes; Lactic acid fermentation-oligosaccharides-NSP-phytic acid; Appetite–growth–digestibility-enteritis; Atlantic salmon *Salmo salar*

* Corresponding author. AKVAFORSK (Institute of Aquaculture Research AS), Sjølsengveien, N-6600 Sunndalsøra, Norway. Tel.: +47 71 69 53 22; fax: +47 71 69 53 01.
E-mail address: stale.refstie@akvaforsk.no (S. Refstie).

0044-8486/$ - see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.aquaculture.2005.01.001

1. Introduction

Soybeans contain approximately 30% indigestible carbohydrates (Bach-Knudsen, 1997) and numerous antinutritional factors (Rackis, 1974; Rumsey et al., 1994; Anderson and Wolf, 1995). Heat labile ANFs like proteinase inhibitors and agglutinating lectins are largely deactivated by the toasting step when producing solvent extracted (de-oiled) soybean meal (Vohra and Kratzer, 1991; Maenz et al., 1999). However, several of the ANFs in soy are heat stable. Among the most critical are still unidentified factor(s) that causes pathomorphological changes in the distal intestine of salmonid fish (Ingh et al., 1991, 1996; Rumsey et al., 1994; Baeverfjord and Krogdahl, 1996; Burrells et al., 1999; Krogdahl et al., 2000). This condition is commonly known as soybean meal-induced enteritis. The precise causative agent is not known, but one or more of the alcohol soluble components of soy are suspected of being involved (Ingh et al., 1991, 1996; Krogdahl et al., 2000).

Inclusion of solvent extracted soybean meal in the diet reduces the overall digestibility of lipid by Atlantic salmon (Refstie et al., 1998, 1999, 2000, 2001; Storebakken et al., 1998). The reason for this is still unclear. Refstie et al. (1999) suggested a negative effect of soy polysaccharides on nutrient absorption both in Atlantic salmon and broiler chickens. The soy polysaccharide fraction is in the form of indigestible non-starch polysaccharides (NSP), of which a large fraction is soluble in water (Bach-Knudsen, 1997). Furthermore, indigestible soy oligosaccharides (α-galactosyl homologues of sucrose) may affect the osmotic conditions in the intestine and facilitate microbial fermentation (Wiggins, 1984). Soybean meal-induced enteritis also corresponds with reduced absorptive capacity for nutrients by the distal intestine of salmonids (Nordrum et al., 2000). How much the latter actually contributes to the reduced absorption of nutrients seen in soybean meal fed salmonids is unclear, as the distal intestine is not recognised as a major absorptive site in fish (reviewed by Buddington et al., 1997).

The factor(s) in soybean meal that induces enteritis in salmonid fish is removed by alcohol washing used in the production of soy protein concentrates (Ingh et al., 1991, 1996; Rumsey et al., 1994; Krogdahl et al., 2000; Refstie et al., 2001). This process also removes sugars and soluble polysaccharides. However, this is an elaborate treatment to produce a high-priced product. Fermentation has been suggested as an alternative means to improve the nutritional value of vegetable protein sources for fish feeds. Shimeno et al. (1994) examined fermentation of solvent extracted soybean meal by yellow mould (*Aspergillus usamii*). Unfortunately, the physical properties of the resulting fermented soy were too poor to allow proper evaluation by a fish trial. Fermentation by lactic acid bacteria (*Lactobacillus acidophilus*) did, however, significantly improve the nutritional value of sesame seed meal to the Indian rohu carp (Mukhopadhyay and Ray, 1999).

Fermentation by a *Lactobacillus* sp. has also been used with success to reduce the levels of non-starch carbohydrates in wheat and barley whole meals (Skrede et al., 2001, 2002, 2003). This lactic acid fermentation was particularly efficient in eliminating soluble mixed-linked (1-3)(1-4)-β-glucans, but also sucrose and raffinose (Gal (α1-6) Glc (β1-2) Fru). Substitution of unfermented cereals by lactic acid fermented cereals in extruded diets resulted in a significant increase in the overall apparent digestibilities of starch, lipid, and energy by Atlantic salmon (Skrede et al., 2002). Similar but slighter responses were observed in mink (Skrede et al., 2001).

Lactic acid fermentation has also been shown to give a significant reduction in phytic acid in cereal (Marklinder et al., 1996; Skrede et al., 2002) and sesame seed (Mukhopadhyay and Ray, 1999) whole meals. However, as the cereals and sesame seed meals were not heated before fermentation, it has been unclear whether this hydrolysis of phytic acid resulted from microbial *Lactobacilli* activity, or phytase endogenous to the grains. Plant seeds express high phytase activity, but these phytases are largely inactivated by thermal treatments of feedstuffs and feeds (Jongbloed and Kemme, 1990).

The objectives of the present work were 1) to investigate how lactic acid fermentation alters the composition of extracted (de-oiled) soybean white flakes, 2) to evaluate lactic acid fermentation as a means to improve the nutritive value of soybean meal white flakes to Atlantic salmon, and 3) to compare the nutritional value of fermented white flakes to that of commercial biotechnologically processed extracted soybean meal in Atlantic salmon.