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Screening of nutrient digestibilities and intestinal pathologies in Atlantic salmon, *Salmo salar*, fed diets with legumes, oilseeds, or cereals

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Abstract

Ten different plant protein and/or starch sources were studied in a 5-week experiment with triplicate groups of 0.7-kg Atlantic salmon in seawater, pre-adapted to a diet with fish meal, faba beans, sunflower cake, and wheat gluten as sources of protein and starch. The experimental ingredients were corn gluten, defatted soybean, defatted sunflower, dehulled lupin, defatted double-low rapeseed, whole field pea, whole and dehulled faba bean, whole wheat and naked oat, tested one at a time (14–24% inclusion). The diets were balanced by addition of pure wheat starch and/or pure cellulose, to obtain equal macro nutrient compositions. The control diet consisted of fish meal, wheat starch, cellulose and fish oil. The results showed reduced faecal dry matter content in fish fed the soybean diet and to a lesser extent in those fed the sunflower, lupin and rapeseed diets. Diets containing lupin and rapeseed resulted in a moderate increase in the viscosity of the digesta, while diets with wheat and oat increased viscosity of digesta more. Apparent digestibility of lipid decreased linearly with increasing dietary cellulose level. A significant reduction in the digestibility of crude protein was seen for the soybean, sunflower, rapeseed and oat diets, reflecting reduced digestibilities of most amino acids. The salmon fed the corn gluten, lupin, pea, bean and wheat diets had protein digestibilities comparable to the control group. The digestibility of phosphorus was highest for salmon fed the rapeseed diet and lowest for fish fed the oat diet. Faecal excretion of sodium was highly elevated for salmon fed the soybean diet, and moderately elevated for fish fed the corn gluten and sunflower diets. Faecal excretion of zinc was elevated in the fish fed the oat diet. None of these observations were significantly related to the dietary concentration of phytic acid. A histological examination of the stomach, mid- and distal intestine of all groups showed no other irregularities than enteritis in the distal intestine of salmon fed soybean meal. The present study demonstrated a potential for several plant ingredients, such as field pea and faba bean, partly replacing high-quality fish meal in diets for Atlantic salmon, based on nutrient digestibilities and absence of pathologies in the stomach and intestine.

Keywords: Atlantic salmon; Corn gluten; Soybean; Sunflower; Lupin; Rapeseed; Field pea; Faba bean; Wheat; Oat; Viscosity; Digestibility; Pathology; Enteritis

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1. Introduction

Supply of fish meal has become a limiting factor for increase in fish production. Thus, increased use of plant protein in the feed is necessary to support rapid and sustainable growth in intensive fish farming. Different salmonid fish species respond differently when fish meal is replaced by plant feed ingredients (Refstie et al., 2000; Glencross et al., 2004a,b; Krogdahl et al., 2004), and responses, therefore, must be assessed with the actual target species.

Plant protein sources with a low degree of processing, like defatted rapeseed, soybean, sunflower, beans, legumes or peas, or crude gluten meals are inexpensive and readily available in high quantities. However, they may contain a variety of antinutrients (Francis et al., 2001). Some heat labile antinutrients, like protease inhibitors, lectins, and some bitter components, are easy to inactivate by moist heating. For example, protease inhibitor activity in soy can be reduced to nutritionally acceptable levels simply by the energy input provided by extrusion of the feed (Marsman et al., 1995; Romarheim et al., 2005). Inactivation of antinutrients that are not destroyed by moderate heating, such as alkaloids, some bitter components, glucosinolates, indigestible oligosaccharides and non-starch polysaccharides (NSP), phytates, and tannins (Francis et al., 2001) requires more specific methods. Lactic acid fermentation (Ibrahim et al., 2002; Skrede et al., 2002; Refstie et al., 2005) and enzyme treatment (Denstadli et al., 2006a) are examples of processes that can potentially be applied by modifications of the feed processing line. Several antinutrients affect nutrient digestibilities. Typically, lipid digestibility is normally reduced when salmon are fed diets with defatted soybean meal (review by Storebakken et al., 2000a). Nitrogen digestibility and faecal cysteine excretion (Olli et al., 1994) are closely associated with protease inhibitor activity in the feed. Faecal excretion of divalent and trivalent ions, like zinc, is elevated when salmon are fed diets containing phytic acid (Denstadli et al., 2006b) and faecal excretion of sodium is elevated in salmon fed soy products (Storebakken et al., 1998, 2000a). The first aim of this experiment, thus, was to study effects of partial replacement of high-quality fish meal with plant protein sources with a low level of processing on the digestibility of macronutrients and the faecal output of sodium and zinc.

Except for corn and wheat gluten meals, plant protein sources that contain starch rather than NSP, like peas

Table 1
Chemical composition of experimental ingredients (g kg^{-1})

Ingredient	Fish meal [a]	Protein-rich plant ingredients					Starch-rich plant ingredients				
		Corn gluten [b]	Soybean [c]	Sunflower [d]	Lupin [e]	Rapeseed [f]	Pea [g]	Whole bean [h]	Dehulled bean [i]	Wheat [j]	Oat [k]
DM	920	918	897	907	901	892	860	866	877	857	872
In DM											
Crude protein	752.2	674.3	500.6	384.8	402.9	371.1	243.0	272.5	296.5	150.5	130.7
Lipid	103.3	92.6	33.4	40.8	92.1	49.3	22.1	21.9	27.4	31.5	95.2
Ash	157.6	16.3	59.1	81.6	27.7	74.0	32.6	34.6	35.3	19.8	20.6
Starch	N.d. [l]	153.6	81.4	N.d.	N.d.	N.d.	523.3	426.1	497.1	658.1	644.5
Dietary fibre	N.a. [m]	49.0	324.4	345.1	370.7	361.0	220.9	244.8	120.9	145.9	119.3
Water soluble fibre	N.a.	N.d.	35.7	14.3	53.3	13.5	19.8	N.d.	N.d.	23.3	49.3
Organic matter	842.4	983.7	940.9	918.4	972.3	926.0	967.4	965.4	964.7	980.2	979.4

[a] Low-temperature dried, NorsEco, Egersund fiskeoljefabrikk, Egersund, Norway. The raw material had the following composition (g kg^{-1}): Blue whiting, 300; capelin, 220; herring, 20; herring filleting by-products, 360; horse mackerel, 110.
[b] Corn gluten meal, Felleskjøpet, Kambo, Norway.
[c] Deno-Soy F®, hexane extracted and toasted soybean meal with hulls, Denofa, Fredrikstad, Norway.
[d] Sunflower (*Helianthus annuus*) seed meal, solvent extracted and mildly heat treated (Rosenkrantz AS, Aalborg, Denmark).
[e] Low alkaloid dehulled white lupins (*Lupinus angustifolius*), reported alkaloid content of <200 mg kg^{-1} (Schouten Products B.V., Giessen, Netherlands).
[f] The rapeseed meal (double low; *Brassica napus*) had been flaked and defatted by hexane extraction at 60 °C and given a short-time heat treatment at 100 °C under pressure. The reported glucosinolate content was 3 mmol kg^{-1} (Karlshamns AB, Karlshamn, Sweden).
[g] Whole field pea (*Pisum sativum*) (Läntmannen, Stockholm, Sweden).
[h] Whole faba bean (*Vicia faba*) (Nordic Bulk Company A/S, Aarhus, Denmark).
[i] Dehulled faba bean (Nordic Bulk Company A/S, Aarhus, Denmark).
[j] Whole wheat (Felleskjøpet, Kambo, Norway).
[k] Naked oat (Felleskjøpet, Kambo, Norway).
[l] Not detectable.
[m] Not analysed.