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Physical properties of extruded fish feed with inclusion of different plant (legumes, oilseeds, or cereals) meals

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ABSTRACT

A study was undertaken to evaluate the effect of various ingredients on the physical quality of fish feeds. Eleven fish meal-based diets, formulated to have the same levels of macronutrients, differing in either starch or protein source, were processed in a five section twin-screw extruder. The purified starch, added to reach the nutritional specifications of the diets, was significantly correlated to expansion ($r = 0.405$, P<0.001), durability ($r = 0.276$, P=0.012), and hardness ($r = 0.494$, P<0.001), while such correlations were not seen for the total starch level in the diets. Cellulose, added as filler to reach the same level of NSP in the diets, was negatively correlated to the expansion ($r = -0.603$, P<0.001). The specific mechanical energy of the extrusion process was weakly correlated to starch gelatinisation ($r = 0.220$, P<0.019). The present study showed that traditional parameters and classifications such as chemical composition of plant ingredients are inadequate indicators of processing effects when used in fish diets. The overall conclusion is that processing parameters needed to achieve the desired physical properties of diets, should be based on specific knowledge of each ingredient in the feed.

1. Introduction

The use of plant meals in feed for carnivorous fish has increased in recent years (Carter and Hauler, 2000; Aslaksen et al., 2007). Most studies have focused on the nutritional properties (Francis et al., 2001; Drew et al., 2007; Gatlin et al., 2007; Glencross et al., 2007), but effects on physical quality of feed have also been reported (Baeverfjord et al., 2006; Glencross et al., 2010). In food science, the nutritional and physical properties of extruded or cooked plant meals have been studied by a number of authors (Parmer et al., 2004; Rocha-Guzmán et al., 2006; González-Pérez and Vereijken, 2007; Hernandez-Diaz et al., 2007).

When attempting to reduce the fish meal levels in fish feed, both typical high-protein meals and combined starch–protein sources should be considered. It is known that globular proteins in plant meals may have a structuring capacity (Areas, 1992; Li and Lee, 1996). The NSP fraction present in plants may result in less expansion (Ainsworth et al., 2007) which is important for how much lipid can be added through the coating process and the sinking velocity of the pellet (Sørensen et al., 2010). NSP might also contribute to harder pellets, which is crucial to ensure that the pellets are not being crushed during handling before it is being distributed to the fish. Legume starch is known to be harder to gelatinise, than cereal starch (Singh et al.,

Abbreviations: DG, degree of gelatinisation; DM, dry matter; DSC, differential scanning calorimetry; NSP, non-starch polysaccharides; st.dev., standard deviation; SME, specific mechanical energy; WAI, water absorption index.

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Table 1
Formulation and chemical composition of the diets (g/kg).

Diet	Control	Protein-rich plant ingredients[a]					Starch-rich plant ingredients[a]				
		Corn gluten	Soybean	Sunflower	Lupin	Rapeseed	Pea	Whole bean	Dehulled bean	Wheat	Oat
Macro ingredients											
Fish meal	712	481	532	539	529	582	631	603	614	669	666
Plant ingredient		278	283	313	326	250	247	301	256	196	196
Wheat starch	128	85	106	128	126	120					
Cellulose	149	132	62			30	107	79	114	121	126
Micro ingredients[b]	11.62	23.37	18.02	19.89	19.94	17.95	15.20	16.61	16.39	13.10	12.96
Chemical composition											
DM	964	960	937	930	944	959	951	946	945	938	944
In DM											
Crude protein	519	551	576	567	566	542	541	547	558	530	521
Starch	147	127	112	121	133	149	122	112	133	125	119
Dietary fibre	167	173	148	132	129	134	162	173	140	168	181
Lipid	49	51	40	45	56	50	53	47	47	56	60
Ash	118	98	123	134	116	12	121	122	123	120	120
Org. matter	882	902	877	866	884	874	879	878	877	880	880
Gelatinisation											
T_f (°C)[c]	71 ± 0.4	70 ± 0.6	71 ± 0.6	69 ± 1	72 ± 0.4	72 ± 0.6	72 ± 0.4	74 ± 0.6	75 ± 0.3	74 ± 0.4	70 ± 0.5
ΔT (°C)[d]	11 ± 1.5	9 ± 1.4	11 ± 2.2	13 ± 0.9	14 ± 2.1	15 ± 0.1	14 ± 2.1	18 ± 2.6	18 ± 1.2	13 ± 0.3	12 ± 4.1

[a] See Table 2 for details on macro ingredients.
[b] Vitamin and mineral premix, monocalciumphosphate and yttrium oxide. See Aslaksen et al. (2007) for details.
[c] T_p shows the peak temperature of gelatinisation ± standard deviation.
[d] ΔT shows the temperature interval of gelatinisation ± standard deviation, calculated by subtracting onset temperature of gelatinisation (T_i) from final temperature of gelatinisation (T_f). T_i and T_f are not shown.

2003; Betancur-Ancona et al., 2004). This may be due to different starch microstructure and other components associated with the starch granule (Gallant et al., 1992; Tester et al., 2004). Thus, NSP may protect starch from gelatinisation (Brennan and Samyue, 2004; Tester et al., 2004).

The extrusion process is composed of both adjustable and non-adjustable variables, and may be characterized as a multiple-input, multiple-output system (Cayot et al., 1995; Nabar and Narayan, 2006; Lee et al., 2009). There are numerous ways to describe the extrusion process (Ganjyal et al., 2006). In the present study, we have used the terms operating variables and process variables, as described by Lu et al. (1992). The adjustable operating variables include retention time in the conditioner, screw speed, feed moisture content, and throughput (Lu et al., 1992). The process variables include observable parameters such as barrel and product temperatures in conditioner and extruder, torque, SME, and die pressure. The parameters temperature, pressure, moisture, and shear are regularly utilised in the studies of physicochemical changes of nutrients under extrusion processing (Akdogan, 1999; Douzals et al., 2001; Singh et al., 2007).

The overall aim of this study was to investigate the effect of plant ingredients on physical quality of extruded fish feed as assessed by a set of physicochemical measurements. The plant meals used were chosen among ingredients with nutritional profiles, suitable for use in fish feeds, and with a low degree of up-front processing (Aslaksen et al., 2007).

2. Materials and methods

2.1. Feed ingredients and production

Eleven diets were extruded (Table 1): a control diet with fish meal as the single protein source and ten diets containing a protein-rich or starch-rich plant ingredient, partly replacing fish meal and/or wheat starch. The chemical composition of the experimental ingredients is shown in Table 2. Diets with starch-rich plant ingredients were formulated, so that the plant ingredient provided all starch in the diet. The protein-rich plant ingredients were included at a level to replace ~200 g/kg of the crude protein from high-quality fish meal. The extruded diets were formulated to contain equal amounts of crude protein, starch, and total dietary fibre by balancing the diets with purified wheat starch (Raisio Plc, Raisio, Finland) and/or cellulose (commercial cellulose MN 100, Macherey-Nagel GmbH & Co. KG, Düren, Germany). Balancing of the diets with starch and cellulose was done using values for starch and NSP in the different ingredients reported by Bach Knudsen (1997). However, the chemical analysis showed that an unintended variation in the level of dietary fibre and starch occurred (Table 1).

The diets were made at Center for Feed Technology, Norwegian University of Life Sciences, Ås, Norway. Dry ingredients were mixed in a Dinnissen twin shaft mixer (Pegasus Menger 400 l, Sevenum, Holland) and milled in a Münch hammer mill (HM 21.115, Wuppertal, Germany) with a 1-mm screen. Then the diets were preconditioned in a double conditioner (BCTC 10, Bühler, Uzwil, Switzerland), extruded with a throughput of 200 kg/h in a co-rotating twin-screw extruder (Bühler BCTG 62/20 D, 5 sections, length/diameter = 20, T = 105–130 °C in 3rd section, 4 mm die), and subsequently dried in a batch dryer (70–90 °C, 40 min). Extruder parameters are shown in Tables 3–5.