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Replacing fishmeal with oilseed cakes in fish feed – A study on the influence of processing parameters on the extrusion behavior and quality properties of the feed pellets

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ABSTRACT

The use of suitable fishmeal substitutes for feed in aquaculture is highly desirable to ensure sustainable and economic fish farming. Soybean, linseed, rapeseed, and sunflower seed cakes were investigated as potential fishmeal substitutes. A replacement of 25% (w/w) of the reference fishmeal formulation with oilseed cakes produced pellets with similar nutritional profiles to the reference fish feed but with less pronounced expansion, increased sedimentation velocity, lower water stability and abrasion resistance. The sedimentation velocity of the pellets containing oilseed cakes could be reduced by improving their radial expansion, which was achieved by altering the screw configuration of the extruder, namely by increasing the number of reverse elements and kneading blocks. A reduction in sedimentation velocity could be similarly achieved using finer milled oilseed cake particles. This study indicates that a partial replacement of fishmeal using oilseed press cakes as a by-product from oil-production is feasible. Additionally, the present findings demonstrate that the physical properties of the final fish feed pellets can be modified to be more similar to the fishmeal reference pellets by varying specific parameters in the extrusion process.

1. Introduction

The per-capita consumption of fish has steadily increased from about 10 kg per year in the 1960s to approximately 20 kg per year in 2012, during which period the world population has doubled (FAO, 2014). As the demand for fish grows, the global fishing of wild fish cannot be intensified as overharvesting endangers the sustainability of the natural fish supply. Consequently, the production of fish in aquaculture has shown a marked growth over the past decades, with a concurrent increase in the demand for fishmeal as the major ingredient in fish feed used in aquaculture (FAO, 2014). This extensive use of fishmeal has led to its limited availability and inevitably higher costs, with the price of fishmeal increasing by more than 300% in the last decade (Barrientos and Soria, 2015). As such, the (partial) replacement of fishmeal by plant-based protein-rich ingredients offers a potentially important alternative to help maintain the future viability and sustainability of aquaculture fish farming.

A series of studies has investigated feed digestibility and growth rate of rainbow trout reared on feed containing different protein-rich plant ingredients in place of fishmeal. The use of crushed and extruded whole peas (Burel et al., 2000), pea meal (Collins et al., 2012), or processed pea protein concentrates (Collins et al., 2012), for instance, did not have any significant negative effects on the growth of rainbow trout, although the digestibility showed improvement with an increasing extent of processing (whole peas < pea meal < pea protein concentrate).

Rapeseed-based meal has similarly been studied (Mwachireya et al., 1999; Burel et al., 2000; Collins et al., 2012; Güroy et al., 2012). Burel et al. (2000) subjected the rapeseeds to an extensive de-hulling followed by two different fat extraction methods,

Abbreviations: ANF, anti-nutritional factor; DM, dry matter; CE, conveying screw element; KB, kneading block; LEI, longitudinal expansion index; n.d., not determined; NFE, nitrogen-free extract; RE, reverse screw element; SEI, sectional expansion index; SME, specific mechanical energy; SPC, soybean protein concentrate; TP, temperature profile.

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namely a direct extraction using solvent or mechanical pressure-cooking with water injection and a power press. The results demonstrated an improved digestibility of the heat-treated rapeseed meal in comparison to the solvent-extracted meal. Mwachireya et al. (1999) compared the digestibility of a commercially available rapeseed protein isolate with different fractions of purified rapeseed meal, namely 1) sieved, 2) ammonia/methanol-extracted with reduced glucosinolates and phenolic compounds, 3) reduced-phytase, and 4) carbohydrase-treated (for enhanced digestibility of alpha-galactosides and other indigestible carbohydrates). An improved digestibility was demonstrated for the rapeseed protein isolate compared to the different meals, but not for the purified meals in comparison to untreated rapeseed meal.

Soybean meal has been investigated as a partial fishmeal replacement in several studies (Romarheim et al., 2006; Harlíoğlu, 2011; Collins et al., 2012; Güroy et al., 2012), with the most promising results being shown for an intermediate product of soy protein concentrate and isolate production (Romarheim et al., 2006) or for soybean protein concentrate (SPC) (Collins et al., 2012).

The digestibility of other plant-based fishmeal substitutes including, seeds, meal, and protein concentrate from lupin (Burel et al., 2000), corn gluten (Burr et al., 2012), pumpkinseed press cake (Lozovsky and Sorokina, 2010), and sesame seed cake (Thu et al., 2011) have also been investigated. In particular, extruded lupin products were found to be very promising replacers for fishmeal due to their high degree of protein digestibility.

Although the aforementioned studies address the problem of the presence of anti-nutritional factors (ANF) in some of the plants used for fishmeal replacement, it is not only the nutritional value but also the physical properties of the fish feed that affect feed intake and digestibility (Sørensen, 2012). Despite this, the physical parameters, which are greatly influenced by the selection of raw materials (Draganovic et al., 2011) and the extrusion parameters employed (Kraugerud et al., 2011), are very often neglected in studies that evaluate new fish feed (Sørensen, 2012). Moreover, a drawback of some of the aforementioned studies is that they use plant-based products like oil, meal, or protein isolates, which can equally be used as human food ingredients and thereby command a higher price.

The aim of the present study was to examine the usability of waste products from oil-production, namely the oilseed cakes from soybean, linseed, rapeseed, and sunflower seed, as a potential (partial) substitute for fishmeal. Rapeseed cake, which exhibited the most promising properties of the oilseed cakes investigated, was used to further study the processing parameters (e.g., extruder screw configuration and temperature profile) and the characteristics of the raw materials (e.g., particle size distribution of oilseed cakes) on the physical properties of the resulting feed pellets.

2. Materials and methods

2.1. Preparation of the fish feed pellets

2.1.1. Pellet formulation

All oilseed cake-based pellet formulations were produced by replacing 25% of the fishmeal, wheat, and wheat gluten formulation either with rapeseed, soybean, linseed, or sunflower seed cake (Table 1). All ingredients except the oilseed cakes were supplied by Aller Aqua GmbH (Christiansfeld, Denmark). Rapeseed, soybean, linseed, and sunflower seed cakes were supplied by Marbacher Ölmühle GmbH (Marbach, Germany). The chemical compositions of the raw materials and the pellets before and after coating with fish oil are presented in Table 1.

For all experiments (except the rapeseed cake's particle size investigation; see below) fishmeal and oilseed cakes were milled (Hosokawa 100 UPZ mill; Alpine AG, Augsburg, Germany) at 800 min^{-1} and sieved through a screen with a mesh width of 0.5 mm (Kraugerud et al., 2011) before mixing for 15 min with other dry ingredients using a paddle mixer (Lescha SM 145 S; Altrad Lescha GmbH, Burgau, Germany). For the rapeseed cake particle size investigation, four rapeseed cake samples were impact-milled until all of each sample could pass through a 0.5 mm, 0.8 mm, 1.0 mm or 2.0 mm mesh screen, respectively. The particle size distributions of the raw materials are shown in Table 2.

2.1.2. Extrusion process and vacuum coating

All fish feed pellets were extruded using a twin screw extruder (Coperion ZSK 26, Coperion GmbH, Stuttgart, Germany) with a screw diameter of 26 mm and a length/diameter ratio of 25/1. The rotational speeds of the screw and the die face cutter were 300 rpm and 500 rpm, respectively. The dry ingredients were fed into the extruder using a twin screw gravimetric feeder (DDW-MD5-DSR67-35, Brabender GmbH & Co. KG, Duisburg, Germany) at 5 kg h^{-1} for the first experimental series that compared different oilseed cakes (section 3.1) and investigated the influence of the temperature profile (section 3.2.2). Dry ingredients were then fed into the extruder at 11 kg h^{-1} in order to assess the impact of the rapeseed cake particle size (section 3.2.3) and the screw configurations (section 3.2.1) on the extruded pellets.

The extruder was equipped with 2 × 3 mm and 4 × 3 mm diameter dies at the lower (5 kg h^{-1}) and higher (11 kg h^{-1}) feed rates of dry ingredients, respectively. Water at ambient temperature was pumped (FD-DKMP-6, Brabender GmbH & Co. KG, Duisburg, Germany) during operation into the top of the extruder barrel, 225 mm downstream from the center of the feed port, which resulted in a feed moisture content of 30 ± 1% (w/w) on a wet basis for all experiments and a mass flow rate of 7.1 (sections 3.1 and 3.2.2) and 15.7 kg h^{-1} (sections 3.2.1 and 3.2.3).

The barrel was segmented into six temperature-controlled zones that were heated by an electric cartridge heating system and cooled with water. The first element (feeding zone) was not heated. The temperature of the other zones was different for temperature profile I (TP I) (cf. sections 3.1, 3.2.1, and 3.2.3), and temperature profile II (TP II) (cf. section 3.2.2). Table 3 provides the details on the temperatures that were set for each temperature-control zone investigating TP I or TP II. The screw profile was built with different screw elements that were assembled on hexagonal shafts. Conveying elements (CE) were used to transport the feed mix forward, whereas kneading blocks (KB) were used for mixing and reverse screw elements (RE) were used to increase pressure, filling degree, and resistance time by pushing back the feed mixture.

All extrusion experiments were performed using screw configuration D. Additional extrusion experiments were accomplished using different screw configurations (A, B, C, and E) in order to generate different specific mechanical energies (SMEs) (cf. section 3.2.1). The screw elements in the respective temperature zones for each screw configuration are shown in Table 3.

After extrusion the pellets were dried in an oven at 90 °C (Airmaster UK2300-25002, Reich Klima-Räuchertechnik, Urbach, Germany) until they reached a moisture content of 4.5 ± 1% (w/w) (Draganovic et al., 2011). The pellets were then coated with fish oil under vacuum (300 mbar) in a rotary evaporator (BÜCHI Labortechnik AG, Flawil, Switzerland) to achieve a final oil content of 18–20% (w/w). The temperature of the fish oil during coating was 50 ± 2 °C.

2.2. Determination of extruder responses

The extruder responses including motor torque [%], pressure