CHAPTER 14

Extruding Aquaculture Diets Containing DDGS

Introduction

EXTRUSION IS THE MOST COMMON THERMAL PROCESS USED TO PRODUCE AQUACULTURE FEEDS, because it improves feed conversion, controls pellet density, provides greater feed stability in water and improves production efficiency and versatility (Khater et al., 2014). Extrusion also results in gelatinization of starch, protein denaturation, hydration, texture alteration, partial dehydration and destruction of microorganisms and toxic compounds (Khater et al., 2014).

Unfortunately, the major challenge with extruding DDGS diets is its inherent low starch and high fiber content (Chin et al., 1989). Reduced starch content of diets reduces expansion during extrusion that affects the physical characteristics, while increased fiber content reduces the mechanical strength and durability of extrudates (Chevanan et al., 2007a).

Extrusion Processes

Extrusion is a process by which a feed or food material is pushed, using a pistonor screw, through an orifice or a die of a given shape. While extrusion is the most common thermal process used to produce aquaculture feeds (Khater et al., 2014), it also has advantages for improving energy and nutrient digestibility in swine (Rojas et al., 2016) and poultry (Lundblad et al., 2011) feeds. Several processes occur during extrusion including fluid flow, heat and mass transfer, mixing, shearing, particle size reduction, melting, texturizing, carmelizing, plasticizing, shaping and forming depending on the material being processed (Camire, 1998). Extrusion has several advantages compared with conventional cooking and steam pelleting processes including: flexibility to make on-line adjustments and achieve desired physical characteristics; manufacture of many types of feed products; has no effluents; is energy efficient; and can be used to process a wide range of materials ranging from dry, highly viscous to moist or wet materials (Maskan and Altan, 2011).

Extruders are available in several designs depending on their application, but are generally classified based on the number of screws. The two general types of extruders are single-screw and twin-screw configurations. Single screw extruders are widely used in the feed industry because of their low initial investment and operating cost compared with twin screw extruders. Single screw extruders operate based on the pressure requirement of the die, slip at the barrel wall and the extent to which the screw is filled, whereas twin screw extruders operate based on the direction the two screws rotate and the extent of intermeshing between the two screws (Chevanan et al., 2005). Single-screw extruders consist of a single rotating screw in a metal barrel, which can be configured in many patterns. The three main components of the single-screw extrusion process consist of the feeder, transition and compression and metering stages. In this design, ground feed or ingredients enter the hopper, and the rotating action of the screw conveys the feed material to the transition section where the screw channel becomes more narrow and compacted. The mechanical energy causing compaction generates heat, which is dissipated to increase the temperature of the material, resulting in gelatinization of starch and cohesion. As the feed material continues to be transported by the metering section, it is pushed through the die opening. Twin screw extruders differ from single screw extruders and have several advantages including: no pre-conditioning, self-cleaning, greater range in length to diameter ratios; good mixing; shorter residence time and good heat transfer; and capable of handling a wide range in moisture content and types of feed ingredients (Harper, 1989).

Factors Affecting Extrusion of Aquaculture Feeds

Many forms of fish feed are produced including extruded-floating, extruded non-floating, steam pelleted, large crumbles, small crumbles and coarse meal, and steam pelleting and extrusion are the two primary methods of manufacturing fish feeds. Most fish require floating pellets, or they can at least be trained to accept floating pellets, whereas shrimp need sinking pellets (Craig, 2009). Steam pelleting is generally used to produce dense pellets that sink rapidly in water. Extrusion is generally used to produce floating pellets, and has several advantages compared with steam pelleting including: continuous, high throughput processing; processes feeds with a wide range in moisture content; energy efficiency; capability of processing dry, viscous feed components; improves texture and flavor characteristics; minimizes thermal changes during processing; results in feeds more stable in water and float on the water surfaces; and is applicable for unconventional ingredients (Chevanan et al., 2005; Brown et al., 2012).

Several factors affect the efficiency of manufacturing and quality characteristics of extruded fish feeds including: nutrient composition (protein, lipid, fiber and ash content); moisture content; particle size distribution; feed throughput; type of screw, screw speed and screw configuration; and temperature (Chevanan et al., 2005). Important measurements of the quality of extruded fish feeds are: apparent and true bulk density, porosity, moisture content, pellet durability, structural integrity, water stability index, water absorption index and buoyancy, but there are no standard methods to evaluate these properties (Chevanan et al., 2005). While nutrient composition of diets is important for producing high quality extruded aquaculture diets, it was not extensively studied before 2011, until Kannadhason et al. (2011) showed that protein content was an important factor in extrudate quality.

Feed ingredient properties that have the greatest effect on extrusion are moisture content, particle size and chemical composition. Starch is useful because of its ability to create expansion and cohesiveness, whereas fiber reduces expansion, cohesiveness, durability and water stability (Brown et al., 2012). Extrusion of high protein ingredients and feeds results in limited expansion and more porous and textured final extrudates, and feeds high in lipid content reduce starch gelatinization and expansion because they act as lubricants (Brown et al., 2012).

Extruding Aquaculture Feeds Containing DDGS

The feed ingredient properties that have the greatest effect on extrusion are moisture content, particle size, and chemical composition. Chemical composition of DDGS continues to evolve as the U.S. ethanol industry adopts new processes to enhance revenue from the production of ethanol and co-products. Because chemical composition of DDGS is an important factor affecting pellet and extrudate quality, it is useful to understand the variability among sources and the impact of partial oil extraction. Traditionally, the nutrient composition of DDGS (Spiehs et al., 2002; Belyea et al., 2004) contained greater concentrations of crude fat, NDF and starch, but lower crude protein content than the reduced-oil DDGS currently being produced (Kerr et al., 2013; **Table 1**). However, regardless of these changes in chemical composition, DDGS has very low starch, and relatively high crude fat and NDF content compared with other common feed ingredients, which makes it challenging when manufacturing high quality extruded aquaculture feeds containing high dietary inclusion rates of DDGS, because these chemical components have negative effects on achieving the desired pellet durability index (PDI). Therefore, binding agents must be added to achieve greater PDI in extruded fish feeds containing DDGS. **Table 2** provides a summary of various binding agents, their typical diet inclusion rates, and characteristics for use in aquaculture feeds.

Several studies have been conducted to evaluate various quality characteristics of extruded fish feeds containing various concentrations of DDGS and are summarized in **Table 3**. Nine studies have evaluated the use of single screw extruders and five studies used twin screw extruders. While many physical and chemical characteristics of diets were reported in these studies, ingredient composition, type of binder used, DDGS inclusion rate, were included along with unit density and pellet durability index (PDI), because these are major factors contributing to quality aquaculture feeds. In general, including DDGS in these formulations created challenges, particularly at high-diet inclusion rates, but the addition of various binding materials generally improved unit density and PDI. Most diets evaluated in these studies, except for those reported by Chevanan et al. (2009) and Rosentrater et al. (2009b), had extruded DDGS diets with unit densities less than 1.0 g/cm^3, which indicates they floated. Furthermore, pellet durability index of extruded diets in the majority of studies was greater than 85 percent in diets containing up to 60 percent DDGS, and only two studies (Chevannan et al., 2008; Kannadhason et al., 2011) reported decreases in PDI as dietary DDGS inclusion rates increased. Specifically, Chevanan et al. (2007b) showed that high-quality (high PDI and low unit density) pellets can be produced when adding 60 percent DDGS to a corn, soy, fish meal diet using whey as a binder. Kannadhason et al. (2011) evaluated the effects of various starch sources with various proportions of DDGS and protein on various physical properties of single screw extrudates and found increasing the levels of DDGS and protein led to an increase in unit density and pellet durability. Increasing moisture content generally increases PDI, but decreases unit density. Increasing die temperature decreases PDI and unit density, but increasing the L:D slightly improves these pellet quality indicators. Therefore, acceptable extruded fish feeds, containing relatively high concentrations of DDGS and a pellet binder (whey or starch), can be produced by properly managing moisture content, die temperature and L:D of the die during the extrusion process.

Hiltonet al. (1981) evaluated the effects of both extrusion processing and steam pelleting on pellet durability, water absorption and physiological response of trout. They determined extruded pellets absorbed more water, had better water stability and were more durable than the steam pellets.

Table 1. Comparison of average, range, and changes in nutrient composition of DDGS resulting from partial oil extraction (dry matter basis)

Nutrient	Corn DDGS (>10 % oil)	Corn DDGS (<10 % oil)[1]
Moisture %	11.1 (9.8-12.8)[1]	12.5 (10.0-14.5)
Crude protein %	30.8 (28.7-33.3)[1,2]	31.2 (29.8-32.9)
Crude fat %	11.5 (10.2-12.6)[1,2]	8.0 (4.9-9.9)
NDF %	41.2 (36.7-49.1)[1]	32.8 (30.5-33.9)
Starch %	5.3 (4.7-5.9)[2]	2.4 (0.8-3.4)
Ash %	5.2 (4.3 – 6.7)[1,2]	5.4 (4.9-6.1)

[1]Spiehs et al. (2002); 2Belyea et al. (2004); 3Kerr et al. (2013)

Table 2. Common binding agents used in steam pelleted aquaculture feeds (adapted from Lovell, 1989)

Binding agent	Amount added to diets %	Comments
Carboxymethylcellulose	0.5 to 2.0	Good binder but expensive
Alginates	0.8 to 3.0	Good binder in moist feeds and must combine with divalent or polyvalent cations to be effective
Polymethylocarbamide	0.5 to 0.8	Very good binder, not approved by U.S. FDA, and unpalatable for some fish
Guar gum	1.0 to 2.0	Good binder but expensive
Hemicellulose	2.0 to 3.0	Moderate binder at a moderate cost
Lignin sulfonate	2.0 to 4.0	Good binder at a moderate cost
Sodium and calcium bentonite	2.0 to 3.0	Less effective than organic binders
Molasses	2.0 to 3.0	Moderate binder with nutritional value
Whey	1.0 to 3.0	Moderate binder with nutritional value
Gelatinized starches from corn, potato, sorghum, rice, and cassava	10 to 20	Good binders with nutritional value but must be added at high diet inclusion rates to be effective
Wheat gluten	2.0 to 4.0	Good binder but expensive

Table 3. Summary of extrusion type, diet composition, binder, DDGS concentration of extruded aquaculture feeds on unit density and pellet durability index of extruded feeds

Extrusion type Reference Fish species, if applicable	Diet Composition	Binder	DDGS %	Unit Density, g/cm3	PDI %
Single screw extrusion					
Chevannan et al. (2008)	Soy flour, corn flour, fish meal, mineral and vitamin premix	None	20	0.96	89
			30	0.93	65
			40	0.93	56
Chevanan et al. (2009)	Soy flour, corn flour, fish meal, mineral and vitamin premix	Whey	20	1.05	94
			30	1.07	94
			40	1.06	94
Chevanan et al. (2007a)	Soy flour, corn flour, fish meal, mineral and vitamin premix	Whey	40	0.88 – 1.03	85 – 98
Kannadhason et al. (2011) Tilapia and channel catfish	Soy flour, fish meal, whey, mineral and vitamin premix	Cassava starch	20	0.78	82
			30	0.88	84
			40	0.86	86
		Corn starch	20	0.90	85
			30	0.94	76
			40	0.91	63
		Potato starch	20	0.79	82
			30	0.88	85
			40	0.90	87
Rosentrater et al. (2009a) Tilapia	Corn starch, soybean meal, fish meal, whey, mineral and vitamin premix	Corn starch	20	1.03	71
			25	1.01	91
			30	1.02	70
Kannadhason et al. (2009)Tilapia	Soybean meal, fish meal, whey, mineral and vitamin premix	Tapioca starch	20	0.94	90
			25	0.93	96
			30	0.99	84
Rosentrater et al. (2009b)Tilapia	Soybean meal, fish meal, whey, mineral and vitamin premix	Potato starch	20	0.85	89
			25	0.97	96
			30	0.93	82
Ayadi et al. (2013) Nile tilapia	Corn flour, fishmeal, 30, 40, or 50 percent soybean meal and mineral vitamin premix	Whey	20	0.97	94
			30	0.89	95
			40	0.90	95
Ayadi et al. (2016) Juvenile Nile tilapia	Soybean meal, corn, fishmeal, whey, mineral and vitamin premix	70 percent amylose 30 percent amylopectin	20	0.97	93
		100 percent amylopectin	20	0.99	94

Table 3. Summary of extrusion type, diet composition, binder, DDGS concentration of extruded aquaculture feeds on unit density and pellet durability index of extruded feeds					
Extrusion type Reference Fish species, if applicable	**Diet Composition**	**Binder**	**DDGS %**	**Unit Density, g/cm3**	**PDI %**
Twin screw extrusion					
Chevanan et al. (2007b)	Soy flour, corn flour, fish meal, mineral and vitamin premix	Whey	20	0.24	98
			40	0.34	98
			60	0.61	97
Kannadhason et al. (2010)Tilapia	Soybean meal, corn, fish meal, soybean oil, mineral and vitamin premix	Whey	0	0.73	93
			17.5	0.90	97
			20	1.00	97
			22.5	0.88	95
			25	0.87	97
			27.5	0.92	93
Ayadi et al. (2011) Rainbow trout	Fish meal, corn gluten meal, whole wheat flour, menhaden oil, Celufil, mineral and vitamin premix	None	0	0.93	83
			10	0.89	91
			20	0.89	89
			30	0.94	88
			40	0.97	92
			50	0.99	95
Fallahi et al. (2011) Nile tilapia	Soybean meal, corn flour, fish meal, soybean oil, mineral and vitamin premix	Whey	20	0.92 – 1.02	94 – 99
Fallahi et al. (2012) Yellow perch	High protein DDG, fish meal, corn gluten meal, whole wheat flour, oils, crystalline amino acids, mineral and vitamin premix	Carboxymethylcellulose	31	0.66	99
	As above + fermented high protein soybean meal		31	0.60	99
	As above + soy protein concentrate		31	0.50	99

In summary, there are significant economic advantages of using high-diet inclusion rates of DDGS in aquaculture diets, but achieving desired PDI often limits DDGS use in commercial feed mills. Several scientific studies have evaluated the use of various pellet binder, single vs. twin screw extrusion processes and dietary DDGS inclusion rates on unit density and PDI of extrudates. There are numerous interactions among extruding variables that contribute to inconsistent PDI values, but several studies have demonstrated adequate unit density and PDI can be achieved when extruding DDGS diets. More research is needed to optimize chemical composition of aquaculture diets containing DDGS for various aquaculture species.

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