

profiles are critical to fish feed formulation. To date, DEXN has generally been included in fish feed at low levels, and it is often incorporated with supplemental lysine and methionine. DEXN can be more palatable to fish and more cost efficient compared with other protein sources (Liu et al 2009).

Research by the National Research Council (1993) has determined that various species need different amounts of protein to grow well. According to Lovell (1989), the protein requirements for aquaculture fish depend on the species and can vary from 26 to 50%. Metabolic demands of fish must be supplied by amino acids (Gunnarsson et al 2009). Lack of essential amino acids such as arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine can result in lower feed efficiency ratios, which will subsequently reduce fish growth performance (Anderson et al 1992). Abdel-Hewah et al (2010) studied that dietary protein contents of fish feed for different species and determined that the optimum dietary protein to reach an optimum growth performance also depended on the hygiene and environmental conditions of the aquaculture facility.

Although DEXN is a good source of protein, its lack of essential amino acids has limited its inclusion in aquafeeds. In several studies, inclusion of DEXN in the main protein source in fish feeds for various species, with and without incorporation of supplemented essential amino acids, was investigated, and few ad-

verse effects on growth performance were observed. For example, juvenile channel catfish with 30–40% DEXN (Williamson and Li 2008; Liu et al 2009) and Nile tilapia with 20–35.5% DEXN (Wu et al 1996; Cople et al 2004; Liu et al 2009).

Moreover, the effect of DEXN inclusion on disease resistance in catfish and tilapia has been evaluated by Liu et al (2009). They found that with 60% DEXN plus lysine, catfish species had good growth performance and demonstrated great resistance to at least one major disease, whereas catfish raised on a diet without DEXN had lower infection than those raised on the DEXN-based feed (MAHMOUD 2012). Overall, when including plant protein sources in aquafeeds, factors such as protein quality, processing conditions, nutritional constraints, and economics should be taken into consideration (Tacon 1997).

Most aquafeeds are produced by extrusion processing. Extrusion is a process for shaping dough by forcing it through a narrow die or orifice. The ingredients are cooked inside the extruder barrel chamber, and then the cooked dough is extruded and shaped in the die (Folk-Sorensen et al 2005). An extruder is essentially a pump, simultaneously transferring, mixing, shearing, stretching, and shaping ingredients inside its barrel at an increasing rate of pressure during a short period. It is also a homogenizer, comminuting the chemical composition within the ingredients (Riaz 2006). The extent of heating, mixing, and compressing inside the barrel of the extruder depends on the raw ingredient properties, processing conditions used, type of extruder, geometry, and operating conditions. In fact, screw speed (NS), screw configuration, die shape, barrel temperature, moisture content of feed, and the rate of feeding all influence the residence time within the extruder, thus material throughput, and mechanical and thermal energy inputs to the machine. All of these changes affect the rheological and physicochemical properties of the dough made inside the barrel, as well as the properties of the extrudates upon the exit (Riaz 2006; Moryet et al 1999).

There are two main types of extruders: single screw and twin screw, each of which can be further classified based on different geometric and operational characteristics. In general, twin-screw extruders offer more flexibility, can process a wider variety of ingredients, and provide better mixing of steam and water compared with single-screw extruders. More specific details regarding extruders are reported by Riaz (2006). Both chemical and physical changes happen during the travel of the dough from the feeding zone to the die exit. Chemical changes can be explained by structural modifications of starch and protein macromolecules as a result of interactions between water, starch, protein, and heat. Physical changes are a result of extrudate expansion because of water evaporation during the exit (Moryet et al 1999). Thus, the role of water is highly important in both chemical and physical phenomena. According to Friess et al (1992), protein denaturation and starch gelatinization are the result of water content,

TABLE 1
Ingredient Components of the Feed Blend Used (% wet basis)
and Resulting Chemical Composition (% dry basis)

Components	% Wet Basis
Extruded dried protein with vitamin ¹	100
Soybean meal ²	100
Crude fish ³	100
Wheat ⁴	0
Potassium metasilicate ⁵	10
Mineral premix ⁶	1
Soybean oil ⁷	1
Total	1000
Chemical Composition	% Dry Basis
Crude protein	64.22
Crude fat	5.76
Crude fiber	6.12
ASH	60.66
Cellulose (acid)	56.80

¹ Dakota Extruded, Brownsville, TX, U.S.A.

² 44.7% protein, solvent extracted, Midwestern Feeds, Brown, MO, U.S.A.

³ 60% protein, corn flour, Cargill Dry Core Ingredients, Paris, IL, U.S.A.

⁴ Dehydrated wheat, Bunge, Coonara, Australia, 50%, U.S.A.

⁵ Special Keltol, Kelco Feeds, Houston, TX, U.S.A.

⁶ A-20-E-R, mineral premix, CIBA Nutrition, Basel, CH, U.S.A.

⁷ 100% pure soybean oil, Cargill Supply Distributing, Brown City, IN, U.S.A.

TABLE 2
Experimental Design^a

Treatment	Control Treatment			Treated Treatment		
	Screw Speed	Extruder Water	Conditioner Steam	Screw Speed (rpm)	Extruder Water (kg/min)	Conditioner Steam (kg/min)
1	1	0	0	1000	0.225	0.22
2	1	0	0	1000	0.225	0.22
3	0	1	0	1000	0.225	0.22
4	0	1	0	1000	0.225	0.22
5	0	0	1	1000	0.225	0.22
6	0	0	1	1000	0.225	0.22
7 (0.2%)	0	0	0	1000	0.225	0.22
8 (0.2%)	0	0	0	1000	0.225	0.22
9 (0.2%)	0	0	0	1000	0.225	0.22
10 (0.2%)	0	0	0	1000	0.225	0.22

^a The control (control) experimental design consisted of two screw speed levels, two extruder water levels, two conditioner steam levels, and one screw speed therefore all of these levels, treated as CPD significant five factors, the 10-level factorial combinations.

Moisture Effects On Mechanical Propertie

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