Maize Dried Distillers Grains with Solubles (DDGS) – A New Alternative Ingredient in Aquafeeds

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As global consumer demand for fish and shellfish products continues to increase, and the aquaculture industry continues to grow to meet this demand (FAO 2009), demand for traditional feed ingredients in aquafeeds, such as fishmeal, is also increasing (Tacon and Metian 2008). Historically fishmeal has been used as a major component in most aquaculture diets because it has a high protein content, well-balance profile of highly digestible amino acids, substantial amounts of essential fatty acids, and high digestible energy, vitamin, and mineral content (Abdelghany 2003). However, the decreased availability of fishmeal and increasing cost have caused nutritionists and feed manufacturers to seek less expensive, high quality alternative ingredients, primarily plant-based meals, to partially or completely replace fishmeal in aquafeeds. Unfortunately, replacement of fishmeal with plant-based feed ingredients often results in reduced growth performance (Mbahinzirek *et al*. 2001, Sklan *et al*. 2004, Gatlin *et al*. 2007), unless an adequate amount of other ingredients or dietary supplements are added to meet nutrient requirements, especially amino acids. Therefore, one of the biggest challenges limiting the successful use of alternative plant-based ingredients in aquafeeds is having knowledge of amino acid composition and digestibility.

FIGURE 1. *Maize DDGS is a high-energy, mid-protein, high digestible phosphorus ingredient that offers significant opportunities for use in aquafeeds to reduce feed costs and achieve satisfactory growth performance.*

The extensive growth in the U.S. fuel ethanol industry in recent years has led to the production of over 36 million t of distillers grains available for use in animal feeds (Renewable Fuels Association 2011). Maize dried distillers grains with solubles (DDGS), the predominant co-product from the dry-grind segment of ethanol manufacture, can be classified as a highly digestible energy and phosphorus, mid-protein ingredient. Other grains (e.g., wheat, sorghum and barley) can also be used or blended with maize to produce DDGS, but maize DDGS is the most common in the USA. During dry-grind ethanol production, one bushel (25.4 kg) of maize yields 10.6 L of ethanol and 7.7 kg DDGS (Bothast and Schlicher 2005, Wheals *et al*. 1999). The American Association of Feed Control Officials (AAFCO 2011) defines DDGS as "the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of a grain or a grain mixture by condensing and drying at least ¾ of the solids of the resultant whole stillage and drying it by methods employed in the grain distilling industry. The predominating grain shall be declared as the first word in the name." The beverage ethanol industry, such as whiskey distilleries, also produces DDGS (< 1 percent of total DDGS production), but it is often dark, tends to be more variable in nutrient content and has lower levels of digestible nutrients than DDGS from fuel ethanol plants.

Historically, the majority of wet and dried distillers grains produced in the USA has been fed to cattle, but in recent years, large quantities are being fed to swine and poultry (20 to 30 percent of total production) because of its high nutritional and economic value compared to maize, soybean meal and other competing ingredients. It is an economically attractive feed ingredient because it is often priced at 75 to 80 percent of the value of maize, but contains three times more nutrients than maize. Depending on the animal species, it has an energy value greater than corn for ruminants, equal to corn for swine and about 85 percent the value of corn for poultry. The lower energy value for monogastric species is due primarily to its moderate fiber content.

Currently less than 1 percent of the total distillers grains produced are being used in aquafeeds. Therefore, there are tremendous opportunities to use DDGS to a much greater extent as an energy, protein, and digestible phosphorus source. Using DDGS can reduce feed costs and reduce the reliance on fishmeal and other expensive dietary ingredients in aquafeeds.

How Does DDGS Compare to Other Maize Co-products?

There is often confusion among nutritionists and feed producers regarding the nutritional similarities and differences among maize co-products. Maize DDGS is produced through a dry-grind process that involves grinding and fermenting the entire kernel, whereas wet milling involves separation of the maize kernel into four major products (on a dry matter basis): starch (67.2 percent), gluten feed (19.6 percent), gluten meal containing 60 percent protein (5.7 percent), and germ containing 50 percent corn oil (7.5 percent). Maize gluten feed and meal are feed co-products of the wet milling process. Starch and oil are used for human consumption or biofuels production. In contrast, brewers dried grains are a co-product of beer manufacturing, consisting of the dried residue of barley malt and other grains that have been used to provide maltose and dextrins for fermentation. Use of brewers dried grains in monogastric animal diets is limited because it has a relatively high fiber level (18 to 19 percent).

As a result of the different grains and processes used to produce co-products, they are nutritionally different. The primary nutritional advantages of DDGS are its high oil and digestible phosphorus content compared to corn gluten feed, corn gluten meal and brewers dried grains. The digestible energy content of DDGS is much higher than corn gluten feed and brewers dried grains, comparable to corn, but less than corn gluten meal for monogastric species. Amino acid levels of DDGS are lower than in corn gluten meal and corn germ meal, and are comparable to corn gluten feed and brewers dried grains, but can vary in their digestibility based on the extent of heating used during drying.

> CURRENTLY LESS THAN 1 PERCENT OF THE TOTAL DISTILLERS GRAINS PRODUCED ARE BEING USED IN AQUAFEEDS. THEREFORE, THERE ARE TREMENDOUS OPPORTUNITIES TO USE DDGS TO A MUCH GREATER EXTENT AS AN ENERGY, PROTEIN, AND DIGESTIBLE PHOSPHORUS SOURCE. USING DDGS CAN REDUCE FEED COSTS AND REDUCE THE RELIANCE ON FISHMEAL AND OTHER EXPENSIVE DIETARY INGREDIENTS IN AQUAFEEDS.

Nutritional Value of DDGS in Aquafeeds

Maize DDGS is a high energy, mid-protein, highly digestible phosphorus ingredient. However, nutrient content and digestibility varies among sources (Spiehs *et al*. 2002). Most energy in DDGS is derived from a relatively high crude fat content, with lesser amounts contributed by residual starch, fiber and protein.

The crude fat content of DDGS is approximately 10 percent (as fed-basis) and the total fat is comprised of linoleic acid (55.7 percent), linolenic acid (7.8 percent) and DHA (0.14 percent). As a result, DDGS has a high omega-6 to omega-3 ratio. During the past two years, over 50 percent of the 207 ethanol plants in the USA are now extracting some of the oil before making DDGS because marketing crude corn oil is highly profitable. Therefore, the crude fat content of DDGS has become more variable (5 to 12 percent) and reduced-oil DDGS will result in less digestible energy.

The starch content of DDGS is low, ranging from 1.1 to 7.9 percent (on a dry matter basis), depending on the extent of starch fermentation to ethanol (Anderson *et al*. 2012). It is not known if starch in DDGS is digestible or in the form of resistant starch.

DDGS has crude fiber (6.6 percent), ADF (11.1 percent), NDF (37.6 percent) and TDF (31.8 percent) and the majority (96.5 percent) of TDF is insoluble fiber (Urriola *et al*. 2010). Neutral detergent fiber content is one of the most variable nutritional components in DDGS and it is unclear whether this is because of high variability in analytical measurement among laboratories or if fiber content is truly this variable among DDGS sources. Fiber digestibility of DDGS has not been determined in fish, but studies conducted with other monogastric species indicate that fiber digestibility can be significant, but variable. Fish with greater ability to utilize high fiber diets perform well at high dietary DDGS inclusion rates compared with other species with very little lower gut fermentation.

Despite the relatively high crude protein content of DDGS (27 percent), lysine, methionine, threonine, and tryptophan concentrations are relatively low in relation to the amino acid requirements of fish. Furthermore, lysine is the most variable of all amino acids among DDGS sources and its digestibility depends on the extent of heating during DDGS production. As a result, fish diets requiring high protein levels must be supplemented with crystalline amino acids when large amounts of DDGS are added. Apparent digestibility of amino acids in DDGS have been determined in rainbow trout diets and are relatively high (> 90 percent for all essential amino acids except threonine) but amino acid digestibility has not been determined for other fish species (Cheng and Hardy 2004a).

The phosphorus content in DDGS (0.75 percent) is greater than other plant-based ingredients and much of the phytate phosphorus is released during corn fermentation in ethanol production, making it highly digestible for monogastric species (Stein and Shurson 2009). However, DDGS phosphorus digestibility and availability have not been determined in fish.

Concentration of vitamins, including riboflavin, niacin, pantothenic acid, folic acid and choline, are about three times greater in DDGS than in corn (Hertrampf and Piedad-Pascual 2000). Macrominerals, such as calcium, chlorine and potassium, are in low concentration in DDGS relative to fish requirements and must be supplemented (Hertrampf and Piedad-Pascual 2000). Furthermore, zinc, iron, manganese and copper concentrations in DDGS are lower than in typical fishmeal, but requirements can easily be met with diet supplementation of these micronutrients. Limited data are available for the xanthophyll content and bioavailability in DDGS, or its impact on flesh color in fish, but the few values reported in the literature indicate that it can vary from 3.5 to 29.8 mg/kg.

One of the distinct advantages of DDGS compared to other plant-based ingredients is that it does not contain antinutritional factors, such as those found in soybean meal (trypsin inhibitors; Wilson and Poe 1985, Shiau *et al*. 1987), rapeseed meal (glucosinolates and erucic acid) and cottonseed meal (gossypol; Jauncey and Ross 1982, Robinson 1991). DDGS contains low levels of phytate compared with other plant-derived feed ingredients.

A Summary of Research Results Using DDGS in Aquafeeds

• Channel Catfish *Ictalurus punctatus*

Multiple studies (Tidwell 1990; Webster *et al*. 1993; Robinson and Lee 2008; Zhou *et al*. 2010) determined that relatively high (30 percent) dietary inclusion rates of DDGS can

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be used without adversely affecting performance. Growth, feed conversion, protein retention, survival, carcass composition, and organoleptic properties of fillets were not affected by diet at this inclusion level of DDGS. One study (Robinson and Lee 2008) suggested that supplementation with lysine at 30 percent DDGS is necessary to support satisfactory growth. Body fat increases for fish fed a DDGS diet compared to fish fed a control diet (Robinson and Li 2008; Lim *et al*. 2009). Overall, DDGS is considered an acceptable ingredient in diets for channel catfish (Tidwell *et al*. 1990, Webster *et al*. 1991).

• Rainbow Trout *Oncorhynchus mykiss*

Apparent digestibility coefficients of nutrients in DDGS for rainbow trout are high (Cheng and Hardy 2004a). However, one of the limitations of using DDGS in rainbow trout diets is the relatively low concentrations of lysine and methionine, which are much lower than in fishmeal. Therefore, supplementation with synthetic lysine and methionine is necessary to achieve satisfactory growth performance. DDGS, without synthetic lysine and methionine supplementation, can be added to the diet up to 15 percent, or replace up to 50 percent of the fishmeal to achieve satisfactory growth performance (Cheng and Hardy 2004a). At 50 percent replacement of fishmeal with DDGS, performance can improve with methionine supplementation (Cheng et al. 2003). DDGS can be included at 22.5 percent, or replace up to 75 percent of fishmeal in rainbow trout diets, with both lysine and methionine supplementation.

Phytase supplementation (up to 1200 FT/kg diet) improves apparent digestibility of nutrients (dry matter, fat protein, energy, amino acids, minerals) in diets containing 30 percent DDGS (Cheng and Hardy 2004b). For diets with 15 percent DDGS and supplemented with lysine, methionine and phytase, the increased availability of minerals suggests that trace mineral supplementation could be reduced when phytase is added to diets.

For diets containing maize gluten meal and maize DDGS, the extent of fishmeal replacement in the diet depends on the ratio of DDGS to gluten meal (Stone *et al*. 2005). Up to 18 percent dietary inclusion of these maize co-products can replace about 25 percent of the fishmeal in practical diets without adversely affecting growth performance. Extrusion of diets containing maize DDGS and gluten meal is of no benefit compared to feeding cold-pelleted diets.

• Nile Tilapia *Oreochromis niloticus*

Feeding diets containing 32 to 40 percent protein and 16 to 49 percent DDGS result in good growth and production performance of fry (Wu *et al*. 1996). The best performance is achieved by feeding a 36 protein commercial diet or a 40 percent protein diet containing 35 percent DDGS. For fingerlings, DDGS can be included up to 29 percent in diets with 32 to 36 percent crude protein (Wu *et al*. 1994).

Diets (28 percent protein) containing 82 percent DDGS and supplemented with synthetic lysine and tryptophan provide similar performance to a 32 percent protein diet (Wu *et al*. 1997). DDGS and other maize co-products, with synthetic amino acid supplementation, can be used to formulate all plant-based diets and replace all of the fishmeal when feeding juvenile tilapia.

Growth of tilapia fed a pelleted DDGS diet is greater than that of fish fed an unpelleted DDGS diet (Tidwell *et al*. 2000). Although growth increases significantly for fish fed a commercial catfish diet, the cost of production is significantly greater ($0.66/kg gain) compared to fish fed unpelleted ($0.26/kg gain) and pelleted ($0.37/kg gain) DDGS diets.

Up to 20 percent DDGS can be added to the diet as a partial substitute for soybean meal and corn meal without affecting growth performance, body composition, hematology, immune response and resistance to a *Streptococcus iniae* infection in juvenile tilapia (Lim *et al*. 2007).

In a study where soybean meal was replaced by DDGS, the best growth rate and feed conversion of fingerling was measured in fish fed diets containing 0 percent, 25 percent, or 50 percent DDGS supplemented with phytase (Abo-State *et al*. 2009). There is no difference in apparent digestibility of diets containing as much as 27.5 percent DDGS, although feed conversion was best in fingerlings fed a diet with 17.5 DDGS (Schaeffer *et al*. 2009).

The performance of Nile tilapia fed 20 to 30 percent DDGS diets is similar. DDGS can be a highly economical feed ingredient in tilapia diets and can be used successfully at relatively high dietary inclusion rates (20 to 30 percent), if deficient amino acids are provided as supplements.

• Sunshine Bass *Morone chrysops x M. saxatilis*

The apparent digestibility of protein in sunshine bass fed practical diets containing DDGS (65 percent) was less than diets containing fishmeal (86 percent) (Thompson *et al*. 2008). The apparent digestibility of organic matter in fish fed DDGS diet (17 percent) was much lower than diets containing fishmeal (89 percent). The quality of the DDGS source used in this study was not defined, but was likely of inferior quality because the protein and organic matter digestibility was poor. These results contrast with results of other studies with other species where DDGS inclusion in diets provided satisfactory growth performance.

• Freshwater Prawn *Macrobrachium rosenbergii*

Levels of up to 40 percent DDGS can be included in practical diets for prawns stocked at a density of 19,760/ha to achieve good performance (Tidwell *et al*. 1993a, 1993b). Replacement of fishmeal with soybean meal and DDGS increases dietary levels of glutamine, proline, alanine, leucine and phenylalanine and decreases aspartic acid, glycine, arginine and lysine levels in diets (Tidwell *et al*. 1993b). Fatty acid profiles of diets also change when soybean meal and DDGS replace fishmeal. Concentrations of 16:0, 18:2*n*-6, and 20:1*n*-9 increase and concentrations of 14:0, 16:1*n*-7, 18:1*n*9, 18:3*n*-3, 20:5*n*-3, 22:5*n*-3 and 22:6*n*-3 decrease. Fishmeal can be partially or totally replaced with soybean meal and DDGS in diets for freshwater prawns raised in ponds in a temperate climate. Furthermore, DDGS can be consumed directly by juvenile prawn (> 2 g); thus, DDGS may serve a dual role as feed and pond fertilizer (Coyle *et al*. 1996).

• Pacific White Shrimp *Litopenaeus vannamei*

Poultry meal, pea meal and DDGS can replace fishmeal (up to 10 percent) as a protein source for shrimp grown in low salinity water (Lim *et al*. 2009).

Potential Benefits of DDGS to Fish Health

Addition of DDGS to aquafeeds improves the immune response and resistance to some diseases in fish. Feeding diets containing 40 percent DDGS to channel catfish provides resistance to *Edwardsiella ictaluri*, likely the result of increased hemoglobin, hematocrit, total serum immunoglobulin, and antibody titers (Lim et al. 2009). Feeding 40 percent DDGS diets to Nile tilapia improves resistance to *Streptococcus iniae* (Lim *et al*. 2007). Presumably the factors contributing to these positive responses were biologically active compounds derived from yeast, which comprises approximately 4 to 7 percent of DDGS. There is limited knowledge of the levels of these compounds in DDGS, but the β-glucan content is approximately 8 percent.

Extrusion of DDGS Diets

In general, high levels of fiber in DDGS are problematic, especially at high dietary inclusion levels. The most critical factors that affect extrusion and pellet quality of DDGS diets are die geometry, temperature, moisture content and screw speed. The addition of various binding materials improves pellet durability and unit density. Floating feeds containing 60 percent DDGS can be produced under specific conditions, resulting in feeds with a density that ranges from 0.24 to 0.61 g/cm^3 and durability from 96 to 98 percent (Chevanan *et al*. 2007, 2009).

Conclusions

Use of DDGS in aquafeeds has been limited, but there are opportunities to use the significant quantities available to achieve satisfactory performance and reduce diet costs. Dietary inclusion rates of DDGS are greatest in species with a greater ability to use fiber, but vary based on the type of ingredient substituted and amounts of other protein sources, such as fishmeal, included in the diet. Supplemental lysine, methionine and other amino acids may be needed at high dietary inclusion rates to meet requirements because DDGS has relatively low levels of these amino acids, despite having a moderately high crude protein content. High-protein aquafeeds should have lower DDGS inclusion rates unless adequate amino acid supplementation is provided. DDGS is high in linoleic acid but low in other essential fatty acids. Favorable attributes and benefits of adding DDGS to aquafeeds include:

- an excellent source of digestible phosphorus,
- no antinutritional factors,
- may provide immunological benefits, and
- high-quality pellets can be produced using appropriate extrusion conditions.

Inclusion rates of 20 to 40 percent have been successfully used in diets for channel catfish and tilapia, and diets containing 15 percent DDGS can be used for rainbow trout. More research is needed to better characterize the benefits and limitations of including DDGS in aquafeeds and to determine optimum dietary inclusion rates.

Notes

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