Chapter 25

Use of DDGS in Aquaculture Diets

Introduction

Aquaculture is one of the fastest growing food producing industries in the world. Historically, fish meal has been used as major component in most aquaculture diets because of its high protein content, well-balance profile of highly digestible amino acids, significant amounts of essential fatty acids, high digestible energy content, as well as its vitamin and mineral content (Abdelghany, 2003). However, the decreased availability of fish meal 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 fish meal in aquaculture feeds. Unfortunately, replacement of fish meal 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 these diets in order to meet nutrient requirements, especially amino acids. However, when two or more complimentary plant protein sources (DDGS and soybean meal) are added to the diet, the potential exists to replace all of the fish meal in the diet. Therefore, one of the biggest challenges limiting the successful use of alternative plant-based ingredients in aquaculture feeds is having knowledge of amino acid composition and digestibility.

Aquaculture, like livestock and poultry production around the world, is also subject to increasing environmental regulations. The two nutrients of greatest concern in fish farm effluent water are nitrogen and phosphorus. Soybean meal and DDGS are relatively high in protein, but much lower in phosphorus than fish meal. As a result, substituting DDGS and soybean meal for fish meal in aquaculture diets reduces the total phosphorus level in the diet and lowers the level of phosphorus in fish farm discharge water.

Nutritional Value of DDGS in Aqua Feeds

Corn DDGS is a high energy, mid-protein, high digestible phosphorus ingredient. However, nutrient content and digestibility can vary significantly among sources (Spiehs et al., 2002). Most of the energy in DDGS is derived from its relatively high crude fat content, with lesser amounts contributed from residual starch, fiber, and protein.

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

Starch content in DDGS is low and can range from 1.1 to 7.9 % (dry matter basis) depending on the extent of starch fermentation to ethanol (Anderson et al., 2012). It is not known if the starch present in DDGS is digestible or in the form of resistant starch.

The average values of crude fiber, ADF, NDF, and TDF content in DDGS are 6.6, 11.1, 37.6, and 31.8% respectively, and the majority (96.5%) 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 due to high variability in analytical measurement among laboratories or if maize fiber content truly is 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. It appears that fish with greater ability to utilize high fiber diets perform well at high dietary DDGS inclusion rates compared with some species with very little lower gut fermentation.

Despite the relatively high crude protein content in DDGS (27%), lysine, methionine, threonine, and tryptophan concentrations are relatively low relative to the amino acid requirements of fish. Furthermore, lysine is the most variable of all amino acids among DDGS sources, and its digestibility is also variable due to the extent of heating during the DDGS production process among sources. As a result, fish diets requiring high protein levels must be supplemented with crystalline amino acids when significant amounts of DDGS are added. Apparent digestibility of amino acids in DDGS have been determined in rainbow trout diets, and are relatively high (> 90% 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%) is higher 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 values have not been determined in fish.

Vitamins, including riboflavin, niacin, pantothenic acid, folic acid, and choline are about three times higher in DDGS than found in corn (Hertrampf and Piedad-Pascual, 2000). Macrominerals such as calcium, chlorine, and potassium are found in low amounts 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 typically found in fish meal, but requirements can easily be met with diet supplementation of these micronutrients. Limited data are available regarding 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 be highly variable and range from 3.5 to 29.8 mg/kg.

One of the distinct advantages of DDGS compared with other plant-based ingredients is that it does not contain anti-nutritional factors 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), and contains low levels of phytate compared with other plant derived feed ingredients.

Channel Catfish (*Lctalurus punctatus*)

Tidwell et al. (1990) conducted an experiment over an 11-week period where channel catfish fingerlings were fed diets containing 0, 10, 20, and 40% DDGS by replacing some of the corn and soybean meal. After the 11-week feeding period, there were no significant differences in individual fish weight, percentage survival, feed conversion, or protein efficiency ratio (PER) among dietary treatments (**Table 1**). However, fish fed the 20% DDGS diet were slightly shorter in length compared to fish fed the other dietary treatments.

Table 1. Length, survival, final body weight, feed conversion, and protein efficiency ratio (PER) in channel catfish fingerlings fed diets containing four levels of distillers grains with soluble (DDGS).

	0% DDGS	10% DDGS	20% DDGS	40% DDGS
Length, mm	115.2	114.1	107.4	117.8
Survival, %	67.5	70.0	80.0	90.0
Final body weight, g	17.3	15.2	13.2	16.5
Feed/gain	2.85	3.23	3.20	2.60
PER	0.99	0.87	0.88	1.05

In a study conducted by Webster et al. (1993), cage reared juvenile catfish were fed diets containing 0, 10, 20, or 30% DDGS which partially replaced corn and soybean meal in the diets. There were no differences in individual fish weights, survival, feed conversion, carcass composition, carcass waste (head, skin, viscera), and organoleptic properties of the fillets among dietary treatments. Results from this study indicate that up to 30% DDGS can be added to channel catfish diets with no negative effects on growth performance, carcass composition, or flavor qualities of the fillets. Therefore, DDGS is considered an acceptable ingredient in diets for channel catfish (Tidwell et al., 1990; Webster et al., 1991).

Robinson and Li (2008) conducted two experiments to evaluate the use of cottonseed meal, DDGS, and synthetic lysine as replacements for soybean meal in channel catfish diets. Fish fed the DDGS and soybean meal diet had higher (experiment 1) or similar (experiment 2) weight gain, and feed conversion ratio was lower in both experiments, than fish fed the control diets. Body fat tended to increase for fish fed the DDGS and soybean meal diet compared to fish fed the control diet. Results from this study suggest that adding up to 30% DDGS to channel catfish diets supports satisfactory growth performance when the diet is supplemented with synthetic lysine.

Diets containing 0, 10, 20, 30, and 40% DDGS with supplemental synthetic lysine to partially replace soybean meal and corn meal on an equal protein basis were fed to juvenile catfish (13 g body weight) for 12 weeks (Lim et al., 2009). Growth performance and feed conversion were similar among dietary treatments, but body fat increased and body moisture decreased when fish were fed diets containing DDGS compared to those fed the control diet.

Similarly, Zhou et al. (2010) replaced soybean meal and maize meals in juvenile hybrid catfish (channel catfish × blue catfish *I. Furcatus*) and observed that diets containing 30% DDGS provided good growth, feed conversion, and protein retention. Overall, the results of these studies indicate that relatively high (30%) dietary inclusion rates of DDGS can be used without adversely affecting survival growth or feed conversion.

Rainbow Trout (*Oncorhynchus mykiss*)

Feed for carnivorous fish like rainbow trout (*Oncorhynchus mykiss*) requires large amounts of fish meal (300 to 500 g/kg diet). As a result, when fish meal prices are high, nutritionists begin evaluating alternative protein sources such as DDGS to use as partial replacements for fishmeal.

Cheng and Hardy (2004a) reported they had unpublished data indicating apparent digestibility coefficients of nutrients in DDGS were high for rainbow trout. Apparent digestibility coefficients for crude protein (90.4%), essential amino acids (> 90% except for threonine which was 87.9%), and non-essential amino acids (> 86% except for cystine which was 75.9%) for the DDGS source they evaluated. However, they pointed out one of the limitations of using DDGS in rainbow trout diets is the relatively low concentration of lysine and methionine, which are much lower than found in fish meal. Therefore, supplemental synthetic lysine and methionine is necessary in order to achieve satisfactory growth performance. As a result, Cheng and Hardy (2004a) conducted a 6-week feeding trial to determine the effects of feeding diets containing 0, 7.5, 15, and 22.5% DDGS, with or without synthetic lysine and methionine supplementation, to assess the nutritional value of DDGS in diets for 50 g rainbow trout. Survival rate of all fish used in the study was 100%. Fish fed diets containing 15% DDGS, or replacing 50% of fish meal on an isonitrogenous and isocaloric basis, had similar weight gain and feed conversion compared to fish fed the fish meal-based diet. These results indicate that DDGS, without synthetic lysine and methionine supplementation, can be added to the diet up to 15%, or replace up to 50% of the fish meal to achieve satisfactory growth performance. In addition, DDGS could be used at the 22.5% dietary inclusion level, or replace up to 75% of the fish meal in rainbow trout diets with lysine and methionine supplementation. Furthermore, Cheng et al. (2003) showed that when soybean meal, DDGS, and 1.65 g/kg of methionine hydroxyl analogue (MHA) were added to rainbow trout (50 g in initial body weight) diets to replace 50% of the fish meal, weight gain, feed conversion, crude protein, and phosphorus retention were significantly improved compared to fish fed an equivalent diet without MHA supplementation.

Cheng and Hardy (2004b) also evaluated the effects of phytase supplementation on apparent digestibility coefficients of nutrients in DDGS, as well as growth performance and apparent nutrient retention of rainbow trout fed diets containing DDGS, phytase, and varying levels of a trace mineral premix. Apparent digestibility coefficients in DDGS diets (30% inclusion rate) containing different levels of phytase (0, 300, 600, 900, and 1200 FTU/kg of diet) ranged from 49 to 59% for dry matter, 79 to 89% for crude fat, 80 to 92% for crude protein, 51 to 67% for gross energy, 74 to 97% for amino acids, and 7 to 99% for minerals. When DDGS was included at a rate of 15% of the diet, and supplemented with lysine, methionine, and phytase, but different levels of trace mineral premix, there were no differences in weight gain, feed conversion, survival, body composition, and apparent nutrient retention among fish fed all diets, except for fish fed a diet without trace mineral supplementation. These results suggest that phytase was effective in releasing most of the minerals, and that trace mineral supplementation could be reduced when phytase is added to rainbow trout diets.

Stone et al. (2005) evaluated the effects of extrusion on nutritional value of diets containing corn gluten meal and corn DDGS for rainbow trout and observed that the extent of fish meal replacement in the diet depends upon the ratio of DDGS to corn gluten meal used. Their results suggest that up to 18% dietary inclusion of these corn co-products could replace about 25% of the fish meal in practical diets without negatively affecting growth performance. They also found that extrusion of diets containing corn DDGS and corn gluten meal was of no benefit compared to feeding cold-pelleted diets.

Tilapia (*Oreochromis niloticus*)

Tilapia (*Oreochromis niloticus*) are one of the most popular warm water fish grown throughout the world. Wu et al. (1994) reported diets containing either maize gluten meal (18%) or DDGS

(29%), and 32% or 36% crude protein, resulted in higher weight gains for tilapia (initial weight of 30 g) than fish fed a commercial fish feed containing 36% crude protein and fish meal. In a subsequent study, Wu et al. (1996) evaluated the growth responses over an 8-week feeding period for smaller tilapia (0.4 g initial weight) by feeding diets containing up to 49% DDGS, up to 42% maize gluten feed, or up to 22% maize gluten meal, at dietary crude protein levels of 32%, 36%, and 40%. Of the eight diets fed, the highest weight gain was achieved by feeding the 36% protein commercial control diet and the 40% protein diet containing 35% DDGS. The highest feed conversion was achieved by feeding the control diet (1.05) and two 40% protein diets containing either 35% DDGS (1.13) or 30% gluten feed (1.12). The highest protein efficiency ratio (weight gain/protein fed) was obtained by feeding the control diet (3.79) and two 36% protein diets containing 49% DDGS (3.71) or 42% corn gluten feed (3.55). From these results, these researchers concluded that feeding diets containing 32%, 36%, and 40% protein, and 16 to 49% protein-rich ethanol co-products will result in good weight gain, feed conversion, and protein efficiency ratio for tilapia fry.

When using DDGS in aquaculture diets, it is also important to know if lower protein diets containing higher amounts of maize co-products (DDGS, gluten feed, gluten meal) and synthetic amino acids can support satisfactory growth performance. Wu et al. (1997) evaluated growth performance of tilapia fry (0.5 g initial weight) over an 8-week feeding period by feeding diets containing 28 or 32% protein, synthetic lysine and tryptophan, and 54 to 92% maize co-products. There were no differences in feed conversion (1.76 vs. 1.43) and protein efficiency ratio (1.82 vs. 2.21) among fish fed the 28% protein diet containing 82% DDGS and synthetic lysine and tryptophan, the 67% gluten feed and 26% soy flour diet, and fish fed the control 32% protein diet (FCR = 1.25, PER = 2.05). Based upon these results, DDGS and other maize co-products can be successfully used, along with synthetic amino acid supplementation, to formulate all plant-based diets and replace all of the fish meal when feeding juvenile tilapia.

Tidwell et al. (2000) evaluated growth, survival, and body composition of cage-cultured Nile tilapia fed pelleted and unpelleted DDGS diets in polyculture with freshwater prawn. Growth rate was higher for fish fed the pelleted DDGS diet than for fish fed the unpelleted DDGS diet, but feeding a commercial catfish diet resulted in increased individual weight, individual length, growth rate, and feed conversion compared to fish fed the pelleted or unpelleted DDGS diets. Although growth was significantly increased for fish fed the commercial diet, the cost of production was significantly higher ($0.66/kg gain) compared to fish fed the unpelleted and pelleted DDGS diets ($0.26/kg gain and $0.37/kg gain, respectively). Production of prawn was 1,449 kg/ha and adding tilapia in polyculture increased total pond productivity by 81%. These researchers concluded that feeding DDGS provided economical growth of tilapia and that polyculture of tilapia may improve overall pond efficiency in freshwater prawn production ponds in temperate climates.

Juvenile Nile tilapia (9.4 g in body weight) were fed diets containing 0, 10, 20, 40% DDGS, and 40% DDGS with supplemental synthetic lysine, as partial replacements for soybean meal and corn meal, for 10 weeks, and challenged with *Streptococcus iniae* (Lim et al., 2007). Fish fed the 40% DDGS diet had the lowest weight gain, protein efficiency ratio, whole body protein, and poorest feed conversion, but supplementing the 40% DDGS diet with synthetic lysine improved weight gain and protein efficiency ratio. Feeding diets containing DDGS had no effect on number of days to first mortality, cumulative mortality 14 days post-challenge, or on hematological and immunological parameters. The authors concluded that up to 20% 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.

Abo-State et al. (2009) replaced soybean in increments between 0 and 100% with DDGS in diets, with or without phytase, and fed them to Nile tilapia (2 g initial body weight). They observed the best growth rate and feed conversion in diets containing 0%, 25%, and 50% DDGS with phytase. Schaeffer et al. (2009) conducted two trials to evaluate the use of DDGS in diets for tilapia (35 g initial body weight). Feeding diets containing 0%, 17.5%, 20%, 22.5%, 25%, and 27.5% DDGS to partially replace fish meal resulted in no difference in apparent digestibility among diets, but weight gain, feed conversion, and protein efficiency ratio (PER) were highest for fish fed the 0% DDGS diet, except the 17.5% DDGS diet which provided better feed conversion and PER. In the second, trial, Nile tilapia were fed 20%, 25%, and 30% DDGS diets with or without a probiotic, and no differences were found for weight gain, feed conversion, or PER among dietary treatments.

Results from these studies indicate that DDGS can be a highly economical feed ingredient in tilapia diets, and can be successfully be used at relatively high dietary inclusion rates if appropriate supplementation of amino acids is done.

Sunshine bass (*Morone chrysops x M-saxatilis*)

A recent study conducted by Thompson et al. (2008) evaluated digestibility of dry matter, protein, lipid, and organic matter of two fish meals, two poultry by-product meals, soybean meal, and DDGS in practical diets for sunshine bass. Fish fed DDGS had the lowest apparent digestibility coefficients for protein (65%) and organic matter (17%) compared to menhaden fish meal, which had the highest protein and organic matter digestibility coefficients (86 and 89%, respectively). The quality of the DDGS source used was not defined, but was likely of inferior quality due to the poor protein and organic matter digestibility observed in this study. These results are in contrast to results of several other studies described for other species previously where DDGS inclusion in diets provided satisfactory performance, and indicate that only high quality DDGS sources should be used in aquaculture feeds in order to achieve satisfactory growth performance and nutrient digestibility.

Freshwater Prawns (*Macrobrachium rosenbergii*)

A few studies have been conducted on feeding diets containing DDGS to freshwater prawns. In an initial study, Tidwell et al. (1993a) fed juvenile freshwater prawns (0.66 g) one of three isonitrogenous diets (29% crude protein) containing 0, 20, or 40% DDGS. There were no differences among dietary treatments for average yield (833 kg/ha), survival (75%), individual weight (57 g) and feed conversion (3.1). These results show that levels of up to 40% DDGS can be included in practical diets for prawns stocked at a density of 19,760/ha to achieve good performance.

In a subsequent study, Tidwell et al. (1993b) evaluated the effects of partially replacing fish meal with soybean meal and DDGS in diets for pond-raised freshwater juvenile prawns (0.51 g). Three diets were formulated to contain 32% crude protein and contained 15, 7.5, or 0% fish meal. Fish meal was replaced with a variable percentage of soybean meal and a fixed percentage of DDGS (40%). There were no differences among dietary treatments for average yield, survival, individual weight, and feed conversion. They noted that replacement of fish meal with soybean meal and DDGS increased dietary levels of glutamine, praline, alanine, leucine, and phenylalanine, and decreases in aspartic acid, glycine, arginine, and lysine levels in the diets. Fatty acid profiles of the diets also changed when soybean meal and DDGS replaced fish meal. Concentrations of 16:0, 18:2*n*-6, and 20:1*n*-9 increased 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 decreased. These results suggest that fish meal can be partially or totally replaced with soybean meal and DDGS in diets for freshwater prawns raised in ponds in temperate areas. Coyle et al. (1996) showed DDGS can be consumed directly by juvenile prawn (> 2 g), and that DDGS may serve a dual role as feed and a pond fertilizer.

Pacific White Shrimp (*Litopenaeus vannamei*)

A study was conducted in the low salinity inland waters in west Alabama to determine the value of replacing fish meal (10%) with poultry meal, pea meal, or DDGS in shrimp diets on a weight basis (Lim et al., 2009). No differences were observed among dietary treatments for growth rate, survival, and feed conversion, indicating that poultry meal, pea meal, and DDGS can successfully replace fish meal as a protein source for shrimp grown in low salinity water.

Potential health benefits of DDGS

Addition of DDGS to aqua feeds appears to have beneficial effects on improving the immune status and resistance to some diseases in fish. Lim and co-workers (2009) have shown that feeding diets containing 40% DDGS to channel catfish provided resistance to *Edwardsiella ictaluri* which was likely due to increased hemoglobin and hematocrit, increased total serum immunoglobulin, and increased antibody titers 21 day post-challenge. Similarly, Lim et al. (2007) showed that feeding 40% DDGS diets to Nile tilapia (*Oreochromis niloticus*) improved resistance to *Streptococcus iniae*. Researchers have presumed that the factors contributing to these positive responses are biologically active compounds derived from yeast, which comprises approximately 4 to 7% of DDGS. Limited data have been published on the levels of these compounds in DDGS, but the β-glucan content of DDGS is approximately 8%.

Extrusion of DDGS diets

In general, high levels of fiber in DDGS are problematic, especially at high dietary concentrations. Researchers have determined that the most critical factors affecting extrusion and pellet quality of DDGS diets are die geometry, temperature, moisture content, and screw speed. Addition of various binding materials improve pellet durability and unit density. Viable floating feeds containing 60% DDGS can be produced under specific conditions to result in feeds that float with unit density values from 0.24 g/cm^3 to 0.61 g/cm^3 and durability values ranging from 96 to 98% (Chevanan et al., 2007; 2009).

Conclusions

Use of DDGS in aqua feeds has been limited, but opportunities exist to use significant quantities to achieve satisfactory performance and reduce diet costs. Dietary inclusion rates for DDGS are highest in species with a greater ability to utilize fiber, but vary based on type of ingredients substituted and amounts of other protein sources (e.g. fish meal) included in the diet. Supplemental lysine, methionine, and other amino acids may be needed at high dietary inclusion rates in order to meet requirements due to the relatively low levels of these amino acids in DDGS despite having a moderately high crude protein content. High protein aquafeeds may 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. Benefits of adding DDGS to aqua feeds include: it is an excellent source of digestible phosphorus, no concerns about anti-nutritional factors, it may provide immunological benefits, and high quality pellets can be produced using the appropriate extrusion conditions. Diet inclusion rates of 20 to 40% DDGS have been successfully used in diets for channel catfish and tilapia, and diets containing 15% DDGS can be used for rainbow trout. More research is needed to better characterize the benefits and limitations of DDGS in aqua feeds and determine optimum dietary inclusion rates.

Based upon recent research studies, maximum dietary inclusion of DDGS are shown in **Table 2**. While none of the scientific reports specified the source or quality of the DDGS used, light colored, golden DDGS sources should be used to ensure the highest nutrient digestibility, especially with high dietary inclusion rates.

Table 2. Current recommendations for maximum dietary inclusion rates of DDGS for various species of fish.

Species	% DDGS	Comments
Catfish	Up to 30%	
Trout	Up to 15%	Without synthetic lysine and methionine supplementation
Trout	Up to 22.5%	With synthetic lysine and methionine supplementation
Salmon	Up to 10%	
Freshwater Prawns	Up to 40%	Can replace some or all of the fish meal in the diet
Shrimp	Up to 10%	Can replace an equivalent amount of fish meal
Tilapia	Up to 20%	Without synthetic lysine and supplementation in high protein diets (40% CP)
Tilapia	Up to 82%	With synthetic lysine and tryptophan supplementation in low protein diets (28% CP)

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