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Use of distiller's dried grains with solubles (DDGS) in rainbow trout feeds

Thomas L. Welker[a,*], Chhorn Lim[b], Frederic T. Barrows[c], Keshun Liu[d]

[a] Agricultural Research Service, United States Department of Agriculture, Hagerman Fish Culture Experiment Station, 3059F National Fish Hatchery Road, Hagerman, ID 83332, USA
[b] Agricultural Research Service, United States Department of Agriculture, Aquatic Animal Health Research Unit, 990 Wire Road, Auburn, AL 36832, USA
[c] Agricultural Research Service, United States Department of Agriculture, Bozeman Fish Technology Center, 4050 Bridger Canyon Road, Bozeman, MT 59715, USA
[d] Agricultural Research Service, United States Department of Agriculture, National Small Grains and Potato Germplasm Research Unit, 1691 S. 2700 W., Aberdeen, ID 83201, USA

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ABSTRACT

Increasing price and reduced availability of fish meal have prompted feed manufacturers and aquaculture producers to search for sustainable and economical alternative protein sources. The majority of these have come from plants, and many, for example soybean meal, have been successfully incorporated into diets of rainbow trout and other fish species. Distiller's dried grains with solubles (DDGS) is a coproduct of the grain-based fuel ethanol industry. Distiller's dried grains with solubles is moderately high in protein (typically around 300 g/kg or higher, depending on the source) and is readily available and competitively priced relative to other alternative protein sources. As with other plant protein sources, there are limits to the use of DDGS in fish feeds. Distiller's dried grains with solubles is deficient or near-deficient in some essential amino acids (EAA), but these deficiencies can be overcome through addition of synthetic EAA. Distiller's dried grains with solubles is also low in phosphorus (P) and about half is present as phytate phosphorous (phytate-P), which has limited bioavailability to trout. This is a concern for commercial hatcheries, because dietary P that cannot be utilized by trout is excreted, which can lead to eutrophication of receiving waters. Phosphorous utilization by trout fed DDGS-based diets can be improved by dietary application of phytase. In addition, high levels of indigestible structural fiber limit the incorporation of DDGS in diets of rainbow trout to approximately 100–200 g/kg. Fractionation of DDGS can reduce indigestible fiber and increase the relative protein concentration to produce a higher value product. Digestibility of these high protein fractionates is improved in trout, and higher dietary levels (up to 300 g/kg) are tolerated. The quality and nutritional composition can also vary considerably between and within DDGS grain sources and between processing plants, which further complicates incorporation of DDGS into trout diets. Production of high-value, high protein products through fractionation or other means may be needed to improve the nutritional value and consistency of DDGS for use in diets of rainbow trout.

Abbreviations: DDGS, distiller's dried grains with solubles; DE, digestible energy; DM, dry matter; EAA, essential amino acids; FM, fish meal; GE, gross energy; MDDGS, maize DDGS; MFM, menhaden FM; NSP, non-starch polysaccharide; SBM, soybean meal; SDDGS, sorghum DDGS; WDDGS, wheat DDGS.

* Corresponding author. Tel.: +1 208 837 9096; fax: +1 208 837 6047.
E-mail address: Thomas.welker@ars.usda.gov (T.L. Welker).

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1. Introduction

Fish meal (FM) is the primary protein source used in commercial rainbow trout diets. It is a complete protein source that is easily digested by trout (Gatlin et al., 2007). However, demand for FM has increased in recent years due to expansion and intensification of aquaculture production worldwide and in particular, Southeast Asia and China, and use of FM in feeds of terrestrial livestock species is also limiting the availability of FM for use in fish feeds (Naylor et al., 2009). Global demand for food-fish is projected to increase markedly in the future, and with most natural fisheries stagnating or declining, food-fish aquaculture production is predicted to experience a 100% increase by 2020 (Brugère and Ridler, 2004). This increased production will continue to place high demand on FM for use in fish feeds. In addition, profit margins for commercial aquaculture are often small with fish feed accounting for the majority (up to 60%) of the production costs (Tan and Dominy, 1997). The price of FM has nearly tripled since 2000 and is projected to rise further in the future (Delgado et al., 2002), which will increase the cost of trout feed. Therefore, trout producers and feed manufacturers have been looking for low-cost alternative protein sources with renewed interest.

The majority of alternative protein sources are derived from plants. Soybean meal (SBM) has been the most widely used alternative protein source and successfully incorporated into diets of rainbow trout and other fish species (Gatlin et al., 2007; Ayadi et al., 2011). However, there are limits to the use of SBM and other plant protein sources in fish feeds. Many plant-based protein sources contain high levels of structural fiber (Naylor et al., 2009), and anti-nutritional factors (*e.g.*, saponins, lectins, alkaloids, phytic acid) (Burrells et al., 1999), which can limit their incorporation into trout feeds. [For the purpose of this review, dietary fiber will be referred to as "structural fiber" comprised of the indigestible non-starch polysaccharide (NSP) components of plant cell walls (cellulose, hemicellulose, and lignin) (Englyst and Kingman, 1990). Derivations from this terminology will be noted]. Many potential plant protein sources are also unsuitable for use in diets of trout due to low protein content, low digestibility of one or more nutrients, low palatability, or imbalanced in essential amino acids (EAA) (Gatlin et al., 2007; Naylor et al., 2009). The latter can be overcome through the use of complimentary protein sources or EAA supplementation. Some plant protein sources possess most of the desirable characteristics, but their low and inconsistent availability or high price relative to FM has limited use in fish feeds (Naylor et al., 2009). Furthermore, the high levels of structural fiber in plant protein sources can lead to higher excretion of waste by fish. Certain minerals, such as P, are higher in plant protein sources but have limited digestibility since it is bound to phytate, which leads to elevated levels from fish excretion in effluent and negatively affect receiving waters (Cheng and Hardy, 2004a). Before plant protein sources can be utilized in trout diets, these problems must be overcome.

In recent years, increasing demand for ethanol as a fuel additive and decreasing dependency on fossil fuels have led to a dramatic increase in ethanol production from various cereal grains (maize, wheat, sorghum, rye, *etc.*) (Liu and Han, 2011). The majority of ethanol production in the United States is from maize using a dry-grind method. During a typical dry-grind method, cereal grains are ground to reduce particle size, mixed with water to produce a slurry, which is cooked, and starch in milled grains is liquefied and saccharified before undergoing yeast fermentation to produce ethanol (Singh et al., 2007). After removal of ethanol by distillation, the remaining non-fermentables are centrifuged, dewatered, mixed, and finally dried to produce the particulate co-product known as distiller's dried grains with solubles (DDGS) (Bothast and Schlicher, 2005). Distiller's dried grains with solubles is currently readily available and competitively priced (on a per unit protein basis) relative to other conventional alternative protein sources, such as SBM (Lim et al., 2011). Besides containing some unconverted starch (about 50 g/kg), DDGS is a concentrated form of non-fermentable components from the original grain and is relatively high in protein, oil, fiber, and ash (Rosentrater and Muthukumarappan, 2006; Liu, 2011). The protein content of DDGS is high enough (typically 250–450 g/kg, depending on the grain source) to be practically used as a protein source in trout diets; however, high fiber content limits the level that can be incorporated into the diet. Distiller's dried grains with solubles is also deficient in a few EAA, but these deficiencies can largely be overcome through addition of EAA during feed formulation and processing. As a fish feed ingredient, DDGS is lower in P content relative to animal ingredients. However, compared to the original grains in which approximately two-thirds of the P is present as phytate (NRC, 2011), only approximately half of the P in DDGS is present as phytate due to phytate hydrolysis by yeast during fermentation and other processing steps (Liu, 2011; Liu and Han, 2011). Phytate-P is largely unavailable to trout (Cheng and Hardy, 2004a). However, methods have or are currently being developed to increase the nutritional value of DDGS for use in fish feeds, which are discussed below. Moreover, the quality and nutritional composition can vary considerably between and within DDGS grain sources and between processing plants, further complicating incorporation of DDGS into trout diets (Ortín and Yu, 2009; Liu, 2011). With a rapid increase in DDGS supply, there is a need to enhance the nutritional value and improve the nutritional consistency of DDGS for use in diets of rainbow trout and other fish species. The nutritional value and limitations to incorporation of DDGS in diets of rainbow trout will be addressed in this review.

2. Physical properties and chemical composition of distiller's dried grains with solubles

2.1. Physical and chemical characteristics

The majority of ethanol produced from cereal grains in the United States is made from maize. Each 2.54 kg of maize fermented in a dry-grind ethanol plant produces 1.02 L of ethanol, 0.28 kg of carbon dioxide, and 0.82 kg of DDGS (Lim and Yildirim-Aksoy, 2008). This process concentrates the nutrient (protein, lipid, ash, fiber, and other nutrients) content of DDGS