Chapter 1
Nutritional Characteristics and Environmental Impacts of Corn Fermented Protein Co-Products

Introduction

Production of sustainable, nutritious, safe, and affordable food for an increasing global population is one of the great challenges faced by our global society today (Shurson, 2017). Feeding the world sustainably requires developing and adopting new innovations to improve nutritional efficiency of food production while managing arable land use, preserving water availability and quality, protecting ecosystems and biodiversity, and mitigating the effects of climate change (Shurson, 2017). Increased competition for grains and oilseeds between biofuels, food, and animal production has led to questions regarding the long-term sustainability of using these resources for production of biofuels (Shurson, 2017). However, using biofuels co-products in animal feeds can contribute to the environmental sustainability of food animal production because converting food crops into biofuels and co-products results in only a 1% to 2.5% loss in overall energy efficiency (Lywood and Pinkney, 2012). Because only the starch and other fermentable carbohydrate fraction of corn is converted to ethanol, the remaining crude protein (CP), oil, fiber, and ash is concentrated in co-products. Therefore, using corn co-products in animal feeds is an efficient way of conserving and utilizing these concentrated sources of energy and nutrients to economically produce meat, milk, and eggs in an environmentally sustainable manner.

Ethanol and co-product production in the United States has changed and increased dramatically over time. Corn co-product production began in the 19th century in the alcoholic beverage distilleries (e.g., whiskey distilleries) that used corn as a primary feedstock, with the resulting wet distillers grains being fed to dairy and beef cattle at nearby farms (Shurson et al., 2012). Up until the 1950s, wet distillers grains were considered to be mainly a protein ingredient and were used to partially replace other protein ingredients, almost exclusively in cattle feeds. In fact, very little corn distillers grains co-products were used in swine and poultry diets until the late 1990s (Shurson et al., 2012). Large wet milling facilities were built in the 1970s and 1980s to produce enough ethanol to consider using it as an additive in gasoline (Shurson et al., 2012). The wet milling process separates starch and corn oil for human food and other industrial applications, leaving behind the protein and fiber fractions. The resulting corn co-products from wet milling processes are corn gluten meal, corn gluten feed, and corn germ meal. Corn germ meal and corn gluten meal are dried and have become popular high protein ingredients in poultry diets, partly because of their concentrated pigments (xanthophylls) which provide natural coloration of egg yolks and broiler skin. In contrast, corn gluten feed has been generally marketed as a wet co-product to beef and dairy farms because these farm animal species were best able to utilize the high fiber content of this co-product. In contrast, during the 1990s to early 2000s, many farmer-owned dry grind ethanol plants were constructed to produce ethanol in larger quantities to meet increased market demands for ethanol use as an oxygenation agent in gasoline (Shurson et al., 2017). This led to the more than 200 dry grind ethanol plants producing about 38 million tons of distillers co-products today, which consist of wet and dried distillers grains without or with solubles, and corn distillers oil (CDO). Two major, and a few minor ethanol and co-product production process designs have been used and have resulted in different nutrient profiles of corn co-products. At the same time, a tremendous amount of animal nutrition research was conducted to expand the use of distillers dried grains with solubles (DDGS) into swine, poultry, and aquaculture diets in both the domestic and export markets. The ensuing educational efforts provided by leading DDGS researchers resulted in much greater DDGS use in U.S. swine and poultry diets, and nutrition consultants for the U.S. Grains Council were instrumental in helping build DDGS demand in the export market, where about 11 million tons of DDGS are exported annually to more than 60 countries.

Corn oil separation from thin stillage after fermentation began around 2005, which reduced the oil (crude fat) content of DDGS and substantially altered its nutrient profile. The reduction in DDGS oil content created concerns about continued use of DDGS in swine and poultry diets based on the assumption that the metabolizable energy (ME) content was reduced. To help DDGS users manage the increased variability in energy and digestible amino acid content among DDGS sources containing variable amounts (4 to 13%) of corn oil, poultry and swine nutrition researchers began developing ME and digestible amino acid prediction equations to accurately estimate these essential components in the specific DDGS source(s) used in feed formulations. Today, almost all U.S. ethanol plants produce DDGS with reduced oil, and the domestic and export markets continue to use DDGS in dairy, beef, swine, poultry, and aquaculture diets. The 4^{th} edition of the U.S. Grains Council DDGS User's Handbook, published in 2018, provides an excellent summary of the feeding value of DDGS with reduced oil to all species of food-producing animals.

Optimization of the efficiency of converting starch to ethanol has resulted in several ethanol facilities following an evolution process similar to that of the wet milling and oilseed processing industries in which nutrients are concentrated in co-products to improve their nutritional value and use in animal feeds. These technologies involve separating corn fiber either prior to, or after fermentation, concentrating the protein and yeast, and removal of variable amounts of corn oil to produce new types of corn co-products called corn fermented protein (CFP). The three major providers of these new proprietary technologies to produce CFP co-products are ICM, Inc., Fluid Quip Technologies, and Marquis Energy. These CFP co-products are much higher in CP (> 50%) content than conventional DDGS with reduced oil (~ 27% CP), with an estimated content of 20 to 29% spent yeast. The energy and digestible nutrient profiles of CFP co-products are also substantially different from high protein distillers dried grains (HP-DDG; 36-48%CP) sources in the market. Corn protein concentrate (CPC) contains the greatest amount of CP (>67%) and least amount of oil (0.5%) of all corn co-products and is produced using distinctly different wet milling processes than those used in dry grind ethanol facilities to produce CFP and HP-DDG. Because of the many types of high protein corn co-products available in the domestic and export market today, it is no surprise that buyers of these co-products are often confused by the terminology and the different nutritional characteristics of these types of corn co-products. Therefore, the purpose of this chapter and Chapter 2, 3, 4, and 5 are to describe the nutritional value and feeding applications of corn fermented protein (CFP) co-products in aquaculture, poultry, swine, and dairy diets, respectively. Chapter 6 provides a summary of the nutritional composition and feeding applications of HP-DDG sources, while Chapter 7 is a summary of CPC feeding applications in aquaculture and poultry diets. Last, Chapter 8 is a summary of the nutritional profiles and feeding studies involving the use of other corn co-products including corn bran and solubles (CBS), deoiled DDGS, and CDO.

Understanding Crude Protein and Amino Acids in Corn Co-Products

On the surface, feed ingredients that contain high concentrations of CP are attractive for use in all animal feeds because CP (amino acids) is the second most expensive component of animal diets after energy, and relatively low amounts of high CP ingredients are often needed to meet an animal's amino acid requirements. However, although CP, crude fat, and crude fiber continue to be universally used in pricing and trading feed ingredients around the world, the actual nutritional and economic value of feed ingredients is not based on these nutritional measures. Instead, the metabolizable energy (ME) or net energy (NE), digestible amino acids, and digestible phosphorus content are the key determinants of actual nutritional and economic value. The CP content of a feed ingredient is determined by measuring the nitrogen content and multiplying this concentration by a constant factor of 6.25, which is the inverse of the weighted average nitrogen content of 16% in proteins (Shurson et al., 2021). Nitrogen is one of the chemical components that make up amino acids, which are building blocks of proteins, and is used as a proxy to estimate the protein content of ingredients. However, the accuracy of using this universal method for estimating the actual concentrations of intact proteins is not sufficient for achieving optimal amino acid (protein) utilization in animal feeds because amino acid profiles vary, and some ingredients contain relatively high concentrations of non-protein nitrogen compounds (e.g., nucleic acids and nucleotides, some vitamins, amines, amides, and urea) that are not proteins. In addition, CP provides no information about concentrations, proportions, digestibility, and bioavailability of amino acids which is required data used in diet formulations (Shurson et al., 2021).

Soybean meal (SBM) is typically used as a global reference or "gold standard" of high protein (44-48% CP) ingredients because it contains high concentrations of all essential (indispensable) amino acids that are highly digestible (85-95%) and in balanced proportions relative to the amino acid requirements of swine, poultry, and fish when combined with a grain-based energy source. Compared with soy protein, corn protein is relatively low in lysine (Lys) content and is considered the first limiting amino acid (most likely to be deficient) in diets for monogastric animals. The Lys to CP ratio in corn co-products (2.8 to 4.0) is much less than in SBM (6.2). As a result, when corn co-products (e.g., DDGS, HP-DDG, CFP) are added to swine, poultry, and aquaculture diets as partial replacements for SBM, supplemental crystalline L-Lys HCl and other synthetic amino acids are usually required to meet digestible amino acid requirements of monogastric animals. In addition, the digestibility of Lys in corn co-products (e.g., DDGS – 65%) is generally substantially less than in SBM (90%) for swine, poultry, and fish. Because swine and poultry diets are formulated on a digestible amino acid basis, ingredients containing lower amounts of digestible Lys (e.g., DDGS) must be either added in greater amounts to meet the digestible amino acid requirements of animals, or crystalline amino acids (e.g., L-Lys HCl), which are about 98% digestible, must be supplemented. The same principle applies to other essential amino acids such as threonine (Thr), tryptophan (Trp), methionine (Met), valine (Val), and isoleucine (Ile) which are generally less digestible in corn co-products (e.g., DDGS – 73-82%) than in SBM (85-91%) for monogastric animals.

Compared with SBM, corn co-products have much greater fiber content (neutral detergent fiber – NDF; total dietary fiber - TDF) which has been shown to increase intestinal mass and mucin secretion in the intestinal tract of pigs. Threonine is the primary amino acid that comprises intestinal epithelial cells and mucin, which leads to increased endogenous losses of Thr when high fiber diets are fed to pigs. Because mucin proteins are poorly digested and amino acids are not reabsorbed, synthetic L-Thr must be added to swine diets containing > 10% corn co-products to compensate for these increased Thr losses and optimize growth performance (Mathai et al., 2016; Wellington et al., 2018). It is unclear if these responses occur in poultry and fish, but it is likely that they do, and L-Thr supplementation may be necessary to optimize growth performance and carcass composition in poultry and fish diets containing moderately high diet inclusion rates of corn co-products.

Leucine (Leu) is the most abundant amino acid in both SBM (3.62%) and corn co-products (e.g., DDGS = 5.30%), but the proportion of Leu relative to Lys in corn protein is in great excess relative of the requirements of pigs, birds, and fish. The consequences of excess Leu become more significant as the diet inclusion rates of corn co-products increase. Excess Leu increases the catabolism of Ile and Val (two other branched-chain amino acids; BCAA) because BCAA have similar molecular structures and catabolic pathways. Therefore, as SBM is partially or completely replaced with the addition of more than 20% of high CP corn co-products in swine diets, synthetic L-Val and L-Ile must be added to compensate for the negative effects of excessive Leu (Cemin et al., 2019a,b; Kwon et al., 2019; Kwon et al., 2020; Siebert et al., 2021; Zheng et al., 2016). However, the optimal digestible Val to Lys and Ile to Lys ratios have not been well defined in pigs, poultry, or fish diets. Similar evidence exists for the need to manage BCAA balance in poultry diets (Waldroup et al., 2002; Peganova and Eder, 2003; Erwan et al., 2008; Ospina-Rojas et al., 2017; Soares et al., 2019), but little is known about the role of dietary excesses of leucine and BCAA balance in aquaculture diets.

In contrast to Leu, the Trp concentrations in corn co-products are lowest of all essential amino acids. Despite its relatively low requirement for swine and poultry, Trp plays several important physiological roles including protein synthesis of lean body tissue, regulation of immune responses, and is a precursor for serotonin which regulates appetite and stress. However, to support optimal serotonin production, adequate amounts of Trp must be transported across the blood-brain barrier. Unfortunately, Trp competes with large neutral amino acids (Ile, Leu, Phe, Tyr, and Val) for transport across the blood-brain barrier. Excess large neutral amino acids (i.e., Leu) decrease serotonin concentrations suggesting that supplementing swine diets with L-Trp may overcome feed intake reductions caused by excess Leu in swine diets resulting from increasing inclusion rates of high CP corn co-products (Salyer et al., 2013; Kwon et al., 2019; Cemin et al., 2020; Kerkaert et al., 2021; Clizer, 2021). Although the ideal digestible Trp to Lys ratio has not been defined in corn co-product diets for swine, research results suggest that this ratio is greater than current NRC (2012) recommendations. It is likely that similar considerations should be given toward increasing the Trp content in poultry and aquaculture diets containing high amounts of high CP corn co-products to optimize growth and carcass characteristics.

Yeast Content of Corn Co-Products

One of the distinguishing features of CFP co-products from other corn co-products is that they contain an estimated 20 to 29% spent yeast (*Saccharomyces cerevisiae*), which is substantially greater than the estimate of 7 to 10% spent yeast in conventional DDGS sources (Shurson, 2018).

However, it is important to note that the residual spent yeast in CFP is not in a viable form that allows it to function as a direct fed microbial (DFM) or probiotic in animal feeds like viable yeast products such as active dry yeast. However, the components of yeast cell walls (mannan oligosaccharides, nucleotides, and β-glucans) have been shown to provide health benefits when fed to animals in some studies (Shurson, 2018). Prohibiting the use of antibiotics for growth promotion in animal feeds in many countries has created tremendous interest in identifying "functional" ingredients that contain compounds that may provide health benefits to food-producing animals (Shurson et al., 2021). There has been an extensive amount of research conducted in recent years to evaluate the effectiveness, magnitude, and consistency of improved growth performance responses from adding various alternative non-antibiotic feed additives to animal feeds, including viable yeast (Vohra et al., 2016) as direct fed microbials (DFM; probiotics), and yeast cell wall derivatives including mannan oligosaccharides, nucleotides, and β-glucans (Shurson, 2018). Therefore, these yeast cell wall components represent one of the potential value-added features of using CFP co-products in animal feeds. Unfortunately, the efficacy and consistency of growth and health responses from adding concentrated forms of mannan oligosaccharides, nucleotides, and β-glucans in animal feeds has been disappointing.

Although summaries of results from more than 733 published trials that evaluated the effects of feeding mannan oligosaccharides to companion animals, horses, rabbits, poultry, pigs, calves, and various aquaculture species have generally shown improvements in growth rate and feed conversion along with reductions in mortality, the responses were not consistent (Spring et al., 2015). In poultry, Hooge (2004a, b) summarized responses (16 to 44 feeding trials) from feeding mannan oligosaccharides to broilers and turkeys and reported that while the magnitude of improvement in growth rate and feed conversion was relatively small and inconsistent, more than half of the studies showed significant reductions in mortality. Miguel et al. (2004) reported that the magnitude of improvement from adding mannan oligosaccharides to nursery pig diets was greater than the responses observed in the poultry studies reported by Hooge (2004a, b), but results were inconsistent. Similarly, Torrecillas et al. (2014) reported that while several studies showed improvements in survival, disease resistance, and growth performance in fish, other studies showed no change when mannan oligosaccharides were added to diets.

The β-glucan concentration in CFP co-products has been estimated to be about 8.2 to 8.4% using the Megazyme International Yeast β-glucan assay (Shurson, 2018). Beta-glucans are classified as prebiotics, but their molecular structure varies among sources and affects their physiological functions. Vetvicka et al. (2014) reviewed studies involving the addition of β-glucans to pig diets and reported improvements in growth and various types of immune responses. However, Vetvicka and Oliveira (2014) concluded that the inconsistent growth and health responses from dietary supplementation of β-glucans in pig diets may be due to differences in their molecular structure, molecular weight, and purity. Feeding yeast β-glucans to several species of fish has been shown to improve pathogen resistance, growth performance, and survival in several studies (Ringo et al., 2012). However, it is unlikely that the concentration of β-glucans in CFP co-products is great enough, at the relatively low dietary inclusion rates of CFP co-products used in aquaculture diets to provide these health benefits.

Yeast-derived nucleotides have been shown to improve intestinal morphology and function, immune response, composition in intestinal microbiota, liver function and morphology, and growth performance (Sauer et al., 2011). However, because yeast contains other bioactive metabolites and cell wall components, it is difficult to attribute improvements in growth and immune responses solely to nucleotides (Sauer et al., 2011). Results from a summary of responses from 15 studies showed consistent improvements in immune responses, pathogen resistance, growth performance and survival from feeding various sources of nucleotides to fish (Ringo et al., 2012). However, most of the responses from 16 studies reviewed by Sauer et al. (2011) that involved feeding various concentrations of *Saccharomyces cerevisiae*, yeast culture, and commercial nucleotide products to pigs showed no effect.

Although the estimated amount of spent yeast in CFP co-products is interesting and a potential value-added benefit beyond the nutritional value of these co-products, it should not be the primary reason for their use in animal feeds for several reasons. First, residual yeast is not in a viable to function as a probiotic. Second, the concentration of spent yeast only represents about 25% of the total mass of CFP co-products, which means that much lower concentrations of individual bioactive yeast cell wall components (mannan oligosaccharides, β-glucans, and nucleotides) are present. Finally, the effectiveness, magnitude, and consistency of growth and health improvements from the addition of concentrated yeast products and their derivatives has been disappointing. To put these points in perspective, Schweer et al. (2017) summarized growth performance responses from over 2,000 research trials with swine that evaluated various non-antibiotic feed additives including oligosaccharides, prebiotics, and yeast products, and reported that only about 30% of these trials showed improvements in growth performance. Among the product categories, direct fed microbials (39.9% of trials), pharmacological levels of zinc and copper (39.2% of trials), and organic acids (31.2%) were the most consistent in improving growth rate of pigs. Of the 98 trials that evaluated yeast products, only 23.5% reported increased growth rate, 12.2% reported increased feed intake, 11.2% showed improved gain efficiency, and only 1% reported reduced mortality. It is commonly believed that alternatives to growth promoting antibiotics may be more effective when animals are under a health challenge or stressful event. However, in this scientific literature review summary, only 8.6% of the trials reported some type of health challenge, and direct fed microbials (35%) and pharmacological levels of zinc and copper (30%) were more likely to provide growth improvements than other feed additives evaluated. These results indicate that while yeast products may provide some growth performance and health benefits to weaned pigs (and poultry and fish) under certain conditions, the likelihood of achieving a consistent positive response is relatively low and the conditions that lead to positive growth responses have not been well defined.

AAFCO Definitions of Corn Co-Products

Accurate and effective communication between sellers and buyers regarding the nutritional composition and feeding value of feed ingredients is essential to avoid unwanted surprises or disappointments. Unfortunately, one of the greatest communication challenges in the corn co-product market (and in the published scientific literature) is the lack of awareness and use of standardized American Association of Feed Control Officials (AAFCO) definitions of various corn co-products. In addition, the use of different brand names for several CFP co-products produced using the same technology has created confusion in the market. A summary of common names, brand names (if applicable), typical analysis, and the AAFCO definitions of various types of corn co-products is shown in **Table 1**. The common names and brand names (if applicable) provided in this table should be used by buyers when communicating with suppliers of various corn co-products to ensure that there is clear understanding of the type of co-product being considered. Marketers of corn co-products are also encouraged to avoid using ethanol industry jargon when communicating with ingredient buyers and nutritionists in the feed industry. For example, terms such as “condensed distillers solubles” should be used instead of “syrup” to help customers align their understanding of the type and characteristics of corn co-products with official AAFCO definitions and terminology. Another common terminology mistake that is frequently made, involves the description of the relative differences in corn oil content among types of DDGS. Terms such as “full-fat”, “reduced-oil”, and “de-oiled” DDGS are often intended to provide a relative indication of the crude fat content of DDGS, but unfortunately, too many times the term “deoiled” is misused when referring to “reduced-oil” DDGS. The only “de-oiled” corn co-product in the market today is produced by solvent extraction of corn oil which results in a DDGS co-product that contains less than 3% crude fat and is marketed under the brand name NovaMeal. Therefore, it is important to clearly define the minimum crude fat or oil content of DDGS sources during communications between buyers and sellers.

Perhaps the most confusing term among ethanol co-products is the use of “high protein” to describe corn co-products that contain more than the 25% to 30% CP found in conventional DDGS. Although HP-DDG (36% to 48% CP) is a distinctly different category of corn co-products than DDGS, it is often confused with CFP co-products, which contain CP concentrations that contain more than 48% CP. The processes used to produce CFP are substantially different than those used to produce HP-DDG and results in different nutritional profiles. This is the main point of differentiation between the two CFP categories is that the Fluid Quip Technologies and the ICM, Inc. processes do not use any additives and are listed in the CFP Mechanically Separated category. The Marquis ProCap™ process uses a flocculant and Harvesting Technologies uses a polymer in their process resulting in classifying these co-products in the Corn Fermented Protein category (without mechanical separation).

Similarly, CFP sources are also confused with CPC sources which are produced by very different wet milling processes resulting in substantially different nutritional profiles. Unfortunately, corn co-product producers, marketers, and researchers have often not carefully described and used appropriate terminology when communicating information about the different co-products in research publications, websites, presentations, technical brochures, and product specifications sheets. Therefore, nutritionists are cautioned to be aware of the significantly different nutrient profiles among various “high protein” corn co-products that have been produced and evaluated in animal feeding trials during the past 15 years when using data from various published research studies. One of the goals of this U.S. Grains Council Corn Co-Product Handbook is to summarize these differences to help ingredient purchasers and animal nutritionists understand the differences among this increasing portfolio of corn co-products.

Table 1. Common names, brand names, typical analysis, and American Association of Feed Control Officials (AAFCO) definitions of corn co-products

Common Name	Brand Name	Typical Analysis (As-Fed Basis)			AAFCO Identification	General Description
		Crude Protein, %	Crude Fat, %	Crude Fiber, %		

DDGS	None - commodity	25-30	6-9	<14	27.6, 27.8	Dried distillers grains with condensed distillers solubles are obtained after the removal of ethanol by distillation from yeast fermentation of a grain by condensing and drying at least ¾ of the solids of the resulting whole stillage and after a portion of oil is removed.
DDGS	Dakota Gold	24-29	4-5	<14	27.6, 27.8	Dried distillers grains with condensed distillers solubles are obtained after the removal of ethanol by distillation from yeast fermentation of a grain by condensing and drying at least ¾ of the solids of the resulting whole stillage and after a portion of oil is removed.
De-oiled DDGS	NovaMeal	26-36	<3	<14	27.9	Solvent-extracted DDGS resulting in a crude fat content of less than 3%.
Full Fat DDGS	None – commodity	25-32	10-14	<14	27.6, 27.8	Dried distillers grains with condensed distillers solubles are obtained after the removal of ethanol by distillation from yeast fermentation of a grain by condensing and drying at least ¾ of the solids of the resulting whole stillage with no oil removed.
DDGS with Bran	None – commodity	23-36	3-16	<14	27.6, 27.8, 48.2	DDGS mixed with bran separated by plant prior to fermentation. Can be in dry or wet form (dry form common analysis is provided here).
DDGS Mechanically Separated	Not commercially available	24-48	3-8	<14	27.6	Post-distillation residual whole stillage resulting from the mechanical separation of fiber and protein. Contains condensed distillers solubles. Can be in dry or wet form (dry form common analysis is provided here).
DDG	None – commodity	24-35	4-8	<14	27.5	Dried distillers grains without condensed distillers solubles is obtained after the removal of ethanol by distillation from yeast fermentation of a grain or grain mixture. May have a portion of oil removed.
High Protein DDG	ANDVantage™ 40Y and other unbranded sources using ICM, Inc. FST™	36-48	4-6	<12	27.5	Dried distillers grains with a portion of fiber and oil removed to concentrate the protein but contains no condensed distillers solubles.
Condensed distillers solubles (syrup)	None – commodity	5-25	3-23	0-4	27.7	Condensed distillers solubles is obtained after removal of ethanol after distillation by condensing the thin stillage fraction into a semi-solid.
Condensed distillers solubles (syrup)	SOLMAX™	19-21	2-7	<1	27.7	Condensed distillers solubles is obtained after removal of ethanol after distillation by condensing the thin stillage fraction into a semi-solid (approximately 50-75% solids).
Distillers Dried Yeast	ALTO YEAST PROPLEX DY	40-55	0-8	0-6	96.5	Dried, non-fermentative, inactive *Saccharomyces cerevisiae* yeast removed from the mash either before or after distillation and must contain more than 40% crude protein.
Hydrolyzed Yeast	ULTRAMAX™	40-45	6-10	3-5	96.12	Concentrated, non-extracted, partially soluble (accomplished by enzymatic hydrolysis), yeast digest.
Bran with Syrup	Solbran™ ANDVantage™ Bran Plus and other unbranded sources using ICM, Inc. FST™	18-28	4-9	15-20	48.2, 27.7	Bran separated from grain prior to fermentation and added to condensed distillers solubles after fermentation before drying. Can be in dry or wet form (dry form common analysis provided).
Fermented Fiber Mechanically Separated	Not commercially available	<24	2-7	10-20	27.6	Post-distillation mechanical separation of the whole stillage resulting in a concentration of fiber. Does not contain distillers solubles unless listed.
Corn Fermented Protein	None	>48	3-8	<8	27.5	Portions of fiber and oil removed by concentrating residual grain and yeast proteins by methods commonly used in the

						distilling industry. Contains concentrated spent yeast. Does not contain condensed distillers solubles unless listed
Corn Fermented Protein Mechanically Separated	A+ Pro BP 50 NexPro® AltiPro™ Still Pro 50™[1] ANDVantage™ 50Y PROTOMAX™ ProCap Gold™	>48	1-5	<8	27.5	Post-distillation separation of protein from the whole stillage, utilizing only mechanical separation. Will contain spent yeast products, no non-mechanical methods utilized post-distillation. Does not contain distillers solubles unless listed.

[1]Still Pro 50™ is no longer being sold under this name but is listed here because it is used in published scientific literature to describe corn fermented protein produced using Fluid Quip Technologies.

Corn distillers oil (CDO) is another major co-product available for use as a supplemental energy source in animal feeds and was not listed in Table 1 because it contains no CP or crude fiber. The process involves partially removing corn oil by centrifugation from the condensed distillers solubles stream or by solvent extraction of DDGS. Corn distillers oil contains more than 85% total fatty acids, less than 2.5% unsaponifiable matter, less than 1% insoluble impurities, and its fatty acid profile, metabolizable energy content and feeding applications for swine and poultry are described in Chapter 8 of this handbook.

Nutrient Profile of Corn Fermented Protein Co-Products

There are at least three different types of proprietary processing technologies used to produce corn fermented co-products. ICM's Advanced Processing Package™ (APP™) is used to produce PROTOMAX™, also sold by The Andersons, Inc. as ANDVantage 50Y. Fluid Quip Technologies' Maximized Stillage Co-Products Technology™ (MSC™) is used to produce CFP co-products with brand names of BP50, A+ Pro, NexPro®, and Altipro. Marquis ProCap™ Technology™ is used to produce a CFP co-product marketed under the brand name of ProCap Gold™. Although each of these types of technologies concentrate the protein and yeast in the final co-products, their nutritional profiles are different (**Table 2**). In addition, other new technologies are being commercialized and will produced new corn co-products that will enter the feed ingredient market in the near future.

On a dry matter (DM) basis, the gross energy content of CFP sources varies from 5,309 kcal/kg DM to 5,795 kcal/kg DM but is substantially greater than the 4,940 kcal/kg DM to 5,140 kcal/kg DM found in conventional DDGS sources (Yang et al., 2021). A few studies have determined and compared the ME content of some CFP sources with DDGS sources for swine (Chapter 6) and broilers (Chapter 5), and the ME content of CFP co-products are 1.2 to 1.5 times greater than in DDGS. The CP content of CFP co-products also varies but is generally greater than 53% (DM basis). Likewise, this wide range in CP content resulted in variable concentrations of many of the indispensable amino acids among CFP co-product sources (**Table 3**), especially for Lys (1.91% to 2.26%), Met (0.93% to 1.37%), Thr (1.86% to 2.15%), and Trp (0.39% to 0.62%).

Although different measures of lipid (ether extract and acid hydrolyzed ether extract) and fiber [neutral detergent fiber (NDF), acid detergent fiber (ADF), soluble dietary fiber, insoluble dietary fiber, and total dietary fiber TDF)] content have been reported in various published studies for different CFP co-products, the concentrations of the nutritional components also vary among sources (**Table 3**). Although the ash content of CFP sources ranges from 1.54% to 8.49%, the calcium and phosphorus concentrations are relatively similar among sources. Therefore, to optimize energy and nutritional efficiency when including any of these CFP co-products in swine and poultry diets, it is essential to use appropriate ME, digestible amino acid, and digestible phosphorus values during feed formulation, and currently available information is summarized in Chapters 5 and 6 of this Handbook.

Table 2. Comparison of the nutritional composition of various sources of corn fermented protein (dry matter basis)

Analyte	ANDVantage 50Y[1]	Still Pro 50[2]	A+ Pro[3]	NexPro[4]	ProCap Gold[5]
Dry matter, %	93.76	100.00	91.73	93.00	88.00
Gross energy, kcal/kg	5,636	NR	5,351	5,309	5,795
Crude protein, %	55.24	53.0	54.73	53.87	55.78
Lys:crude protein	3.46	4.19	3.96	3.95	3.93
Ether extract, %	NR*	5.1	5.0	NR	NR
Acid hydrolyzed ether extract, %	10.56	NR	NR	6.02	10.78
Neutral detergent fiber, %	30.56[6]	24.1	26.52	NR	NR
Acid detergent fiber, %	22.22[6]	4.83	5.27	NR	NR
Soluble dietary fiber, %	2.99	NR	NR	3.66	1.16
Insoluble dietary fiber, %	29.2	NR	NR	26.23	24.74
Total dietary fiber, %	31.14	NR	NR	29.89	25.90
Ash, %	1.54	5.49	5.98	8.49	8.39
Ca, %	0.02[6]	0.05	0.04	NR	0.05
P, %	0.70[6]	1.1	0.89	NR	0.88

*NR = not reported.
[1]Unpublished data from Lee and Stein (2021) obtained with permission from The Andersons, Inc.
[2]Published data obtained from Correy et al. (2019); Still Pro 50™ is no longer being sold under this name but is listed here because it was used in this study to describe corn fermented protein produced using Fluid Quip Technologies.
[3]Published data obtained from Yang et al. (2021).
[4]Published data obtained from Acosta et al. (2021).
[5]Published data obtained from Cristobal et al. (2020).
[6]Unpulished data obtained with permission from The Andersons, Inc.

Table 3. Comparison of amino acid profiles of corn fermented protein sources (dry matter basis)

Analyte	ANDVantage 50Y[1]	Still Pro 50[2]	A+ Pro[3]	NexPro[4]	ProCap Gold[5]
Dry matter, %	93.76	100.00	91.73	93.00	88.00
Crude protein, %	55.24	53.0	54.73	53.87	55.78
Indispensable amino acids, %					
Arg	2.53	2.49	2.57	2.48	2.81
His	1.22	1.41	1.57	1.43	1.59
Ile	2.14	2.24	2.46	2.35	2.31
Leu	6.87	5.80	6.87	6.11	6.33
Lys	1.91	2.22	2.17	2.13	2.15
Met	1.37	1.05	1.17	1.09	1.24
Phe	2.93	2.67	2.90	2.68	2.85
Thr	2.13	2.06	2.19	2.15	2.15
Trp	0.62	0.45	0.40	0.45	0.56
Val	2.71	3.08	3.21	3.04	3.23
Dispensable amino acids, %					
Ala	4.07	3.51	4.09	3.73	3.88

Asp	3.72	3.62	3.89	3.81	3.84
Cys	1.19	0.90	1.07	0.94	1.14
Glu	9.46	7.61	8.88	7.94	8.55
Gly	2.09	2.00	2.18	2.16	2.34
Pro	4.45	3.46	NR	3.76	4.00
Ser	2.55	2.25	2.47	2.33	2.50
Tyr	2.47	2.08	2.22	2.13	2.16

*NR = not reported.
[1]Unpublished data from Lee and Stein (2021) obtained with permission from The Andersons, Inc.
[2]Published data from Correy et al. (2019); Still Pro 50™ is no longer being sold under this name but is listed here because it was used in this study to describe corn fermented protein produced using Fluid Quip Technologies.
[3]Published data from Yang et al. (2021).
[4]Published data from Acosta et al. (2021).
[5]Published data from Cristobal et al. (2020).

Environmental Impacts of Corn Fermented Protein Co-Products

The future of the planet and human societies is dependent on our ability to create a regenerative, circular economy that reduces waste, carbon and nitrogen footprints, and climate change while improving efficiency of resource use to keep consumption within planetary boundaries with an ever-increasing global population of people. One of the most widely debated topics involving food security and sustainability is whether food animal production should continue to be a part of our global food system.

Animal agriculture is central to our global food system, economies, and society, and accounts for 40% of agricultural gross domestic product, employs 1.3 billion people, creates livelihoods for 1 billion poor people, provides 33% of dietary protein intake, and is a potential solution for overcoming undernourishment (Steinfeld et al., 2006). However, animal agriculture is a major contributor to many environmental problems including land degradation, climate change, air pollution, water shortage and pollution, and loss of biodiversity (Steinfeld et al., 2006).

Estimates of global greenhouse gas (GHG) emissions from livestock production have been reported to range from 8 to 51% which has created confusion among scientists and policy makers (Herrero et al., 2011). While this estimate has been highly debated, the current estimate is 14.5% (Gerber et al., 2013). Depending on animal species, type of production system, and geographic location, feed production contributes 50 to 85% of climate change impact, 64 to 97% of eutrophication potential, 70 to 96% of energy use, and about 100% of land occupation in monogastric animal production systems (Garcia-Launay et al., 2018). Therefore, because feed ingredients used in animal feed production have a large influence on environmental impact, one of the most effective strategies to reduce the environmental impact of food animal production is to use multi-objective diet formulation approaches including low environmental impact feed ingredients determined by LCA (Mackenzie et al., 2016b; Garcia-Launay et al., 2018; de Quelen et al., 2021; Méda et al., 2021; Soleimani and Gilbert, 2021). Life cycle assessment (LCA) is a compilation and evaluation of the inputs, outputs, and environmental impacts of a system used to produce a product throughout its life cycle (van Middelaar et al., 2019). Standardized methodology and guidelines have been established for determining various LCA environmental impact indicators (LEAP, 2015), but most of the limited number of LCA feed ingredient databases include feed ingredients used in the European Union, and LCA values are not directly applicable to ingredients used in the United States. However, the Global Feed LCA institute (GFLI; https://tools.blonkconsultants.nl/tool/16/) has developed the largest database (962 feed ingredients) with the most LCA indicator variables (n = 18; **Table 4**) and the most widespread global application (European Union, United States, and Canada).

Table 4. Global Feed LCA Institute environmental impact measures that have been applied to feed ingredients

Environmental impact measure	Unit	Description
Global warming with or without land use change	kg CO_2 equiv./kg product	Indicator of potential global warming due to emissions of greenhouse gases to the air, using carbon dioxide as a standard, with or without a change in land use
Stratospheric ozone depletion	kg CFC11 equiv./kg product	Indicator of emissions to air that cause destruction of the stratospheric ozone layer using chlorofluorocarbon-11 as a reference standard
Ionizing radiation	kBq Co-60 equiv./kg product	Impact on radiation as measured by kilobecquerels of cobalt-60 radioactive isotope as a reference standard
Ozone formation, human health	kg NOx equiv./kg product	Impact on nitrous oxide gases that affect the ozone and human health
Fine particulate matter formation	kg PM2.5 equiv./kg product	Impact on air quality as atmospheric particulate matter with particles having a diameter of less than 2.5 micrometers
Ozone formation, terrestrial ecosystems	kg NOx equiv./kg product	Impact on nitrous oxide gases that affect the ozone and human health
Terrestrial acidification	kg SO_2 equiv./kg product	Indicator of the potential acidification of soil and water due to the release of nitrogen oxide and sulfur oxide gases
Freshwater eutrophication	kg P equiv./kg product	Indicator of the potential for increased phosphorus emission to freshwater
Marine eutrophication	kg N equiv./kg product	Indicator of the potential for increased nitrogen emission to freshwater
Terrestrial ecotoxicity	kg 1,4-DCB/kg product	Impact of toxic substances emitted to the environment on land organisms using 1,4-dichlorobenzene as a standard
Freshwater ecotoxicity	kg 1,4-DCB/kg product	Impact of toxic substances emitted to the environment on freshwater organisms using 1,4-dichlorobenzene as a standard
Marine ecotoxicity	kg 1,4-DCB/kg product	Impact of toxic substances emitted to the environment on sea water organisms using 1,4-dichlorobenzene as a standard
Human carcinogenic toxicity	kg 1,4-DCB/kg product	Impact of carcinogenic toxic substances to the environment using 1,4-dichlorobenzene as a standard
Human non-carcinogenic toxicity	kg 1,4-DCB/kg product	Impact of non-carcinogenic toxic substances to the environment using 1,4-dichlorobenzene as a standard

Land use	m^2a crop equiv./kg product	Impact of converting non-agricultural land into agricultural use
Mineral resource scarcity	kg Cu equiv./kg product	Indicator of depletion of natural inorganic mineral resources using copper as a standard
Fossil resource scarcity	kg oil equiv./kg product	Indicator of the depletion of natural fossil fuel resources
Water consumption	m^3/kg product	Indicator of the amount of water (cubic meters) required to produce a kg of product

In addition to GHG emission and carbon footprint, the Food and Agriculture Organization of the United Nations recently initiated a new focus on improving nitrogen (N) utilization and reducing N waste by 50% by 2030. The global livestock industry contributes about one-third of human-induced N emissions (nitrates, ammonia, nitrous oxide, and other nitrogen oxides), poultry and pork supply chains contribute 29% of the total from food animals, and 68% of these N emissions are associated with feed production (Uwizeye et al., 2020). Nitrous oxide is a potent greenhouse gas, and ammonia and nitrogen oxides contribute to air pollution, cause acidification and eutrophication, and pose risks to human health (Galloway et al., 2008; Sutton et al., 2013). Nitrates and organic N have caused increased water pollution and biodiversity loss (Galloway et al., 2003; Hamilton et al., 2018; Ascott et al., 2017; Erisman et al., 2013). Globally only 20% of N is retained in useful products with 80% of various forms lost to the environment (Sutton et al., 2019). Therefore, there is a tremendous need to improve the protein-amino acid-nitrogen utilization of diets in food animal production, especially those that may provide a substantial amount of amino acids like CFP, toward meeting the daily requirements of efficient food animal species of fish, poultry, and pigs.

Phosphorus (P) is the third most expensive nutritional component of animal diets beyond energy and amino acids. Oster et al. (2018) identified several gaps that must be addressed to balance the agricultural P cycle and improve sustainability of pig and poultry production and suggested improving animal feeding strategies (adding phytase to diets), reusing and recycling (manure and slaughter waste), focusing on soil agroecosystems, improving farmer economic performance, and developing effective government policies and regulations (P quota, P tax). One important aspect missing from these strategies is the use of corn co-products such as CFP and DDGS which have relatively high concentrations of digestible P which can reduce reliance on inorganic P supplements and P excretion in manure. If corn co-products are not included in swine, poultry and aquaculture diets, the only other option to optimize P utilization when feeding diets containing plant-based ingredients with relatively high amounts of phytate to swine is to add exogenous phytase enzymes. By using phytase, the proportion of dietary P used by the animal is increased, the amount of P excretion in manure is reduced, and the antinutritional effects of phytate on digestibility of other nutrients are minimized (Shurson et al., 2021). In fact, several ethanol plants add phytase during the fermentation process which further increases the conversion of indigestible phytate to digestible phosphate (Reis et al., 2018). All of these benefits are provided by using CFP and other corn co-products because the amount of phytate in corn is naturally converted to digestible phosphates by yeast during the fermentation process. Therefore, achieving the goal of “phytate-free” nutrition proposed by Cowlieson et al. (2016) is possible if corn co-products and phytase are used strategically in monogastric diets.

Corn production uses large amounts of water, land, and other inputs that contribute to GHG emissions, climate change, fossil fuel depletion, air pollution, and local water scarcity (Smith et al., 2017). The U.S. ethanol industry and animal production are the primary consumers of corn and are becoming increasingly focused on assessing and improving environmental sustainability. While some studies (Kraatz et al., 2013) have suggested that converting whole stillage into electricity, heat, and fertilizer has 54% less energy intensity and 67% less global warming potential than processing it into DDGS, Smith et al. (2017) developed a model to account for country-level environmental impacts of using U.S. corn in animal production and ethanol supply chains and showed that these effects vary among location, industry sector, and environmental indicators evaluated. Several studies have evaluated various environmental impacts of feeding corn distillers' grains with solubles to beef cattle (Hünerberg et al., 2014; Leinonen et al., 2018; Asem-Hiablie et al., 2019; Werth et al., 2021), dairy cattle (Aguirre-Villegas et al., 2015), poultry (Kebreab et al., 2016; Benavides et al., 2020), swine (Stone et al., 2012; Meul et al., 2012; Kebreab et al., 2016; Mackenzie et al., 2016a,b; Benavides et al., 2020), and aquaculture (Henriksson et al., 2017; Cortés et al., 2021). Depending on the system boundaries being modeled, allocation method, and proportion of environmental impacts assigned to ethanol and DDGS, there are positive and negative environmental benefits of feeding DDGS to various animal species. However, this is not different than for most other feed ingredients.

Because of the tremendous need to reduce the carbon footprint in biofuels and co-product production, Marquis Energy was one of the first U.S. ethanol and co-product production facilities to become certified in the International Sustainability and Carbon Certification (ISCC) program in 2010. The ISCC was formed to meet the European Union directive of reducing GHG emissions by using renewable energy, and a low carbon intensity (CI) score is required to market biofuels in the European Union. In Japan, ISCC Plus is required for biofuels marketers. Although the ISCC was designed for assigning a CI score to biofuels, the program also assigns a CI score to corn co-products produced such as DDGS and CFP (ProCap Gold™). Unlike most LCA determinations, all CI inputs in the ISCC program are distributed to each product stream (including corn co-products) based on the energy content derived from each stream. This results in equal CI scores for ethanol and co-products at the ethanol plant gate. The current carbon intensity of DDGS in the U.S. ethanol industry is about 700 g of CO_2 equivalent/kg of DDGS. The DDGS and CFP (ProCap Gold™) produced by Marquis Energy has a CI score (https://www.iscc-system.org/certificates/valid-certificates/) that is only about 25% (175 g of CO_2 equivalent/kg of DDGS and ProCap Gold™) of the corn co-product sources in the industry. This dramatic reduction in carbon intensity has been achieved by strategically investing and implementing technology and practices that include carbon capture and sequestration. The ISCC measures CI using LCA at various steps throughout the entire ethanol and co-product supply chain beginning at the farm and ending with the end-user. Marquis Energy works closely with corn farmer suppliers to ensure through third party audits that low carbon practices (e.g., no conversion of virgin timber or prairie grassland into cropland, erosion control, responsible nutrient management, maintaining natural habitat) have been implemented and followed. Only corn produced by farmers who voluntarily participate in this ISCC program can be used to produce ISCC certified ethanol and corn co-products.

Corn fermented protein co-products are relatively new to the feed ingredient market, and much smaller quantities are produced and used in animal feeds compared with DDGS. Therefore, there is limited information on feeding CFP co-products to various animal species and their environmental impacts. However, a recent study conducted by Burton et al. (2021) estimated the dietary effects from feeding diets containing increasing amounts of CFP on GHG emissions per kg of body weight gain and kg of meat produced in broilers (**Table 6**), per kg of body weight gain in turkey poults, and per kg of feed and weight gain in Atlantic salmon (**Table 7**) using an economic allocation. Results from the feeding trials used in this study are provided and discussed in Chapter 2 (aquaculture) and Chapter 3 (poultry). The Global Food LCA Institute (GFLI) database was used to obtain data for feed ingredients in experimental diets to calculate the GHG emissions. However, because the GFLI database does not contain LCA data for CFP, these researchers used environmental impact data from Tallentire et al. (2018) for a different high protein corn co-product produced in the ethanol industry in the calculations. This assumption is questionable because different inputs and processes are used for producing different sources of CFP. Furthermore, CFP partially replaced some of the SBM in diets used in these feeding trials, but LCA data for SBM is highly variable based on country of origin and can have a significant effect on the results. Unfortunately, these details were not described in this study. Although these issues contribute to questionable results, it appears that increasing amounts of CFP in broiler diets reduced GHG emissions per kg of weight gain and per kg of meat produced (**Table 5**). Furthermore, although adding 10% CFP to broiler diets resulted in similar N retention compared with feeding the control diets with 0% CFP, N retention was improved by feeding 5% CFP diets. Feed formulations that improve N retention may also reduce N excretion which may be another beneficial environmental effect. Similarly, feeding diets containing 0%, 4%, and 8% CFP to turkey poults reduced GHG emissions (kg CO_2 equivalent per kg of body weight gain) from 3.96 (0%) to 3.77 and 3.40 kg CO_2 equiv, respectively. Likewise, the addition of increasing amounts of CFP to partially replace SBM in Atlantic salmon diets appears to reduce GHG emissions per kg of feed and per kg of weight gain (**Table 6**). Therefore, the use of CFP to replace SBM in salmon diets likely has a significant advantage for reducing the carbon footprint of salmon production, especially under European conditions where importation of SBM from deforested regions of South America is discouraged.

Table 5. Effects of feeding increasing dietary levels of corn fermented protein to broilers on nitrogen retention and estimated greenhouse gas emissions during a 42-day feeding period (adapted from Burton et al., 2021)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %		
	0%	5%	10%
Nitrogen retention, %	29.4[b]	30.4[a]	28.7[b]
Greenhouse gas emissions, kg CO_2 equiv./kg body weight gain	2.48	2.21	2.01
Greenhouse gas emissions, kg CO_2 equiv./kg meat	5.85	5.03	4.57

[a,b]Means without common superscripts within rows are different ($P < 0.05$).

Table 6. Effects of feeding diets containing 0, 5, 10, 15, and 20% corn fermented protein as a partial replacement for soybean meal to Atlantic salmon (initial weight = 304 g) on estimated greenhouse gas emissions during a 12-week feeding period (adapted from Burton et al., 2021)

Measure	Dietary Corn Fermented Protein Inclusion Rate, %				
	0%	5%	10%	15%	20%
Greenhouse gas emissions, kg CO_2 equiv./kg feed[1]	1.64	1.55	1.47	1.39	1.30

Greenhouse gas emissions, kg CO_2 equiv./kg gain	1.59	1.44	1.37	1.36	1.27

[a,b]Means without common superscripts within rows are different ($P < 0.05$).

Conclusions

Corn fermented protein (CFP) co-products are produced using new technologies in dry grind ethanol facilities and contain high concentrations of energy, crude protein, and amino acids that have feeding applications primarily in aquaculture, broiler, and weaned pig diets, but can be broadly used in all animal feeds. The nutrient profiles and amino acid digestibility vary among sources of CFP which requires communicating with suppliers to apply appropriate metabolizable energy and amino acid digestibility coefficients to the specific CFP source used in feed formulations. The amino acid profile of corn protein is relatively low in lysine and tryptophan, but high in leucine which creates an amino acid imbalance with valine and isoleucine that requires supplementation of synthetic amino acids as dietary inclusion rates of CFO increase in monogastric diets to achieve satisfactory growth performance and carcass composition responses. These co-products also contain an estimated 20 to 29% spent yeast, which contributes to slightly improved amino acid profile relative to amino acid requirements and may provide animal health benefits depending on diet inclusion rates and health status of fish, pigs, and poultry.

Use of low environmental impact feed ingredients is an essential part of sustainable food animal production. Although several life cycle assessments of adding DDGS in animal feeds have shown an increase in greenhouse gas (GHG) emissions, several other environmental impacts are greatly reduced by feeding DDGS. A few U.S. ethanol plants have become certified in the International Sustainability and Carbon Certification program to meet the European Union directive of reducing GHG emissions by using renewable energy and a low carbon intensity score for ethanol and corn co-products. An initial study has been conducted to estimate the effects of feeding diets containing CFP to broilers, turkeys and Atlantic salmon on GHG emissions and showed substantial reductions.

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