CHAPTER 10

DDGS Color IS NOT a Reliable Indicator of DDGS Quality and Nutritional Value

Why is DDGS Color a Quality Issue?

THERE ARE NO GRADING SYSTEMS, OR DEFINED AND REGULATED QUALITY STANDARDS FOR DDGS like there are for corn (e.g. U.S. #2) and other U.S. grain commodities. As a result, misunderstandings can occur between buyers and sellers of U.S. DDGS worldwide. Establishing prices, writing contracts and meeting expectations are problematic in the absence of quality standards. While professionals in industry, government, and academia have discussed, and attempted to develop quality standards for DDGS during the past decade, attempts failed due to disagreements on the need for defined quality standards and perhaps the fear of increased transparency and ability to distinguish quality and value differences among DDGS sources. Most U.S. DDGS marketers prefer to focus only on maximum guarantees for moisture and fiber, and minimum guarantees for fat and protein. However, because of variability in nutrient content and quality among U.S. DDGS sources, many international DDGS buyers often demand more guarantees for specific quality attributes to minimize their risk of obtaining co-products that don't meet their expectations.

The color of DDGS has become a quality factor of great importance for some buyers in the export market, and it is being used to differentiate real or perceived quality and value among DDGS sources. Several years ago, some DDGS marketers and buyers developed a subjective color evaluation system using a five-color scoring card (**Figure 1)** to differentiate color among DDGS sources. Although this DDGS color score card is still used in the market today, many marketers have stopped using it because it is too subjective and resulted in frequent arguments with buyers because of different interpretations of the actual color score of DDGS. As a result, many marketing contracts now being negotiated between U.S. suppliers and foreign buyers (especially in Asian countries) contain a minimum guarantee for a quantitative measure of color (e.g. L* - lightness or darkness of color). The minimum guarantee currently being used to differentiate lightness of DDGS color is a Hunter L* greater than 50 to meet some buyers expectations. Increasing amounts of U.S. DDGS continue to be exported to various countries regardless of color, but for some markets demanding a guarantee of light-colored DDGS (i.e. L* greater than 50), there is a significant price premium obtained for those who can guarantee an L* greater than 50 in the DDGS sources they market.

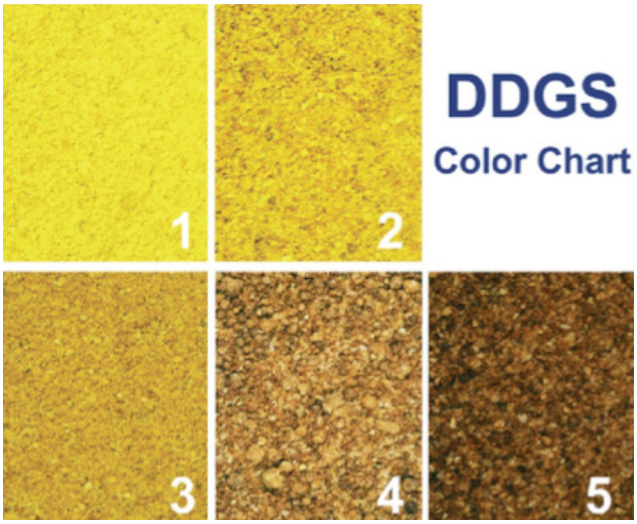

Figure 1. Example of a DDGS color score card

As a result, some U.S. suppliers have become frustrated and question the value of using DDGS color as an indicator of quality, especially if they are unable to supply DDGS that meets the buyer's color expectations. Therefore, the purpose of this paper is to define DDGS quality and the role of using color as a quality indicator in the marketplace, and provide a description of a variety of other quality characteristics and measurements that can be used to assess DDGS value.

How Do We Define Quality?

There are many definitions of quality. Quality is defined as an essential character or inherent feature that represents a degree of excellence, superiority, or a distinguishing attribute (http://www.merriam-webster.com/dictionary/quality).

In the context of business (http://www.businessdictionary.com/definition/quality.html), quality has been defined as a general measure of excellence or state of being free from defects, deficiencies, and significant variations. The ISO 8402-1986 standard defines quality as "the totality of features and characteristics of a product or service that bears its ability to satisfy stated or implied needs." In the context of manufacturing, quality is defined as strict and consistent adherence to measurable and verifiable standards to achieve uniformity of output that satisfies specific customer or user requirements. Quality can be

determined objectively using criteria that are measurable, and subjectively which may be characteristics that can be observed and may be approximated, but cannot be measured. As a result, quality is a general term that refers to the desirable characteristics of material things and can mean different things to different people.

How is Quality Determined in Feed Ingredients and Feeds?

Feed manufacturers and animal producers use a variety of qualitative and quantitative methods to assess the quality of feed ingredients and feeds including physical, chemical and biological tests. Physical evaluation of feeds is qualitative but used to identify changes in the nature of the raw materials and feeds. The physical characteristics commonly evaluated include color, particle size, bulk density, homogeneity, smell, taste, touch and sound. The presence of other grains, weed seeds, husks and sand are the most common physical contaminants that can be identified by physical evaluation.

Chemical tests are quantitative and allow precise estimation of nutrient content and possible contaminants. Using a commercial laboratory to determine the proximate analysis of feed ingredients is a common practice to evaluate quality. These measurements typically include moisture, crude protein, crude fiber, crude fat and ash. Ingredient specifications (nutrient content) are essential for feed manufacturing quality assurance programs and serve as the basis for writing purchasing agreements, assessing quality, and to some extent, formulating diets. These nutrient specifications are the standards to which the delivered ingredient must conform to expectations and sometimes include measuring some potential contaminants of concern (e.g. mycotoxins, dioxin).

Feed microscopy is also used in determining if feeds or feed ingredients have been adulterated or contain contaminants. It involves examining samples of feed ingredients with a microscope under low (8x to 50x) and high (100x to 500x) magnification to evaluate shape, color, particle size, softness, hardness and texture of feeds.

Biological evaluation of feed ingredients is also done, but is generally confined to universities or large feed companies with animal and laboratory research facilities. It involves the use of animals, and personnel with specialized training to conduct digestion and metabolism trials on various animal species. These methods are time consuming, expensive and, as a result, cannot be routine procedures used as part of a feed manufacturing quality control program. However, they provide the best assessment of feed ingredient quality and feeding value compared to all other methods.

Thus, quality is a general term that refers to the desirable characteristics of material things and can mean different things to different people. For some, DDGS quality may refer to the absence of mycotoxins, and other undesirable anti-nutritional factors that may be detrimental to animal health and performance. To others, it may refer to consistency of nutrient content and digestibility. By these definitions, color can be, and is, used in some markets to define DDGS quality.

Why is Color Measured?

Color has been used as a subjective indicator of the nutritional quality of feed ingredients for decades. Free amino acids (especially lysine) can undergo Maillard reactions by combining with reducing sugars, rendering them indigestible by the animal. Louis Camille Maillard discovered and described the first evidence of these chemical reactions between sugars and amino acids in 1912. Maillard reactions are a group of chemical reactions that occur when heating sugars and amino acids, as well as complex carbohydrates and amides. These reactions commonly occur when mid- to high-protein feed ingredients are overheated during the production and drying process, and can be characterized by darkening of color (browning), burned flavor and burned smell. Drying temperatures used in dry-grind ethanol plants can range from 127 to 621° C. The nutritional significance of the Maillard reactions in DDGS has been shown in ruminants (Klopfenstein and Britton, 1987), as well as in pigs and chickens (Cromwell et al., 1993) and is responsible for losses in protein quality in DDGS (Cromwell et al., 1993; Fastinger and Mahan 2006; Stein et al., 2006). The Maillard reactions also occur in other common ingredients such as dried whey, blood meal and soybean meal. A darkening of color of these ingredients also indicates overheating and reduced protein quality. Therefore, feed ingredient purchasers and feed manufacturers have been trained to use color as a general indicator for differentiating protein quality and digestibility among feed ingredient sources.

In addition, color can give an indication of the maturity of the grain, storage conditions, presence of toxins, contamination due to sand and possible use of insecticides/fungicides, which give a dull and dusty appearance. Sorghum with an orange to red color may indicate high tannin content. Browning or blackening of grain or grain co-products can indicate excessive heat treatment or spoilage due to improper storage, thus reducing nutritive value. Black colored fish meal may indicate rancidity of fish oil.

How is Color Measured?

Hunter and Minolta colorimeters have been used for many years in human food industry as indicators of nutritional and physical characteristics of heat-processed products such as candy bars, cookies and bread. In these food products, color is often an important quality attribute that determines the attractiveness of the product to consumers. Color is measured by reading three color characteristics specifically defined by the *Commission Internationale d'Eclairage*, in Vienna, Austria. [Lightness or L* (0 dark, 100 lighter), a* (redness-greenness) and b* (yellowness-blueness); **Figure 2**]. Colorimetric measurements of feed ingredients, especially for DDGS, have become common in the feed industry to assess the extent of heat damage of mid- to high-protein ingredients. It is important to realize color scores using Minolta colorimeters are lower than for Hunter Lab colorimeters. Urriola et al. (2013) showed that L* readings are generally 2.9 units lower and b* readings are 1.7 units lower for Minolta compared to Hunter readings of the same sample. However, the ranking of samples by color scores using both methods is the same. Therefore, if color measures are used as criteria for marketing DDGS sources, it is essential the method used (e.g. Hunter or Minolta) is defined in the contract to avoid misinterpretation of results.

Figure 2. Hunterlab color measurement scales

Why is Color Important in Some Export Markets?

When living and working in a global economy, it is essential to understand how different cultures around the world perceive things, the symbolic nature of how they may think and the basis for the actions they choose to take. As an example, the web site (http://webdesign.about.com/od/colorcharts/l/bl_colorculture.htm) describes what different colors mean in different cultures. For example, the color yellow in Chinese culture is considered the most beautiful and corresponds with earth and the center of everything (http://en.wikipedia.org/wiki/Color_in_Chinese_culture). Yellow is ranked above brown and also signifies neutrality and good luck. Yellow was the color of Imperial China, is the symbolic color of the five legendary emperors of ancient China, often decorates royal palaces, altars and temples and was used in the robes and attire of the emperors. Yellow also represents freedom from worldly cares and is highly regarded in Buddhism.

Furthermore, consumers in many Asian countries prefer dark yellow-colored egg yolks and yellow-colored chicken skin over pale colored egg yolks and chicken skin typical of that found in the U.S. Therefore, the color yellow or golden is held in higher esteem than brown and is likely one of the contributing factors to why "golden" DDGS is the preferred color of DDGS in many parts of Asia.

Is There a Relationship Between DDGS Color and Nutritional Value?

Variation in color among DDGS sources

There are significant differences in color among U.S. corn DDGS sources (**Figure 3**). Fifteen studies have been conducted to evaluate the range of color (L*, a* and b*), or degree of heating, among DDGS sources and its relationship to differences in nutritional quality and physical characteristics. A summary of the key findings of these studies is shown in **Table 1**. All but two studies (Urriola et al, 2013; Song and Shurson, 2013) evaluated DDGS samples from a limited number of sources (two to nine sources). However, despite the limited number of sources evaluated in most of these studies, there was a significant range in L* color scores among the samples analyzed except for the studies reported by Rosentrater (2006), Pahm et al. (2009), and Kingsly et al. (2010). Samples of DDGS from beverage ethanol plants were included in the Cromwell et al. (1993) and Urriola et al. (2013) studies, which may be the reason for the extremely low L* values (dark samples) in those studies, but does not explain the low L* values obtained in the studies by Fastinger and Mahan (2006) and Bhadra et al. (2007), when only DDGS from fuel ethanol plants were evaluated.

Figure 3. Color differences among U.S. corn DDGS sources

Table 1. Summary of research results involving DDGS color (or degree of heating) on nutritional and physical characteristics

Reference	# DDGS sources	L* range	a* range	b* range	Key findings
Cromwell et al. (1993)	9	28.9-53.2	ND	12.4-24.1	Significant correlation between DDGS L* and lysine level and L* and b* with weight gain and gain:feed in broiler chicks. Effects were similar in pigs. ADIN of DDGS sources was also highly correlated with chick weight gain and gain:feed.
Whitney et al. (2001)	2	ND; Light and Dark	ND	ND	Lighter colored DDGS had an AID for lysine of 47.4 percent but darker colored DDGS had an AID for lysine of 0 percent for pigs.
Ergul et al. (2003)	4	41.8-53.8	ND	32.9-42.8	Significant correlations between L* and b* and digestible lysine in poultry.
Roberson et al.(2005)	2	ND; Light and Dark	ND	ND	Light-colored source had 29.8 mg/kg xanthophyll, dark-colored source had 3.5 mg/kg xanthophylls
Rosentrater (2006)	6	40.0-49.8	8.0-9.8	18.2-23.5	L*, a* and b* were correlated with several physical properties
Batal and Dale (2006)	6	47.9-62.9	4.1-7.6	8.8-28.4	Significant correlations were found between digestible Lys, Thr, Arg, His and Trp and L* values and b* values, but not with a* values.
Fastinger and Mahan (2006)	5	28.0-55.1	6.7-9.0	15.8-41.9	DDGS sources with higher L* and b* color had greater apparent and standardized digestibility of AA in pigs than DDGS sources of a darker color.
Urriola (2013)	34	36.5-62.5	8.0-12.0	21.3-47.0	Digestible crude protein and amino acids were poorly predicted (R2 less than 0.30) from Minolta or Hunter color scores in pigs. Correlation (R2 =0.48) between L* and SID lysine was higher among samples with L* less than 50 than samples with L* greater than 50 (R2 =0.03).
Bhadra et al. (2007)	3	36.6-50.2	5.2-10.8	12.5-23.4	Color parameters a* and b* had high correlations with water activity and moderate correlations with thermal properties which may be important for feed storage and further processing
Martinez Amezcua and Parsons (2007)	ND	ND; heat process-sed light colored DDGS sample	ND	ND	Increased heating of DDGS significantly increased relative phosphorus bioavailability in DDGS in poultry, but amino acid digestibility, especially lysine, was greatly reduced.
Ganesan et al. (2008)	ND	40.8-54.1	12.4-18.7	57.6-73.3	Amount of solubles added to grains to make DDGS reduced L* and increased a* and interacts with moisture content to affect DDGS color.
Liu (2008)	6	44.9-59.6	8.3-11.4	31.0-46.4	Most DDGS samples showed a decrease in L* and b* and a slight increase in a* as particle size increased.
Pahm (2009)	7	49.3-56.4	10.4-14.5	36.7-43.9	Correlation between L* and SID lysine in chicks was poor (0.29), but very high (0.90) for relative bioavailability of lysine.
Kingsly et al. (2010)	1	49.0-53.4	8.8-11.3	24.7-26.5	As the CDS level was reduced, L* value increased and a* decreased.
Song et al. (2013)	31	45.2-58.1	9.3-12.4	26.6-42.4	Significant correlations between measures of fat oxidation (TBARS and PV) and L* and b*. DDGS TBARS were 5 to 25x greater than corn.

ND = not measured

Is Color Related to Lysine Digestibility in DDGS?

Research by Evans and Butts (1948) was the first to show that excessive heating of feed ingredients can result in binding of amino acids and protein to other compounds, such as fiber, and reduce amino acid digestibility (especially lysine) in monogastric animals (i.e. swine, poultry, fish). As a result, the use of color as an indicator of excessive heating and reduced amino acid digestibility in DDGS, has been a primary objective in seven of the 15 research studies conducted (**Table 1**). The first evidence of the relationship between DDGS color, lysine content, and animal performance was published by Cromwell et al. (1993). They showed that lysine concentrations tended to be highest in the lightest colored DDGS sources, intermediate in the medium colored, and lowest in the darkest-colored DDGS sources. In addition, there was a significant correlation between Hunter L* and weight gain and gain:feed in broiler chicks. When DDGS sources of similar color scores were blended and fed to pigs, performance results were similar to those observed in the chick studies. Additional poultry studies by Ergul et al. (2003) and Batal and Dale (2006) evaluated DDGS sources representing a wide range of L* and b* values and confirmed the results by Cromwell et al. (1993) by showing that L* and b* were significantly correlated with digestibility of lysine and other amino acids. However, results from a recent study by Pahm et al. (2009), which evaluated seven DDGS sources that could be classified as "golden" in color, and had a narrow range in L* values (49 to 56), showed no effect of L* on lysine digestibility in poultry, but there were significant differences in the relative bioavailability of lysine among these sources.

Similarly, results from additional pig studies (Whitney et al., 2001; Fastinger and Mahan, 2006) showed lower amino acid digestibility in DDGS sources that had lower L* values (darker in color) compared with sources with higher L* values. However, Urriola et al. (2013) was the first to demonstrate using a large number of DDGS samples (n = 34) over a wide range of L* values (37 to 63) that digestible crude protein and amino acids were poorly predicted (R2 less than 0.30) from Minolta or Hunter color scores in pigs. The association between L* and digestible lysine was greater for samples with an L* less than 50 compared to samples with L* greater than 50 (**Figure 4**). However, even for DDGS samples with L* less than 50, the correlation between L* and digestible lysine content in pigs was relatively low (R2 = 0.48), indicating color cannot be used to accurately predict digestible lysine content among DDGS sources. The results from these studies indicate that L* and b*, but not a* may be useful general indicators of relative lysine digestibility if L* values are less than 50, but not if L* values are greater than 50.

Relationship Between DDGS Drying Temperature and Relative Phosphorus Bioavailability

Although, there is consistent evidence that excessive heating (lower L* and dark color) during DDGS drying reduces digestibility of lysine and other amino acids, it may increase the relative bioavailability of phosphorus for poultry. Martinez-Amezcua and Parsons (2007) applied increasing heating temperatures to light-colored DDGS samples and observed that the relative bioavailability of phosphorus was improved, but amino acid digestibility was greatly reduced. This is the first evidence demonstrating excessive heating of DDGS may enhance its nutritional value for poultry by improving the utilization of phosphorus.

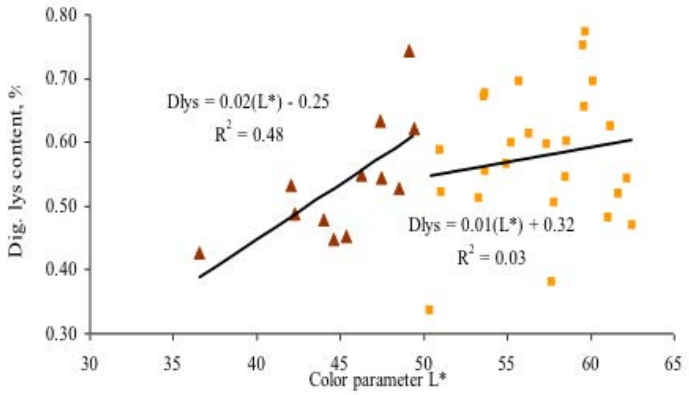

Figure 4. Relationship between lightness of color (L*) and digestible lysine content of corn DDGS for swine. (Urriola et al., 2013)

Relationship Between DDGS Color and Xanthophyll Content

Limited studies have been conducted to determine xanthophyll content in DDGS. Xanthophylls are yellow/orange pigments naturally occurring in corn and corn co-products, and are valuable components in poultry diets in many countries, especially Asia, to produce a desired golden color in egg yolks and broiler skin. Synthetic xanthophyll pigments (often derived from marigold petals) are very expensive, but are commonly added to poultry diets in Asian countries as the primary source of pigment. Therefore, adding corn co-products such as corn gluten meal, and to a lesser extent, DDGS, to poultry diets reduces the need for using expensive synthetic pigments and consequently, reduces diet cost while meeting desired egg yolk and skin color quality standards preferred by consumers.

Xanthophyll values in DDGS have been reported to be between 10.6 mg/kg and 34.0 mg/kg (Sauvant and Tran, 2004). Roberson et al. (2005) did not use Minolta or Hunter colorimeters to measure color, but showed that dark-colored DDGS contained 3.5 mg/kg xanthophyll compared to light golden colored DDGS which contained 29.8 mg/kg xanthophyll. They indicated that overheating of DDGS may cause oxidation of xanthophyll resulting in lower concentrations. Therefore, it appears that lighter colored DDGS is more likely to contain higher amounts of xanthophylls than darker colored DDGS.

Relationship Between DDGS Color and Lipid Peroxidation

Limited research has been conducted to evaluate the extent of oil peroxidation in corn DDGS. Dried distillers grains with solubles contains five to 13 percent corn oil, and corn oil contains high concentrations of polyunsaturated fatty acids (particularly linoleic acid) susceptible to lipid peroxidation. Drying temperatures used by ethanol plants can vary substantially (85 to 600°C), and increased drying time and temperature used during the drying process accelerates lipid peroxidation. Feeding diets containing peroxidized lipids have been shown to negatively affect pig and broiler health and growth performance (L'Estrange et al.,1967; Dibner et al., 1996; DeRouchey et al., 2004; Hung et al., 2017). Harrell et al. (2010) showed that feeding peroxidized corn oil or DDGS to nursery pigs resulted in reduced growth performance compared with pigs fed fresh (non-peroxidized) corn oil. Song and Shurson (2013) determined the thiobarbituric acid reactive substances (TBARS) and peroxide value (PV), which are common analytical methods to measure lipid peroxidation, in 31 corn DDGS, and reported that TBARS content ranged from 1.0 to 5.2 ng MDA equivalents/mg oil, and PV ranged from 4.2 to 84.1 meq/kg oil. The DDGS sample with the highest TBARS and PV values was 25 and 27 times greater, respectively, than the concentrations found in corn. These authors also reported there was a significant negative correlation between L* and b* and the level of lipid peroxidation among DDGS sources. These results indicate that darker and less yellow DDGS source may have greater concentration of peroxidized compounds than lighter colored DDGS sources.

Is There a Relationship Between DDGS Color and Physical Characteristics?

Five experiments **(Table 1**) have been conducted to understand the relationship between DDGS color and its physical characteristics, which may affect storage and further feed processing. Rosentrater (2006) was the first to report that L*, a* and b* were correlated with several physical properties (moisture, water activity, conductivity, resistivity, bulk density and flowability) of DDGS. Bhadra et al. (2007) confirmed these findings and showed a* and b* had high correlations with water activity and moderate correlations with thermal properties of DDGS indicating color may be an indicator for assessing feed storage and further processing characteristics.

Variable amounts of condensed distiller's solubles are added to the coarse grains fraction to produce DDGS among ethanol plants. The proportion of solubles and coarse grains used to produce DDGS affects the nutrient composition of DDGS because the nutrient content of each of these fractions is substantially different. The coarse grains fraction is higher in dry matter (33.8 vs. 19.5 percent), crude protein (33.8 vs. 19.5 percent), and crude fiber (9.1 vs. 1.4 percent), but lower in crude fat (7.7 vs. 17.4 percent), ash (3.0 vs. 8.4 percent), and phosphorus (0.6 vs. 1.3 percent) than the condensed solubles fraction. Therefore, increasing proportions of condensed solubles added to the coarse grains fraction will increase crude fat, ash and phosphorus but reduce crude protein and crude fiber content of DDGS.

Noll et al. (2006) evaluated the nutrient composition and digestibility of batches of corn DDGS produced with varying levels of solubles added to the wet grains. The DDGS samples produced contained solubles added at approximately 0, 30, 60 and 100 percent of the maximum possible addition of solubles to the grains. This corresponds to adding 0, 12, 25 and 42 gallons of syrup to the grains fraction per minute. Dryer temperatures decreased as the rate of solubles addition to the grains decreased. Particle size increased, and was more variable, as increasing additions of solubles were added to the grains fraction. Adding increasing amounts of solubles resulted in darker colored DDGS (reduced L*) and less yellow color (reduced b*) (**Table 2**). Increased addition of solubles resulted in increased crude fat, ash, TMEn (poultry), magnesium, sodium, phosphorus, potassium, chloride and sulfur, but had minimal effects on crude protein and amino acid content and digestibility. Ganesan et al. (2008) and Kingsly et al. (2010) demonstrated that as the amount of condensed distillers solubles added to the coarse grains fraction is increased, L* is reduced and a* increases. Therefore, DDGS L* and a* can be general indicators of nutrient composition changes among DDGS samples.

University of Minnesota research has shown there is considerable variation (256 to 1,217 µm) in particle size among DDGS sources, and DDGS particle size can affect digestible energy (DE) and metabolizable energy (ME) content for swine (Liu et al., 2012). Liu (2008) reported most DDGS samples showed a decrease in L* value and b*, and a slight increase in a* value as DDGS particle size increased.

Table 2. The Effect of the Rate of Solubles Addition to Mash on Color Characteristics of DDGS.

Color (CIE Scale)	0 gal/min	12 gal/min	25 gal/min	42 gal/min	Pearson Correlation	P Value
L*	59.4	56.8	52.5	46.1	- 0.98	0.0001
a*	8.0	8.4	9.3	8.8	0.62	0.03
b*	43.3	42.1	40.4	35.6	- 0.92	0.0001

Adapted from Noll et al. (2006).

Is Color the Best Indicator of DDGS Quality?

No. As previously discussed, there are many factors that affect the color of DDGS and some of these factors have positive effects while others have negative effects on nutritional value of DDGS It is also important to remember there are many criteria that can be used to describe DDGS "quality." Color is correlated with several nutritional components and physical characteristics of DDGS. While many nutritionists perceive that dark-colored DDGS is an indication of low lysine digestibility, the association of color over a broad range of L* values (36 to 64) with lysine digestibility indicates it is a poor predictor. Furthermore, DDGS sources with a high L* may indicate greater xanthophyll content, and minimal lipid peroxidation. In contrast, darker colored DDGS sources may have higher concentrations for some nutrients compared to lighter colored DDGS sources. For example, adding increasing levels of solubles to the coarse grains fraction when producing DDGS sources increases the energy, crude fat and mineral content, with minimal effects on crude protein and amino acid content and digestibility, compared to lighter colored DDGS sources containing less solubles. Furthermore, darker colored samples appear to have higher relative phosphorus bioavailability for poultry. Particle size, moisture content and other physical properties of DDGS are also correlated with color, but the value of these relationships is more difficult to assess from a feed manufacturing and nutritional perspective. **Therefore, using color as an indicator of DDGS quality is not recommended**.

How Should DDGS Quality Be Determined?

For most DDGS users, a high-quality DDGS source is one is high in energy and nutrient content and digestibility, and free of anti-nutritional factors such as mycotoxins. Energy, followed by protein (amino acids) and phosphorus are the three most expensive nutritional components in animal feeds. Therefore, accurate methods for determining the metabolizable energy, digestible amino acids and digestible or available phosphorus among various DDGS sources must be used. To do this, accurate ME and digestible amino acid prediction equations have been developed, validated and published for swine and poultry. For more information about these prediction equations, see **Chapters 19 and 22** in this handbook. Unfortunately, accurate prediction equations have not been developed for estimating digestible or available phosphorus in DDGS for swine and poultry, nor have prediction equations been developed to estimate net energy, rumen degradable and undegradable protein of DDGS sources for ruminants. Recommended methods for determining mycotoxin content in DDGS are discussed in **Chapter 8** of this handbook.

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