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Short communication/Technical note

Properties of solvent extracted low-oil corn distillers dried grains with solubles

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ABSTRACT

Corn-based ethanol is exponentially growing in the US, as is the need for valuable uses for coproducts of the production process, such as distillers dried grains with solubles (DDGS). Currently, DDGS is used as livestock feed, thereby replacing some corn components in animal diets. As the industry continues to grow, there will be an increased need to find additional uses for DDGS. Physical and chemical properties of coproduct streams are becoming increasingly investigated, as these characteristics affect many aspects of utilization, such as target species, optimal dietary substitution rates, transportation, flowability, and behavior during storage. Potential avenues for future use of DDGS may include value-added feed, food, and industrial products. Additionally, much interest lies in extracting oil from DDGS to produce bio diesel and other products. If oil is extracted from DDGS, the resulting chemical and physical properties of the remaining constituents may be substantially altered. The objective of this study was to quantify, using standard laboratory methods, physical and chemical property values for low-oil DDGS. The extracted DDGS exhibited water activity, thermal properties, bulk density, and angle of repose values similar to unmodified DDGS. Color values were substantially lighter, however. Additionally, fat levels (2.7% db) were much lower, while protein (34.0% db) and fiber (8.4% db) were higher than traditional DDGS. Results from this study will be valuable to ethanol manufacturers and livestock producers alike, as more uses for ethanol coproducts are implemented. Thus more value can be extracted from the humble kernel of corn.

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1. Introduction

Modern technologies allow corn grain to be processed into substantial amounts of ethanol fuel relatively efficiently. Two primary methods of production are currently used in the industry: dry grind and wet milling. Dry grind production methods are utilized more often due to lower capital requirements, while yielding high proportions of ethanol. The dry grind process is discussed in depth by refs. [1–3]. Briefly, the production process consists of six major stages: grinding, cooking, liquefaction, saccharification, fermentation, and separation [4]. End products typically include ethanol fuel, distillers dried grains, and carbon dioxide. For example, 25.4 kg of corn typically produces approximately 7.98 kg ethanol, 8.16 kg distillers grain, and 8.35 kg carbon dioxide; therefore each product stream generally yields between 30

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and 33% of the raw corn itself [2]. At the beginning of 2008, the United States expected to produce approximately 27.4 hm^3 of ethanol via 134 manufacturing plants. Currently, another 77 plants are under construction or expansion, and will be able to produce an additional 23.5 hm^3 of ethanol [5].

In addition to animal feed, many other potential applications for DDGS exist, such as value-added food products intended for humans, biodegradable plastics, inert fillers for plastics, and other industrial applications, to name only a few possibilities [6]. Value-added applications will be dependent, to a large extent, upon the chemical composition of these coproduct streams. Several studies have reported chemical and nutritional properties of distillers grains, such as refs. [7–10]. Much of this information has been summarized and reviewed by ref. [11]. Typical ranges for some DDGS constituents include: protein (26.8–33.7%), lipid (3.5–12.8%), carbohydrates (39.2–61.9%), and total dietary fiber (24.2–39.8%). These values indicate that potential food use, especially for medical conditions such as diabetes and Celiac disease, may be promising (due to the low starch content and the absence of gluten). On the other hand, the lipid fraction (i.e., oil) in DDGS represents a logical opportunity for value-added use as a feedstock for biodiesel production. In fact, many commercial ethanol manufacturers see this as a next step in the evolution of corn-based biorefineries. Thus, a great deal of interest currently lies in the commercial extraction of oil from DDGS (Fig. 1).

As of now, however, minimal research has been completed in terms of quantifying physical properties of DDGS; and none has been reported for low-oil DDGS. Physical and chemical property information is essential for the design of transportation systems, unit operations, processing facilities, and storage structures; this information is needed by industry. Thus, the specific objective of this research was to report initial findings for some physical and chemical properties of DDGS that had the oil removed via commercial extraction (i.e., for potential biodiesel applications).

2. Materials and methods

Samples of commercial solvent extracted DDGS were collected from a dry grind corn ethanol processing facility in eastern South Dakota during 2007. Fourteen 1.0 L samples were collected and stored at room temperature (24 ± 1 °C) in sealed plastic buckets.

Fig. 1 – Low-oil distillers dried grains with solubles (DDGS).

All physical property determinations, except moisture content, were conducted at room temperature. Moisture content was determined following ASAE Method S352.2 [12], using a forced-convection laboratory oven (Thelco Precision, Jovan Inc., Wincester, VA) at 103 °C for 72 h. Water activity was measured using a calibrated water activity meter (AW Sprint TH 500, Novasina, Talstrasse, Switzerland). Thermal conductivity, resistivity, and diffusivity were determined with a thermal properties meter (KD2, Decagon Devices, Pullman, WA), which utilized the line heat-source probe technique [13]. Bulk density was measured using a standard bushel tester (Seedburo Equipment Co., Chicago, IL) following the method prescribed by USDA [14]. Angle of repose was determined by allowing DDGS to fall onto a 44 mm diameter circular plate following the method described by Mohsenin [15]. Color was measured using a spectrocolorimeter (LabScan XE, Hunter Associates Laboratory, Reston, VA) using the L-a-b opposable color scales [16].

Proximate composition was also determined for the samples. Crude protein, fiber, fat, and ash contents were determined following the official Method 990.03, 978.10, 920.39, and 942.05, respectively [22]. Nitrogen free extract (NFE) was then determined by the difference.

For each physical property studied, three replicates from each of the 14 samples were measured; this resulted in a total of $n = 42$ total observations for each property. Single replicates ($n = 1$) were measured for the chemical properties of each sample, which resulted in a total of 14 observations for each chemical property. Statistical analyses on all collected data were performed via Microsoft Excel™ v.2003 (Microsoft Corporation, Redmond, WA) software.

3. Results and discussion

Summary statistics included minimum, maximum, mean, and standard deviations for each property. Results for the physical properties are provided in Table 1; chemical property results are given in Table 2. Physical properties for low-oil DDGS are comparable to those determined by Rosentrater [17], who examined properties of typical, unmodified DDGS. Moisture content values for low-oil DDGS ranged between 7.04 and 8.83% (db – dry basis), which indicated that these samples were fairly dry – a necessity for transporting and storing these materials. Moisture content values were somewhat higher in unmodified DDGS (13.2–21.2%) [17]. Water activity (a measure of the free water available for microbial growth) results for low-oil DDGS ranged between 0.225 and 0.244, compared to unmodified DDGS values of 0.53–0.63 [17]. Lower values are indicative of a long potential shelf life, because very little free water is available for microorganism growth. Water activity values must remain below approximately 0.91 to prevent bacterial growth, below 0.87 to inhibit molds, and below 0.80 to stop yeast growth [18].

Low-oil and unmodified samples [17] both demonstrated similar thermal conductivity levels, ranging from 0.06 to 0.08 W m^{-1} °C^{-1}. These low values indicated that both the unmodified as well as the extracted DDGS's ability to conduct heat energy is quite low. Water content typically raises the thermal conductivity level in biological materials; however, these DDGS samples contained little water. Unmodified DDGS values were similar, with a range of 13.1–15.6 m °C W^{-1} [17]. Based upon the findings of thermal conductivity and resistivity, it was not surprising to find that low-oil and unmodified DDGS samples both had low thermal diffusivity. Values varied between 0.13 and 0.15 mm^2 s^{-1}, and generally indicated an inability to further conduct and store heat once it has been transferred into the grain mass [19].

A crucial parameter related to the storage and transport of distillers grains is bulk density. Low-oil values varied between 469.4 and 493.8 kg m^{-3}, compared to unmodified DDGS values ranging from 389.3 to 501.5 kg m^{-3} [17]. These ranges were similar to each other, indicating packing of DDGS for transportation would be comparable for low-oil and unmodified DDGS. Another key parameter for storage is angle of repose. Results for low-oil DDGS showed a range between 19.94° and 24.30°. These values dictate the quantity of DDGS that can be piled into storage facilities such as bins, tanks, trucks, or railcars. Values were somewhat lower than unmodified DDGS, which ranged from 26.5° to 34.2° [17]. This indicated that an increased quantity of the low-oil DDGS could be placed into freight cars and storage bins compared to the unmodified DDGS.

Color has been shown to be a possible indicator of nutritional value, especially nutrient digestibility [20]. Although these results are not completely conclusive, color differences

Table 1 – Physical properties of low-oil distillers dried grains with solubles (DDGS).

Physical property	Number of observations	Minimum	Maximum	Mean	Standard deviation
Moisture content (%, db)	42	7.04	8.83	7.74	0.54
Water activity (–)	42	0.225	0.244	0.235	0.005
Thermal					
Conductivity (W m^{-1} °C^{-1})	42	0.06	0.08	0.07	0.00
Resistivity (m °C W^{-1})	42	12.90	15.60	14.00	0.57
Diffusivity (mm^2 s^{-1})	42	0.13	0.15	0.14	0.01
Bulk density (kg m^{-3})	42	469.4	493.8	482.2	5.0
Angle of repose (°)	42	19.94	24.39	21.74	1.33
Hunter color values					
Hunter L (–)	42	52.45	56.69	54.10	0.83
Hunter a (–)	42	5.97	7.57	7.23	0.26
Hunter b (–)	42	18.70	22.03	21.15	0.49

Table 2 – Chemical properties of low-oil distillers dried grains with solubles (DDGS).

Chemical property	Number of observations	Minimum	Maximum	Mean	Standard deviation
Crude protein (% db)	14	33.4	34.7	34.0	0.3
Crude fiber (% db)	14	7.5	9.3	8.4	0.6
Crude fat (% db)	14	2.3	3.4	2.7	0.3
Ash (% db)	14	4.8	4.9	4.8	0.1
Nitrogen free extract (% db)	14	48.9	51.3	50.1	0.8

can often be an indication of compositional differences. Hunter L values lie on a scale of 0 = black to 100 = white, indicating sample darkness to lightness. For the extracted DDGS in this study, the low-oil DDGS Hunter L values ranged from 52.45 to 56.69. Hunter a color value indicates the amount of green (−) to red (+) exhibited by a material. The low-oil DDGS had Hunter a values between (+) 5.97 and 7.57. Finally, Hunter b values quantify the relative blue (−) to yellow (+). These low-oil DDGS samples had Hunter b values ranging between (+) 18.70 and 22.03. The low-oil distillers grains samples were ''pale yellow'' in appearance, in comparison to the color of untreated distillers grains, which generally appear ''golden yellow''. Values from unmodified DDGS have been shown to have Hunter L values between 40.0 and 49.8; Hunter a values between 8.0 and 9.8; and Hunter b values between 18.2 and 23.5 [17]. These values indicate that untreated DDGS was darker, contained more red pigments, but had similar yellow pigments compared to the low-oil counterparts examined in this study. Lowering the oil concentration and removing lipid-soluble pigments (such as carotenoids) is one potential method to brighten the color of food and feed materials, and has been the topic of other research [21].

Regarding chemical composition, the low-oil DDGS did indeed have a much reduced fat content; 2.7% (db), on average. Average protein and fiber levels were elevated (34.0 and 8.4%, db), respectively; this increase was a consequence of the reduction in the lipid content of the DDGS. These constituent values are at the high end of protein and low end of fat, which have been reported elsewhere [11]. Ash content of the low-oil DDGS was 4.8% (db), which falls within the typical range of most DDGS previously examined [11].

The DDGS samples used in this study were examined at room temperature; moisture content was not altered from the original shipping levels. Variables such as moisture content, temperature, and humidity can ultimately affect physical properties and chemical structures. An understanding of DDGS according to these synergisms is imperative, as the results will impact design and utilization considerations for applications areas such as manufacturing, processing, transporting, and storage.

4. Conclusions

The purpose of this paper was to quantify physical and chemical property data for DDGS that had the oil extracted. Moisture content, water activity, thermal properties, bulk density, and angle of repose values were similar to traditional DDGS, which has not had the oil removed. Color, on the other hand, was impacted by the oil extraction, as low-oil DDGS was ''paler'' in nature compared to untreated counterparts. Physical property data are important to industry, as they are necessary for the design of equipment, processes, facilities to handle and store, transportation methods, and value-added applications for coproduct streams. This research represents an initial stage in value-added product development, and in assessing next-general fuel ethanol coproduct streams.

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