Environ Sci Pollut Res (2017) 24:15401–15405
DOI 10.1007/s11356-017-9130-2

RESEARCH ARTICLE

A survey of mycotoxin contamination and chemical composition of distiller's dried grains with solubles (DDGS) imported from the USA into Saudi Arabia

Alaeldein M. Abudabos[1] · **Raed M. Al-Atiyat**[1] · **Rifat Ullah Khan**[2]

Received: 5 September 2016 / Accepted: 26 April 2017 / Published online: 15 May 2017
© Springer-Verlag Berlin Heidelberg 2017

Abstract Distiller's dried grains with solubles (DDGS) is a source of nutritional feedstuff for poultry farmers and industry. The DDGS is a by-product of ethanol industry and an economical feed source of energy, amino acids, crude fiber, minerals, and vitamins. The use of DDGS as a feed ingredient is a novel idea and little information is available on its dietary composition. Many factors such as the type of plants, locality, year of production, and the conditions during distillation process affect the chemical composition of DDGS. In this paper, the chemical composition and the presence of mycotoxin in DDGS imported from the USA into Saudi Arabia as a feedstuff for poultry have been documented.

Keywords Distiller's dried grains with solubles · Poultry · Composition · Mycotoxin

Introduction

Corn distiller's dried grains with solubles (DDGS) is produced during ethanol production. During this process, the non-fermentable products such as protein, fat, vitamins, minerals, and fiber are separated as DDGS (NRC 1994; Salim et al. 2010). Increased production of ethanol is associated with the increased production of DDGS especially in the USA which plays a leading role in the world, since 50% of the grains are produced in this country (Salim et al. 2010). Domestically, the DDGS produced in the USA is used as livestock feed as well as exported to the outside especially Asia. Except starch, DDGS is considered a rich source of crude proteins, minerals, fibers, and other nutrients (Swiatkiewicz and Koreleski 2008). A number of factors determine the exact composition of DDGS such as source of corn, level of converting starch to ethanol, duration, and temperature of drying process (Salim et al. 2010). Swiatkiewicz and Koreleski (2008) concluded that DDGS could be safely used at 5–8% in broiler and turkey feed during the starter phase and 10–15% dietary level during growing phase and thus could successfully replace costly feed items such as cereal grains and soybean.

The increased price and scarcity of protein for animal production has led to the development of utilization of DDGS. However, DDGS may pose a serious threat to animal health due to the presence of toxic compounds such as mycotoxins (Rodrigues and Chin 2012). For the animal scientists, the composition of DDGS is of great interest due to its wide use as feed ingredient for livestock. The composition analysis is mainly focused on the nutritional value of DDGS such as amino acid and energy profile, nutrient digestibility, and mineral contents (Kim et al. 2008). Thus, a complete chemical analysis of DDGS should be performed according to a standardized method before formulating diet for poultry, since DDGS is increasingly available as a feed ingredient.

This study was conducted to evaluate the representative imported samples of DDGS from the USA into Saudi Arabia for the parameters most important for poultry production.

Responsible editor: Philippe Garrigues

✉ Alaeldein M. Abudabos
aabudabos@ksu.edu.sa

[1] Department of Animal Production, College of Food and Agriculture, King Saud University, Riyadh, Saudi Arabia

[2] Department of Animal Health, Faculty of Animal Husbandry & Veterinary Sciences, The University of Agriculture, Peshawar, Pakistan

Materials and methods

Sample collection and analysis

Arrangements were made with three feed mills/farms in Saudi Arabia to get samples of DDGS upon arrival. One hundred and fifty DDGS samples were obtained from three feed mills in Saudi Arabia. Samples were vacuum sealed and stored in a freezer at −20 °C until the time of analysis. The analysis of the samples includes dry matter (AOAC-930.15), moisture (100-dry matter), ash (Method 942.05, AOAC 2000), crude protein (AOAC-2001.11), crude fiber (AOAC-978.10), crude fat (AOAC-2003.06), acid detergent fiber (Method 973.18, AOAC 2000), and neutral detergent fiber (Van Soest et al. 1991). Cellulose was calculated as the difference between neutral detergent fiber (NDF) and acid detergent fiber (ADF). The concentrations of Arabinose and xylose were determined using trifluoacetic acid treatment (Dien et al. 1997) and phosphorus (985.01, AOAC 2000).

The amino acid composition was determined after acid hydrolysis (Method 994.12; AOAC 2002), and the total sulfur amino acid composition was determined after performing acid oxidation followed by acid hydrolysis (Method 994.12; AOAC 2002). The fatty acid composition was determined for 15 samples (Method 996.01).

The mycotoxin test was performed by high-performance liquid chromatography (HPLC), and samples were analyzed for aflatoxins B_1 (AFB_1), B_2 (AFB_2), G_1 (AFG_1), and G_2 (AFG_2) (AOAC-990.33). Aflatoxin total (AF_{total}) was determined by adding aflatoxins B_1, B_2, G_1, and G_2. Deoxynivalenol (DON) (Kotal and Radova 2002); fumonisins B_1 (FB_1), B_2 (FB_2), and B_3 (FB_3) (Method 995.15, AOAC 2000), fumonisinsol total (FB_{total}) was determined by adding fumonisins B_1, B_2, and B_3; and zearalenone (ZEA) (MacDonald et al. 2005).

Results

A summary of the average composition of DDGS samples on a dry matter basis, amino acid profile, and fatty acid profile is given in Tables 1, 2, and 3. The moisture content is 7.1%, crude protein is 28.9%, crude fat is 6.1%, crude fiber is 8.17%, ADF is 9.9%, NDF is 26.9%, hemicellulose is 17.0%, phosphorus is 0.7%, and ash is 6.0%. Xylan and arabinan were determined to be 8.2 and 5.3%, respectively. The apparent metabolizable energy (AMEn) was calculated to be 2854 kcal/kg (Table 1).

The amino acid composition for DDGS ($n = 30$) is listed in Table 2. The lysine, methionine, cysteine, total sulfur amino acid, threonine, phenylalanine, and histidine contents of DDGS were measured to be 1.06, 0.58, 0.63, 1.21, 1.22, 1.90, and 0.93%, respectively.

The fatty acid composition for DDGS ($n = 15$) is listed in Table 3. The palmitic acid $C_{16}H_{32}O_2$, oleic acid $C_{18}H_{34}O_2$, and linoleic acid $C_{18}H_{32}O_2$ were the major components of the fatty acid profile (21.05, 22.12, and 49.92%, respectively).

By comparing the chemical analyses obtained in this trial to one of the reference (Mirasco, USA), it was found that moisture content, crude protein, crude fiber, NDF, ADF, and ash were higher for the reference (10.85, 30.82, 8.22, 27.17, 10.43, and 6.68%, respectively). The amino acid composition was very comparable to the reference. The results for mycotoxin analyses for the 150 samples of DDGS are presented in Table 4. The percent of samples tested positive for AFB_1, AFB_2, AFG_1, AFG_2, AF_{total}, DON, FB_1, FB_2, FB_{total}l, and ZEA were 14.0, 6.0, 2.7, 4.0, 14.0, 28.7, 25.3, 23.3, 6.0, 25.3, and 34.7%, respectively. ZEA was the most predominant mycotoxin present in 34.7% of analyzed samples with an average of 167.6 μg/kg, followed by DON which was found in 28.7% of analyzed samples with an average of 3.0 mg/kg, followed by FB_{total} which was found in 25.3% of analyzed

Table 1 Composition (dry matter basis) of distiller's dried grain with solubles (DDGS)

Analysis (%)	Mean	Median	Std. deviation	SEM	Maximum	Minimum	Range
Moisture	7.1	6.9	0.87	0.07	10.6	5.1	5.6
Crude protein	28.9	28.9	0.92	0.08	32.3	26.4	5.9
Crude fat	6.1	6.1	0.72	0.06	8.2	5.0	3.2
Crude fiber	8.1	8.1	0.68	0.06	10.1	6.2	4.0
ASH	6.0	6.2	0.77	0.06	8.3	4.3	4.0
ADF	9.9	10.0	0.63	0.05	11.0	8.1	2.9
NDF	26.9	27.0	0.94	0.08	28.9	24.1	4.8
Hemicellulose	17.0	17.0	0.86	0.07	19.3	14.7	4.6
Phosphorus	0.7	0.7	0.03	0.00	0.8	0.4	0.4
Xylan	8.2	8.2	0.13	0.01	8.7	7.9	0.8
Arabinan	5.3	5.3	0.12	0.01	5.5	4.7	0.8
ME	2854	2858	35.19	2.87	2922	2680	242.0

ME metabolizable energy

Table 2 Amino acid analysis of DDGS samples

Amino acid	Mean	Median	Std. deviation	SEM	Maximum	Minimum	Range
Lysine	1.06	0.98	0.36	0.07	1.91	0.69	1.22
Methionine	0.58	0.59	0.06	0.01	0.69	0.45	0.24
Cysteine	0.63	0.64	0.03	0.01	0.68	0.58	0.10
Total sulfur amino acid	1.21	1.22	0.06	0.01	1.34	1.09	0.25
Threonine	1.22	1.19	0.16	0.03	1.72	0.98	0.74
Phenyl alanine	1.90	1.73	0.61	0.11	3.46	1.22	2.24
Histidine	0.93	0.94	0.04	0.01	0.99	0.85	0.14
Isoleucine	1.20	1.16	0.27	0.05	1.83	0.13	1.70
Leucine	2.99	3.01	0.28	0.05	3.40	2.10	1.30
Tyrosine	1.61	1.50	0.66	0.04	2.05	1.39	0.66
Arginine	1.59	1.51	0.27	0.05	2.29	1.30	0.99
Aspartic acid	2.59	2.63	0.43	0.08	3.66	2.02	1.64
Serine	1.41	1.42	0.09	0.02	1.66	1.24	0.42
Glutamine	5.21	5.17	0.22	0.04	6.02	4.99	1.03
Alanine	1.98	2.01	0.21	0.04	2.30	1.41	0.89
Valine	1.42	1.43	0.07	0.01	1.54	1.20	0.34
Glycine	1.25	1.25	0.05	0.01	1.37	1.11	0.26

samples with an average of 1.01 mg/kg, and finally AF_{total} which was present in 14.0% of samples with average of 6.3 μg/kg (1755 g/kg; median of positive 1393 g/kg). OTA and AF were the less prevalent groups of mycotoxins, present in 25% (average 2 g/kg; median of positive 4 g/kg) and 19%.

Discussion

The DDGS contains all the essential nutrients except starch which is converted into ethanol during fermentation. Since most of the starch is converted into ethanol, therefore, several folds increase in the concentration of the remaining nutrients are expected. The DDGS could be a rich source of amino acids, minerals, and other important nutrients for poultry. The composition of DDGS is high variable; therefore, a complete analysis is essential before formulating a poultry feed (Spiehs et al. 2002; Abd El-Hack et al. 2015).

The nutritive values of DDGS imported into Saudi Arabia are mostly in the range reported for the corn DDGS imported into Korea from the USA (Salim et al. 2010). The mean ME value reported in this study was slightly higher than the values reported

Table 3 Fatty acid analysis of DDGS samples

Fatty acid	Mean	Median	Std. deviation	SEM	Maximum	Minimum	Range
Myristic acid $C_{14}H_{28}O_2$	0.07	0.07	0.004	0.001	0.07	0.06	0.01
Palmitic acid $C_{16}H_{32}O_2$	21.05	22.59	5.198	1.342	23.24	2.40	20.84
Palmitoleic acid $C_{16}H_{30}O_2$	0.37	0.33	0.239	0.062	1.19	0.15	1.04
Heptadecanoic (margaric) acid $C_{17}H_{34}O_2$	0.05	0.05	0.007	0.002	0.06	0.04	0.02
Stearic acid $C_{18}H_{36}O_2$	2.66	2.66	0.097	0.025	2.87	2.51	0.36
Elaidic acid $C_{18}H_{34}O_2$	0.02	0.02	0.004	0.001	0.02	0.01	0.01
Oleic acid $C_{18}H_{34}O_2$	22.12	22.10	0.436	0.113	22.80	21.20	1.60
Methyl (8E,11E)-8,11-octadecadienoate $C_{18}H_{32}O_2$	0.18	0.15	0.175	0.045	0.80	0.02	0.78
Linolelaidic acid $C_{18}H_{32}O_2$	0.09	0.06	0.135	0.035	0.58	0.04	0.54
Linoleic acid $C_{18}H_{32}O_2$	49.92	49.99	0.787	0.203	51.56	48.33	3.23
3,6-octadecadienoic acid, methyl ester $C_{19}H_{34}O_2$	0.85	0.84	0.333	0.086	1.97	0.49	1.48
Linolenic	1.38	1.38	0.032	0.008	1.43	1.33	0.10
11-eicosenoic acid $C_{20}H_{38}O_2$	0.20	0.20	0.027	0.007	0.27	0.16	0.11
Docosanoic (bhenic) acid $C_{22}H_{44}O_2$	0.13	0.14	0.023	0.006	0.18	0.09	0.09
Tetracosanoic (lignoceric) acid $C_{24}H_{48}O_2$	0.26	0.26	0.019	0.005	0.31	0.24	0.07

Table 4 Mycotoxin analysis of DDGS samples

Mycotoxin (μg/kg)	Mean	Median	Std. deviation	SEM	Maximum	Minimum	Range
Aflatoxin B_1	5.8	5.1	2.18	0.47	9.9	1.0	8.9
Aflatoxin B_2	0.5	0.5	0.09	0.03	0.6	0.3	0.3
Aflatoxin G_1	0.5	0.5	0.15	0.07	0.7	0.4	0.3
Aflatoxin G_2	0.8	0.9	0.26	0.11	1.1	0.5	0.7
Aflatoxins total	6.3	5.4	2.60	0.57	11.3	1.0	10.3
Deoxynivalenol	3.0	2.2	2.24	0.34	8.1	0.8	7.3
Fumonisinsol B_1	1.64	1.48	0.78	0.13	3.64	0.43	3.21
Fumonisinsol B_2	0.59	0.40	0.50	0.085	2.10	0.21	4.1
Fumonisinsol B_3	0.36	0.30	0.16	0.05	0.65	0.21	0.44
Fumonisinsol total	1.01	0.88	0.55	0.09	2.20	0.21	1.99
Zearalenone	167.6	117.5	109.65	15.21	501.0	33.0	468.0

by NRC (1994) for poultry, Waldroup et al. (1981) and Applegate et al. (2009) for broilers, Roberson et al. (2005) for layers, and Noll et al. (2005) and Noll and Brannon (2005) for turkeys. The difference in ME value reported depends upon the type of plants and geographical location. The high energy content has been attributed to a high level of fat in corn DDGS (Swiatkiewicz and Koreleski 2008).

Spiehs et al. (2002) reported nutrient content of DDGS from plant sources and found that crude protein was 30.2%, crude fiber 8.8%, crude fat 10.9%, ash 5.8%, NDF 42.1%, ADF 16.2%, lys 0.85%, met 0.55%, and P 0.89%. Cromwell et al. (1993) reported the nutritional composition of DDGS as follows: fat from 2.9 to 12.8%, crude protein ranged from 23.4 to 28.7%, ADF from 10.3 to 18.1%, ash from 3.4 to 7.3%, NDF from 28.8 to 40.3%, methionine (met) from 0.44 to 0.55%, tryptophan (trp) from 0.16 to 0.23%, lysine (lys) from 0.43 to 0.89%, and threonine (thr) from 0.89 to1.16%. The higher variability in the reported composition of DDGS in different studies could be due to the variability in plants, year of production, and efficiency of starch fermentation (Swiatkiewicz and Koreleski 2008). Salim et al. (2010) reported that CP content of DDGS imported from USA into Korea was 27.15%. The CP content of DDGS we analyzed was higher (28.9%) than reported by Salim et al. (2010). Dale and Batal (2005) found 24–29% CP in DDGS, while Spiehs et al. (2002) reported 30.2% CP from Minnesota and South Dakota. Reese and Lewis (1989) reported 7.8 to 10% CP in DDGS in Nebraska. The possible variations may be due to the differences in the varieties of DDGS, drying procedures, amount of soluble or syrup, and geographical locations. The crude fat and ADF reported in this study are slightly lower, while crude protein, crude fiber, and ash concentration were similar to the report of Belyea et al. (2004). Variability is the most prominent in two limiting amino acids (lysine and methionine) for poultry (Spiehs et al. 2002).

Higher phosphorous (P) availability has been reported in DDGS in comparison to cereals grains (Lumpkins and Batal 2005). Phosphorous is available in the form of phytate and poultry requires phytase enzyme to separate P from phytate (Nelson 1967). The higher P availability may be due to the fermentation process, drying, and temperature. The DDGS is an excellent source of P in poultry feed. The *P* value reported in this study is closely agreed with Martinez-Amezcua et al. (2004) who reported 0.73% P in 20 DDGS samples collected from Minnesota and NRC (1994).

Mycotoxins can easily colonize the crop and may adversely affect health and productivity of birds. Rodrigues (2008) reported that 99% of DDGS samples are positive to the presence of mycotoxins. Commonly, five types of mycotoxins occurring in DDGS are deoxynivalenol (vomitoxin), zearalenone, fumonisin, ochratoxin, and aflatoxin (Wu and Munkvold 2008). Recently, numerous studies have reported detectable mycotoxins in DDGS which have increased the concerns about US imported DDGS. Rodrigues (2008) reported that 99% of the samples showed at least one detectable mycotoxins including aflatoxin, deoxynivalenol, fumoninsin, T-2 toxin, and zearalenone. Tangendjaja (2008) found aflatoxin B1, zearalenone, and deoxynivalenol to the tune of 24, 333, and 2130 ppb, respectively, in DDGS samples. A survey covering 409 DDGS samples over 5-year duration worldwide, only 2% samples showed a contamination level below the detectable limit, 6% samples were positive for at least 1 mycotoxin, and 92% samples were contaminated with two or more types of mycotxins (Rodrigues and Chin 2012).

Conclusion

Based upon the result of the present study, it can be concluded that DDGS could be a source of high-quality nutrients in poultry feed. It provides a rich source of amino acids, energy, xanthophylls, minerals, and other nutrients and could successfully replace expensive feed ingredients such as cereal grains and soybean. In addition, the product was also contaminated with various types of mycotoxins.

Acknowledgements This project was funded by the National Plan for Science, Technology and Innovation (MAARIFAH), King Abdulaziz City for Science and Technology, Kingdom of Saudi Arabia, Award Number (12-AGR-2495-02).

References

Abd El-Hack ME, Alagawany M, Farag MR, Dhama K (2015) Use of maize distiller's dried grains with solubles (DDGS) in laying hen diets: trends and advances. Asian J Anim Vet Adv 10:690–707

AOAC Official Method 994.08, 2000. Aflatoxins in corn, almonds, brazil nuts, peanuts, and pistachio

AOAC Official Method 994.12 (2002) Official Methods of Analysis of AOAC International, 17th edn. AOAC International, Gaithersburg

AOAC Official Method 995.15 (2000) Natural poisons: method fumonisin B1, B2 and B3 in corn. In: Official Methods of Analysis. Association of Official Analytical Chemists, Inc., USA

Applegate TJ, Troche C, Jiang Z, Johnson T (2009) The nutritional value of high protein corn distillers dried grains for broiler chickens and its effect on nutrient excretion. Poultry Sci 88:354–359

Belyea RL, Rausch KD, Tumbleson ME (2004) Composition of corn and distillers dried grains with solubles from dry grind ethanol processing. Bio Technol 94:293–298

Cromwell GL, Herkelman KL, Stahly TS (1993) Physical, chemical, and nutritional characteristics of distillers dried grains with solubles for chicks and pigs. J Anim Sci 71:679–686

Dale N, Batal AB (2005) Distiller's grains: focusing on quality control. Poultry Science Department. University of Georgia. Athens, WATT poultry USA

Dien BS, Hespell RB, Ingram LO, Bothast RJ (1997) Conversion of corn milling fibrous co-products into ethanol by recombinant *Escherichia coli* strains K011 and SL40. World J Microbiol Biotechnol 13:619–625

Kim EJ, Amezcua CM, Utterback PL, Parsons CM (2008) Phosphorus bioavailability, true metabolizable energy and amino acid digestibilities of high protein corn distillers dried grains and dehydrated corn germ. Poult Sci 87:700–705

Kotal F, Radova Z (2002) A simple method for determination of deoxynivalenol in cereals and flours. Czech J Food Sci 20:63–68

Lumpkins BS, Batal AB (2005) The bioavailability of lysine and phosphorus in distillers dried grains with solubles. Poultry Sci 84:581–586

MacDonald SJ, Sharron A, Paul BRW, Andrew D (2005) Determination of zearalenone in barley, maize and wheat flour, polenta, and maize-based baby food by immunoaffinity column cleanup with liquid chromatography. J AOAC Intern 88(4):1733–1740

Martinez-Amezcua C, Parsons CM, Noll SL (2004) Content and relative bioavailability of phosphorus in distillers dried grains with solubles in chicks. Poultry Sci 83:971–976

National Research Council (1994) Nutrient requirements of poultry. 9th review edition. National Academy Press, Washington

Nelson TS (1967) The utilization of phytate phosphorus by poultry: a review. Poultry Sci 46:862

Noll SL, Brannon J (2005) Influence of dietary protein level and inclusion level in DDGS on performance of market tom turkeys. Minnesota Turkey Growers Association. USA, Gobbles 62(4):6–8

Noll SL, Brannon J, Kalbfleisch JL, Roberson KD (2005) Metabolizable energy value for corn distillers dried grains with solubles in turkey diets. Poultry Sci 84 (Suppl. 1): Abstract

Reese DE, Lewis AJ (1989) Nutrient content of Nebraska corn. Nebraska Cooperation Extension Service, EC 89–219 pp 5–7

Roberson KD, Kalbfleisch JL, Pan W, Charbeneau RA (2005) Effect of corn distiller's dried grains with solubles at various levels on performance of laying hens and egg yolk color. Inter J Poultry Sci 4:44–51

Rodrigues I (2008) Crucial to monitor mycotoxins in DDGS. Asian pork Magazine

Rodrigues I, Chin LJ (2012) A comprehensive survey on the occurrence of mycotoxins in maize dried distillers' grain and solubles sourced worldwide. World Mycotoxin J 5:83–88

Salim HM, Kruk ZA, Lee BD (2010) Nutritive value of corn distillers dried grains with solubles as an ingredient of poultry diets: a review. World's Poultry Sci J 66:411–432

Spiehs MJ, Whitney MH, Shurson GC (2002) Nutrient database for distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J Anim Sci 80:2639–2645

Swiatkiewicz S, Koreleski J (2008) The use of distillers dried grains with soluble (DDGS) in poultry nutrition. World's Poultry Sci J 64:257–265

Tangendjaja B (2008) Update on DDGS quality consideration. In: 16th Annual ASA-IM SEA Feed Technology and Nutrition Workshop, May 26–30. The Regent, Singapore

Van Soest PJ, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J Dairy Sci 74:3583–3597

Waldroup PW, Owen JA, Ramsey BE, Whelchel DL (1981) The use of high levels of distillers dried grains plus solubles in broiler diets. Poultry Sci 60:1479–1484

Wu F, Munkvold GP (2008) Mycotoxins in ethanol co-products: modeling economic impacts on the livestock industry and management practices. J Agr Food Chem 56:3900–3911