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Compositional profile and variation of Distillers Dried Grains with Solubles from various origins with focus on non-starch polysaccharides

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ABSTRACT

Corn-, wheat- and mixed cereal Distillers' Dried Grains with Solubles (DDGS) were investigated for compositional variability among DDGS origins, ethanol plants, and the relationship between corn and corresponding DDGS. A total of 138 DDGS samples were analyzed by use of Near Infrared Reflectance Spectroscopy for common constituents, while 63 DDGS samples along with 11 corn samples were characterized for their non-starch polysaccharide (NSP) content. The results indicated that the compositional profile of DDGS reflected the nutrient content of the parent grain but with a greater content of remaining nutrients (*e.g.* protein, fat, fibre and minerals) after fermentation of starch to ethanol. Corn DDGS differentiated from wheat DDGS by a greater content of fat ($P \leq 0.006$), insoluble-NSP ($P<0.001$), uronic acids ($P<0.001$), cellulose ($P=0.032$), and arabinose/xylose ($P<0.001$) – and uronic acid/xylose-ratio ($P<0.001$). Wheat DDGS differentiated from corn DDGS by a greater content of ash ($P=0.001$), soluble-NSP ($P<0.001$), and Klason lignin ($P<0.001$). Among the three sources of DDGS, the greatest variation was observed for the content of soluble-NSPs, especially soluble arabinoxylan. Based on the compositional profiles of the DDGS, principal component analysis allowed for a visual differentiation of corn DDGS from five different ethanol plants, indicating the potential of each ethanol plant to produce DDGS with consistent compositional characteristics. Furthermore, investigation of corn and corresponding DDGS indicated that the NSP fraction is modified during the fermentation process, especially arabinoxylan, by an increase in soluble arabinoxylan proportion in DDGS. In addition, the arabinose/xylose ($P<0.001$) and uronic acid/xylose-ratio ($P<0.001$) were greater for corn, compared with corresponding DDGS, indicating modifications of the endosperm arabinoxylan during the fermentation and drying process.

Abbreviations: ADF, acid detergent fibre; AH, acid hydrolysis; A/X, arabinose-to-xylose; Cel./NSP, cellulose-to-NSP; CV, coefficient of variation CF, crude fibre; CP, crude protein; DF, dietary fibre; DM, dry matter; DDGS, distillers dried grain with solubles; EE, ether extract; I-NSP, insoluble NSP; NCP, non-cellulosic polysaccharide; aNDFom, neutral detergent fibre assayed with heat stable amylase exclusive residual ash; NIRS, near infrared reflectance spectroscopy; NSP, non-starch polysaccharides; PCA, principal component analysis; S-Ara, soluble arabinose; S-NSP, soluble NSP; S-Xyl, soluble xylose; T-NSP, total NSP; UA/X, uronic acid-to-xylose.

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1. Introduction

Distillers' Dried Grains with Solubles (DDGS) is the major co-product from the dry-grind production of bioethanol from cereal grains. After the conversion of grain starch to ethanol during the fermentation process, the non-fermentable part remains, with an increase of all nutrients except starch compared with those in the parent grain. For both corn- and wheat DDGS an increase of approximately 3-fold of nutrients such as protein, fat, vitamins, minerals and fibre is observed (Widyaratne and Zijlstra, 2007; Stein and Shurson, 2009).

Compositional variability of DDGS from various bioethanol plants has previously been reported for both corn (Spiehs et al., 2002; Belyea et al., 2004; Batal and Dale, 2006; Liu, 2011), and wheat origins (Nyachoti et al., 2005; Bandegan et al., 2009; Cozannet et al., 2010). The variability in the chemical composition of DDGS is due to a number of factors including differences in processing technologies among the bioethanol plants, and variability in chemical composition of the grains (Liu, 2011; Olukosi and Adebiyi, 2013). The majority of the reported compositional profiles of DDGS have focused mainly on common constituents such as crude protein (CP), crude fibre (CF), neutral detergent fibre, acid detergent fibre (ADF), fat, minerals, and amino acids (Liu, 2011; Olukosi and Adebiyi, 2013). Non-starch polysaccharides (NSP) make up 25–30% of the DDGS, with the two major components of the NSP being arabinoxylan and cellulose. Arabinoxylan consists of D-xylose units joined by β-linkages substituted with arabinose residues along the chain (Kim et al., 2008). The substitution of arabinose occurs randomly allowing other substitutes such as D-glucuronic acid and acetyl groups to attach to the xylan backbone (Bedford, 1995). These random substitutes together with feruloylated arabinose residues induce the arabinoxylan cross-linking to form strong heterogeneous intermolecular complexes, affecting the potential for enzymatic degradation along with the potential encapsulation of nutrients within the cell wall (Hartley, 1973; Lequart et al., 1999; Lapierre et al., 2001; Piber and Koehler, 2005). Despite the high content of NSPs in DDGS detailed characterization of the NSPs in DDGS is limited as only a few reports describe the NSP composition (Widyaratne and Zijlstra, 2007; de Vries et al., 2013). Characterization of the NSP composition in DDGS of various origins may contribute to the overall understanding and interpretation of opportunities and limitations in DDGS degradation *in vitro* and *in vivo*, which is particularly useful for feed manufactures and enzyme producers targeting DDGS degradation.

The current study describes the compositional profiles and extent of variation in DDGS from three different grain origins; corn, wheat, and mixed cereal. A total of 138 DDGS samples from three sources of grain and 24 different bioethanol plants were analyzed based on the common constituents, with detailed NSP profiles of 63 DDGS samples. Multivariate data analysis was applied to the compositional data to determine grouping and separation of DDGS samples according to grain origins and bioethanol plants.

2. Materials and methods

2.1. Materials

A total of 138 DDGS samples were collected from 24 ethanol plants in the U.S. and E.U., covering the following three parent grain origins; corn, wheat, and a mix of cereal (mixed).

A total of 72 corn DDGS samples were collected from 21 different ethanol plants in the U.S.; 11 DDGS samples along with 11 corn samples were sampled over 11 months with one sample every month from a plant in Nevada (P1), 17 samples were sampled over 1½ months from a plant in Minnesota (P2), 10 samples were sampled over 20 days from another plant in Minnesota (P3), 10 samples were sampled over 20 days from a plant in Wisconsin (P4), 8 samples were sampled over 8 days from a plant in Iowa (P5), and 16 samples were supplied by a DDGS supplier in Iowa, representing samples from 7 plants in Minnesota, 4 plants in Iowa, 2 plants in Nevada, and 1 plant in Illinois, Indiana and Kentucky.

A total of 56 wheat DDGS samples were collected from 2 different ethanol plants in the E.U., with 46 samples from a plant in the U.K. sampled over a period of app. 3 months, and 10 samples from a plant in France sampled over 20 days.

Finally, 10 DDGS samples of a mixed grain origin were sampled over 20 days from a plant in Sweden. The parent grains used in the production of the mixed DDGS were wheat, triticale, barley, and rye. However, their individual proportion is unknown.

2.2. Chemical analysis

All 138 DDGS samples (72 corn, 56 wheat, and 10 mixed) and 11 corn samples were milled (0.5 mm) and scanned from 1100 to 2498 nm by near infrared reflectance spectroscopy (NIRS) on a FOSS NIRSystems 5000 (Foss). The spectral data were predicted by Aunir, AB Agri Ltd., UK, for the composition of: moisture, fat ether extract (EE), fat acid hydrolysis (AH), CP ($N \times 6.25$), CF, ash, starch, total sugars, aNDFom and ADF, using the calibration available for DDGS and corn, respectively.

A total of 63 DDGS samples (47 corn, 11 wheat, and 5 mixed) and 11 corn samples were quantified for total and soluble NSP content along with their constituent sugars by gas–liquid chromatography for neutral sugars and by a colorimetric method for uronic acids, with procedure and calculations according to Bach Knudsen (1997), with the modification that 2 mol/L sulfuric acid for 1 h was used to hydrolyze the non-cellulosic polysaccharides (NCP) rather than 1 mol/L sulfuric