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Evaluation of value-added components of dried distiller's grain with solubles from triticale and wheat

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ABSTRACT

This study focused on the detection of value-added co-products in dried distiller's grain plus soluble (DDGS), a possibility that could open new avenues for further processing and marketing of DDGS and improving economic sustainability of ethanol industry. Varieties of triticale, wheat and two benchmarks, CPS wheat and Pioneer Hi-Bred corn, were fermented using two very high gravity (VHG) fermentation approaches: jet-cooking and raw starch processing (STARGEN fermentation). DDGS from STARGEN fermentation could be promising sources of value-added co-products. Pronghorn triticale DDGS (STARGEN fermentation) had the highest concentration of sterols (3.7 mg/g), phenolic compounds (13.61 mg GAE/g), and β-glucan (2.07%). CDC Ptarmigan DDGS (STARGEN fermentation) had the highest concentration of tocopherols and tocotrienols (107.0 μg/g), 1.93% of β-glucan, and 53.0 mg/g of fatty acids. AC Reed DDGS (STARGEN method) showed 1.97% of β-glucan. This study shows that proper choice of fermentation approach and feedstock for ethanol production could improve commercial quality of DDGS.

1. Introduction

In western Canada and Europe, wheat is used as a feedstock for fuel ethanol production (Boland, 1995). Triticale is an alternative crop for the production of fermentable starch (Wang et al., 1997, 1998). As a feedstock, triticale is able to grow in more marginal lands (Çiftci et al., 2003) and its genetic modification does not carry the same trade implications as wheat.

In the dry-grinding process for ethanol production, α-amylases and glucoamylases enzymes have traditionally been used for the pre-treatment of grains prior to fermentation. α-amylase decreases mash viscosity by breaking the α-(1,4)-glucosidic bonds of starch, producing smaller dextrin chains (Park and Rollings, 1994). This process, i.e., liquefaction, is done at high temperatures of 90–120 °C (Wang et al., 2007) with direct steam injection (jet-cooking). During subsequent saccharification, these dextrins are converted into fermentable sugars by glucoamylase. Recently, a new generation of starch hydrolyzing enzymes that are effective at cold temperatures was developed, for example, STARGEN 001 that is a cocktail of modified α–amylase and glucoamylase (Wang et al., 2007).

In ethanol industry, fermentation produces a co-product known as dried distiller's grain with solubles (DDGS). Since only starch and sugars are converted into ethanol, non-fermentable components in cereal grains are concentrated by a factor of two to three in DDGS (Weigel et al., 1997; Gibreel et al., 2009). Currently, the vast majority of the DDGS is used as an ingredient for livestock feeds (Kelsall and Lyons, 2003). However, the rapid increase in ethanol production capacity has resulted in an excess of DDGS (Fastinger et al., 2006) and identification of new value-added uses of DDGS is becoming essential for the ethanol industry to remain profitable. Cereal grains contain nutrients such as linoleic acid, dietary fiber such as β-glucan and antioxidants (e.g. vitamin E) that as a part of a diet may reduce risk factors for coronary heart disease (Truswell, 2002) and provide other health benefits (Charalampopoulos et al., 2002). These nutrients are concentrated in the DDGS; however, their concentration and thus potential for extraction has been poorly described.

The objective of this study was to detect higher value chemicals and co-products with potential commercial value in DDGS of spring and winter wheat (six cultivars) and triticale (two cultivars) resulting from ethanol fermentation in comparison to corn and CPS wheat. Simultaneous saccharification and fermentation (SSF) was used with very high gravity (VHG) mashes. Enzymatic treatment

Abbreviations: DDGS, dried distiller's grain with solubles; SSF, simultaneous saccharification and fermentation; VHG, very high gravity fermentation (fermentation that contains 27 grams or more of solids/100 grams of mash); GAE, gallic acid; DM, dry matter; GE, gross energy.

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Table 1
Fermentation data of grains by VHG fermentation methods[A].

Grain name	Total starch concentration (%)	Fermentation method	Residual starch (%)[B]	Ethanol concentration (% v/v)	Fermentation efficiency (%)[C]
Pioneer Hi-Bred corn	62.1	VHG jet-cooking	0.6^{efghi}	13.8^{def}	88.7^{bc}
		VHG STARGEN	4.5^{a}	14.5^{abcde}	84.5^{bcd}
CPS wheat	56.2	VHG jet-cooking	0.4^{fghi}	11.9^{fg}	91.3^{ab}
		VHG STARGEN	1.0^{cdefg}	13.3^{def}	85.2^{bcd}
Ultima triticale	53.8	VHG jet-cooking	0.2^{hi}	11.1^{g}	88.5^{bc}
		VHG STARGEN	0.7^{defghi}	11.9^{fg}	80.6^{cde}
Pronghorn triticale	58.9	VHG jet-cooking	0.2^{i}	13.0^{ef}	84.1^{bcd}
		VHG STARGEN	0.3^{ghi}	14.4^{abcde}	85.5^{bcd}
AC Reed wheat	61.7	VHG jet-cooking	1.9^{b}	15.4^{a}	81.0^{cde}
		VHG STARGEN	$0.9^{cdefghi}$	14.6^{abcd}	83.9^{bcde}
AC Andrew wheat	59.8	VHG jet-cooking	0.4^{fghi}	13.8^{bcde}	83.8^{bcde}
		VHG STARGEN	1.0^{cdefgh}	14.2^{abcde}	85.2^{bcd}
Average Ptarmigan wheat	63.5	VHG jet-cooking	0.3^{fghi}	15.1^{bc}	98.2^{a}
		VHG STARGEN-	$0.9^{cdefghi}$	15.0^{abc}	85.0^{bcd}
Large Ptarmigan wheat	63.5	VHG jet-cooking	1.6^{bc}	15.4^{ab}	97.2^{a}
		VHG STARGEN	0.7^{defghi}	14.1^{abcde}	80.0^{de}
CDC Ptarmigan wheat	66.1	VHG jet-cooking	1.5^{bcde}	13.6^{cde}	80.0^{de}
		VHG STARGEN	1.3^{bcde}	14.9^{abc}	82.4^{cde}
Small Ptarmigan wheat	63.8	VHG jet-cooking	1.13^{bcdef}	15.5^{a}	75.8^{e}
		VHG STARGEN	0.6^{efghi}	14.2^{abcde}	81.6^{cde}
SEM			0.14	0.27	1.44
P-value					
Grain			<0.001	<0.001	<0.001
Fermentation			<0.001	0.031	0.031
Grain × Fermentation			<0.001	<0.001	<0.001

[A] Within a column, means without a common superscript differ ($P < 0.05$).
[B] Residual starch (%) was calculated relative to the total mass of starch available at the start of fermentation.
[C] Fermentation efficiency (%) was calculated by dividing D by E where: D = gm of ethanol produced per 100 gm of starch involved in fermentation × 100 and E = 56.7 [which is the amount of ethanol (in gm) theoretically expected from complete hydrolysis and fermentation of 100 gm of starch].

coupled with "jet-cooking" and the alternative raw starch hydrolysis, based on the application of the STARGEN 001 enzyme system at 55 °C, was utilized for the generation of small amount of glucose during a short pre-saccharification step prior to fermentation. Elucidating the effects of fermentation processing steps on the recovery of value-added components in the resulting DDGS was another key objective described below.

2. Methods

2.1. Grain samples

Two triticale samples (cultivars Ultima and Pronghorn) were supplied by Alberta Agriculture and Rural Development (Lacombe, Alberta, Canada). Two samples of spring wheat (cultivars AC Reed, AC Andrew) were provided by Agriculture and Agri-Food Canada (Lethbridge, AB, Canada). Winter wheat samples of Large Ptarmigan, Average Ptarmigan, and Small Ptarmigan were provided by Western Agriculture Lab. Ltd. (Saskatchewan, Canada), whereas CDC Ptarmigan was provided by McDougall Acres (Saskatchewan, Canada). As benchmarks, CPS wheat (Alberta Agriculture and Rural Development; Barrhead, Alberta, Canada) and Pioneer Hi-Bred corn (Pioneer Hybrid Ltd.; Chatham, Ontario, Canada) were used. Grain was ground in a Jacobson-Carter Day Cutler-hammer mill (using a 1.98 mm sieve) or in a Retsch mill (model ZM 100, using a 0.5 mm sieve). Ground grain samples were stored in air-tight plastic bags at room temperature.

2.2. Enzymes, reagents, and chemicals

The STARGEN 001 (α-amylase and glucoamylase blend for processing uncooked starch), Optimash TBG (viscosity reducing) and Fermgen (protease) enzymes were provided by Genencor International (Palo Alto, CA, USA). Viscozyme Barley (viscosity reducing), Viscozyme Wheat (viscosity reducing), Liquozyme SC (α-amylase), and Spirizyme (glucoamylase) enzymes were obtained from Novozymes (Franklinton, NC, USA). Megazyme kits (Megazyme, Bray, Ireland) were used for starch and β-glucan determination. SuperStart *Saccharomyces cerevisiae* was provided by Ethanol Technology (Milwaukee, WI, USA). Urea was purchased from Fisher Scientific.

2.3. Preparation of the mash for fermentation

2.3.1. Preparation of mashes for VHG jet-cooking fermentation

Grain mashes were prepared for VHG jet-cooking fermentation using ground grains (1.98 mm, a particle size similar to what generally utilized in industry) as previously described (Gibreel et al., 2009).

2.3.2. Preparation of mashes for VHG STARGEN fermentations

The grains were milled to a particle size of 0.5 mm (this size was based on the recommendation of Genencor International to achieve optimal starch hydrolysis). The mashes were prepared as previously described (Gibreel et al., 2009).

2.4. Fermentation processes

In general, 2–3 kg of the mash of each grain (27 to 30% solids) was fermented in duplicate for 72 h in a 5-L high performance Minifors bioreactor (Rose Scientific Ltd., Mississauga, Ontario, Canada). The transfer of mashes into heat-sterilized (121 °C, 20 psi for 1 h) bioreactors and different fermentation experiments were carried out as described by Gibreel et al. (2009). Tests for microbial contamination were performed at three different stages as previously reported (Gibreel et al., 2009). Fermentation efficiency (%) was defined as the ratio between the actual and the theoretical ethanol yield × 100. The actual ethanol yield was calculated as