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Coproduct yield comparisons of purple, blue and yellow dent corn for various milling processes

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ABSTRACT

Anthocyanins can be used as naturally sourced colors in food and cosmetics. Colored corn cultivars like purple corn and blue corn are rich in anthocyanins. Potential utilization of coproducts in corn processing industry makes colored corns economically attractive for anthocyanin extraction. There is lack of information on various processing characteristics of colored corn cultivars. In this study, wet-milling, dry-milling and dry-grind characteristics of purple and blue corn were compared against yellow dent corn using 1 kg lab scale procedures to test whether these can be effectively used in industry. In wet-milling, purple and blue corn starch yields were 63.4 and 61.5% (db) as compared to 70.1% (db) for yellow dent corn. In dry-milling, total endosperm yield was largest for yellow dent corn and minimum for blue corn at 84.9 and 77% (db), respectively. All the corn types had softer endosperm. In dry-grind process, final ethanol concentration was largest for yellow dent corn at 17.2% (v/v) and lowest for blue corn 14.3% (v/v). DDGS yield was highest for purple corn 41.6% (db) and lowest for yellow dent corn 32.9% (db). Purple and blue corn can potentially be used in all the three milling processes with yield differences being offset by health promoting properties of various coproducts recovered. This study will provide a valuable insight about various milling properties of purple and blue corn to the processing industry.

1. Introduction

In the year 2014, US corn processing industry processed almost 47% of the 14.2 billion bushels of corn harvested. Dry-grind industry alone utilized 5.4 billion bushels of corn producing 14.3 billion gallons of ethanol and 36 million metric tons of distillers dried grain with solubles (DDGS) used as animal food. Wet-milling and dry-milling industry together processed another 1.3 billion bushels (National Corn Growers Association, 2015; Renewable Fuels Association, 2015). Due to wide fluctuations in corn and coproduct prices, industry is increasingly looking for higher value coproducts (Rosentrater, 2007 and Rodriguez et al., 2010). Some of the value-added coproducts that have been proposed are biodegradable plastics (Bothast and Schlicher, 2005), zein (Dickey et al., 2001), corn fiber oil (Moreau et al., 1996), biodegradable cat litter (Vaughn et al., 2011) and furfural (Xiang and Runge, 2014).

Some colored corn cultivars are rich in anthocyanins and can be used for their commercial extraction. Anthocyanins can potentially be used as a natural alternate to chemical colors in foods, cosmetics as well as dietary supplement. They belong to the class of flavonoids present in plant matter and are responsible for vivid colors expressed in flowers, vegetables, fruits and leaves. In addition to assisting plants in physiological functions, anthocyanins deter herbivores and parasites (Lev-Yadun and Gould, 2008) and also help in protecting plants from UV-radiation (Mazza and Miniati, 1993). More than 635 different anthocyanins have been identified in nature imparting blue, purple and red colors to plant matter (Andersen and Jordheim, 2008).

Studies have shown that high intake of anthocyanins can decrease the occurrence of some of the chronic diseases. Red wine rich in anthocyanins has been associated with low incidence of heart disease in French despite their high fat diet, popularly known as French Paradox (Renaud and de Lorgeril, 1992). Although a single class of compounds cannot account for all the health benefits, however, anthocyanins in combination with other phytochemicals are known to be powerful antioxidants, help in preventing cardiovascular diseases, demonstrate anti-carcinogenic/anti-inflammatory activities and assist in controlling obesity and diabetes (Matsumoto et al., 2002; Zhang et al., 2008 and He and Giusti, 2010). Increas-

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ing health concern among customers and documented harmful behavioral and neurological effects of synthetic dyes on children (McCann et al., 2007) are forcing food industry to look for natural food colorants to replace synthetic dyes. Wu et al. (2006) analyzed 24 different fruits, vegetables and nuts for anthocyanin contents and found out that chokeberries, elderberries, black raspberries and blueberries contained 14.8, 13.7, 6.8 and 4.8 g/kg anthocyanins, respectively. Purple corn (*Zea mays* L.), a colored variety of corn native to Andes region of South America is a rich source containing 6 g/kg anthocyanins (Yang et al., 2009). Blue corn (*Z. mays var. saccharata*) is reported to contain about 0.3 g/kg anthocyanins (Li et al., 2011).

Currently anthocyanins are recovered mainly from purple colored fruits and vegetables like blueberries, black carrots, sweetpotatoes etc. and most of the biomass ends up as processing waste. Resulting high costs associated with anthocyanin recovery have largely limited their use in food industry and there is a significant interest in exploring economical ways of recovery. In one study, possibility of using industrial purple fleshed sweetpotatoes for anthocyanin extraction has been explored (Bridgers et al., 2010). Having longer storage life and with significant anthocyanin content, colored corns can potentially be used for their recovery and remaining fractions be further utilized. Vast scale of US corn processing industry offers this unique opportunity of economically recovering anthocyanins from colored corn. However, various milling properties of these anthocyanin containing varieties of corn need to be ascertained checking their suitability for conventional corn processing industry.

There is lack of research comparing various milling characteristics of purple and blue corn with yellow dent corn. In this study wet-milling, dry-milling and dry-grind characteristics of purple and blue corn were compared against yellow dent corn using 1 kg lab scale procedures. Prime and coproduct yields of these three corn types were compared.

2. Materials and methods

2.1. Materials

Purple corn was procured from specialty foods vendor Angelina's Gourmet (Swanson, CT), Jerry Peterson Blue Organic corn was purchased from Johnny's Selected Seeds (Fairfield, ME) while high starch yielding variety of yellow dent corn (*Z. mays var. indentata*) was sourced from a major seed supplier. Moisture content (m.c.) of purple corn, blue corn and yellow dent corn were approximately 14.5, 16.2 and 12.5%, respectively. Corn was cleaned by using a 12/64" (4.8 mm) sieve for the removal of broken corn and foreign material (BCFM). For wet-milling process, corn moisture content was determined using 103 °C air-oven method (Approved Method 44-15A, AACC International, 2010). Moisture of corn flour for dry-grind process was determined with an air-oven at 135 °C for 2 h (Approved Method 44-19, AACC International, 2010). Corn moisture content for dry-milling process was measured by using an electronic moisture measurement device (GAC II, Dickey-John, Auburn, IL). Moisture contents of all the fractions were measured by using two-stage oven method. Fractions were dried overnight in 49 °C oven and moisture content of dried samples were ascertained using air-oven at 135 °C for 2 h (Approved Method 44-18, AACC International, 2010).

Physical properties of corn kernel were determined using standard procedures. Test Weight (TW) was ascertained using specified apparatus according to standard method (Approved Method 55-10, AACC International, 2010) and expressed in kilograms per hectoliter (kg/hL). Absolute density of corn was measured using ethanol column test as described in Hill et al. (1990). Thousand-kernel weight was measured using the procedure outlined by Groos et al. (2003). All physical properties were measured in triplicates.

Compositional analysis of the corn types was done for crude protein content (Method 990.03, AOAC, 2003), crude fat content (Method 920.39, AOAC, 2003) and neutral detergent fiber (Van Soest et al., 1991) at a commercial analytical laboratory (Illinois Crop Improvement Association, Champaign, IL). Starch content was measured using acid hydrolysis method described by Vidal et al. (2009). All the analyses were done in duplicate.

2.2. Milling processes

2.2.1. Wet-milling process

For wet-milling of corn, 1 kg lab scale wet-milling procedure described by Eckhoff et al. (1993) was used with slight adaptation. 1 kg corn was steeped in 2 L water, 0.5% lactic acid and 0.2% sulfur dioxide for 24 h at 52 °C using batch steeping conditions. Post steeping, steep water was measured by using 2000-ml graduated cylinder. Steeped corn with 2 L water was ground using blade inverted Waring commercial-grade blender (Dynamic Corp. of America, New Hartford City, CT) for 5 min at 4500 RPM and 500 mL water was used to clean the blender jar. Slurry and germ skimming was done in a 10 L basket using 14- and 18-mesh stainless steel screens. Germ was rinsed with 1 L water over 1-mm round hole screen for the removal of starch and fiber from germ. Degerminated slurry was finely ground using a Quaker City plate mill (Model 4-E, The Straub Co., Hartboro, PA) and further 1 L water was used to wash the mill and bucket. Finely ground slurry was then allowed to settle down for 30 min and 2 L water was decanted. Slurry was then poured on a vibrating screen of 270-mesh for separating fiber. 4 L of fresh water and 2 L decanted water was used to wash the fiber of all the starch and gluten. Starch and gluten slurry was allowed to settle down for 30 min and 4 L water was decanted before separating the starch and gluten according to the tabling procedure described in Eckhoff et al. (1993). Amount of fresh water used for starch tabling was 2 L for purple corn compared to 1 L for blue and yellow dent corn. Starch was allowed to dry on the table overnight and scraped the next day. Percentage of gluten dry matter and steep solution were determined by two-stage air-oven method. Fiber, germ and starch fractions were dried over night in 49 °C oven and moisture contents ware determined using air oven at 135 °C for 2 h (Approved Method 44-18, AACC International, 2010).

2.2.2. Dry-milling process

1 kg corn samples were dry milled employing a slightly adapted laboratory-scale dry-milling procedure with single-stage tempering proposed by Rausch et al. (2009). Corn kernel moisture was tested using electronic moisture tester and requisite amount of water was calculated to increase the moisture content to 23.5% wb. Corn kernel and water were tempered in 4 L plastic containers which rotated continuously for 20 min on horizontal axis at 0.5 rpm. Increased moisture corn was made to pass through a lab-scale horizontal drum degerminator and resulting fractions were placed in a convection oven at 49 °C for 2 h. Conditioned fractions were then sifted for 3 min over 5 mesh screen in a box sifter (Model 130-11, Great Western, Leavenworth, KS). Both the +5 and −5 fractions were roller milled in lab-scale roller mill (Allis Chalmers, Appleton, WI) twice. +5 fractions were sieved on a 10 mesh screen and +10 fractions were collected as germ and pericarp while −10 as large grits. −5 fractions were also sieved on a 10 mesh screen. +10 fractions were collected and added to germ and pericarp while −10 fractions constituted small grits and fines. −10 fractions were further sieved on 24 mesh screen, +24 fractions constituted small grits while −24 fractions were collected as fines. Germ and pericarp were separated by employing a small lab-scale aspirator (Model 6DT4, Kice Metal Products, Wichita, KS). Moisture content the frac-