Journal of Stored Products Research 61 (2015) 85–89

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

Short communication

Changes in unreacted starch content in corn during storage

Benjamin M. Plumier, Mary-Grace C. Danao*, Kent D. Rausch, Vijay Singh

Department of Agricultural and Biological Engineering, University of Illinois, Urbana, IL, 61801, USA

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form
9 November 2014
Accepted 10 November 2014
Available online 25 December 2014

Keywords:
Resistant starch
Dry grind ethanol
Distillers dried grains with solubles (DDGS)
Storage temperature
Storage time

ABSTRACT

In the dry grind process, corn is ground, mixed with process water and cooked; starch is enzymatically hydrolyzed to sugars, and subsequently fermented to ethanol by yeast. The conversion of starch into ethanol, however, is not complete as distillers dried grains with solubles (DDGS) often contain more than 5% starch. The amount of unreacted starch represents inefficiencies in the process and reducing this amount is important to improving profitability of the ethanol industry. Additionally, dry grind facilities have reported seasonal variation in ethanol yields. In order to minimize variation in ethanol yields and the amount of unreacted starch in DDGS, it is important to understand the effects that storage temperature and time have on the digestibility of the corn starch. While starch quality is largely controlled by genetics and growing conditions, postharvest practices (handling, storage, and processing conditions) also affect starch composition and structure. In this study, changes in unreacted starch content of corn during storage were monitored to provide an explanation for the seasonal variation in ethanol yields observed by dry grind facilities. Yellow dent corn was harvested in 2011 and 2012 and stored indoors, outdoors, and under refrigeration for 5–12 mo. Results with the 2011 harvest corn showed unreacted starch content ranging from 2.17 to 14.1% over a 48 wk period. Unreacted starch was more influenced by storage time, initially decreasing at a rate of 0.31% per wk during the first 10 wk and steadily increased at an average rate of 0.16% per wk for the duration of storage. Results with the 2012 harvest corn, however, showed a higher average unreacted starch content of 13.0% during 20 wk of storage and no appreciable change in unreacted starch content regardless of storage temperature.

1. Introduction

Production of ethanol from corn has become an essential fuel industry in the U.S. With the goal of producing 36 billion gallons of ethanol from corn and biomass sources by 2022 (Schnepf and Yacobucci, 2010), the ethanol industry is clearly of great economic importance. Greater process efficiency could lead to increased production so it is important to understand and be able to monitor corn quality and how it changes over time. The most common method used for converting corn into ethanol is the dry grind process, which is responsible for 86% of domestic production (Mueller, 2010). The dry grind ethanol process involves grinding corn, producing a slurry, then breaking down starch molecules with alpha amylase in the presence of heat and water. Glucoamylase is added to further break down the starch into glucose so that it can be consumed by yeast and converted into ethanol. A strong correlation between starch content and ethanol yield would be expected; however, Singh and Graeber (2005) found that there was a lack of correlation among final ethanol concentration, starch extractability, and starch content for 18 hybrids of yellow dent corn. The lack of correlation may be due to a number of factors – non-extractable starch is converted into ethanol due to the physical separation (milling), thermal treatment (cooking), enzymatic reactions (liquefaction and saccharification); other micronutrients present in the corn are required by the yeast during fermentation (Ingledew, 2009); and a certain amount of starch that is resistant to enzymatic hydrolysis is physically extracted during milling but does not ferment to ethanol. Several researchers have noted the chemical composition of the starch, specifically, its amylose to amylopectin ratio, had a significant effect on the efficacy of enzymatic hydrolysis (Jane, 2009; Ji et al., 2003; Murthy et al., 2011; Sharma et al., 2007). Resistant, or unreacted, starch in corn is highly correlated with amylose levels (Berry, 1986). Yangcheng et al. (2013) reported average starch to ethanol conversion efficiency of 93.0% for waxy corn, which has low amylose to amylopectin ratio, compared to that of regular corn (88.2%).

* Corresponding author.
E-mail address: gdanao@illinois.edu (M.-G.C. Danao).

http://dx.doi.org/10.1016/j.jspr.2014.11.006
0022-474X/

There are four main sources of resistant starches (*RS*): *RS*1, resistant starches that are sterically inaccessible to enzymes; *RS*2, starches with a crystalline structure that are undigestible unless gelatinized; *RS*3, retrograded starches; and *RS*4, chemically modified or cross-linked starch (Fuentes-Zaragoza et al., 2010; Alsaffar, 2011). In literature, the terms resistant, residual, and unreacted starch are often used interchangeably but, in this study, the term resistant starch will be used to describe starch that is resistant to acid or digestive systems and the term *unreacted starch* will be used to describe starch that is not broken down by enzymes, such as those used in the dry grind process.

RS of cereal grains is not only dependent on genetics and growing environment but handling, storage, and processing practices may encourage its development. In processed foods, *RS* is largely dependent on the degree of food processing (Englyst et al., 2007). Garcia-Rosas et al. (2009) found that making corn into tortillas increased *RS*, and *RS* continued to increase with storage time. High temperature processing techniques such as baking, boiling, and roasting also increased *RS* in corn (Rendon-Villalobos et al., 2002) and in wheat, rice, and pearl millet (Vaidya and Sheth, 2011), as well. In addition, warm holding at 65–70 °C for 1 h increased digestive *RS* from 2.2 to 4.8% and slow cooling from 3.6 to 6.3% (Gormley and Walshe, 1999). Milling is a high-shear process that damages the crystalline regions of starch granules. Any disruption of the granule structure resulting from milling increases the susceptibility of the starch to enzymatic degradation (Karkalas et al., 1992; Tester et al., 1994; Lehmann and Robin, 2007; Devi et al., 2009). Processing temperature of starch was shown to have an effect on alpha amylase/pullulanase *RS* of wheat starch, with higher autoclaving temperatures producing more resistant starch (Berry, 1986). Although higher processing temperatures cause an increase in unreacted starch content (*US*), higher temperatures in the liquefaction stage of the dry grind ethanol process can have the opposite effect. Sharma et al. (2010) found that processes that had higher temperature in the liquefaction stage were shown to have lower final *US* in the DDGS. It has also been theorized that high temperature processing with amylase may cause lipid–amylose complexes to form, serving as competitive inhibition to *RS* formation (Gruchala and Pomeranz, 1992).

Changes in the chemical structures and functional properties of grains that occur during storage are inevitable and impact processing characteristics and quality of the final products. For example, wheat dough rheology and properties tend to improve with storage time (Zeleny, 1948). *RS* content of processed foods may also be modified during storage as retrogradation of gelatinized potato starch and water mixtures (1:1 w:w) have been observed at single storage temperatures between 5 and 50 °C (Nakazawa et al., 1985). Park et al. (2009) determined when gelatinized starch from waxy corn was stored at cycled temperatures of 4 and 30 °C, amylopectin crystals of different melting characteristics formed and ultimately reduced digestibility of the starch when compared to starch gels stored at a constant 4 °C.

Similarly, dry grind facilities have observed variation in ethanol yields and residual starch content in DDGS with time (Singh, 2012). In the U.S. Midwest, most of the corn crop is harvested during September and October and corn is stored year round to provide a continuous supply of feedstock to ethanol facilities. Typically, ethanol yields are low during the first month after harvest of new

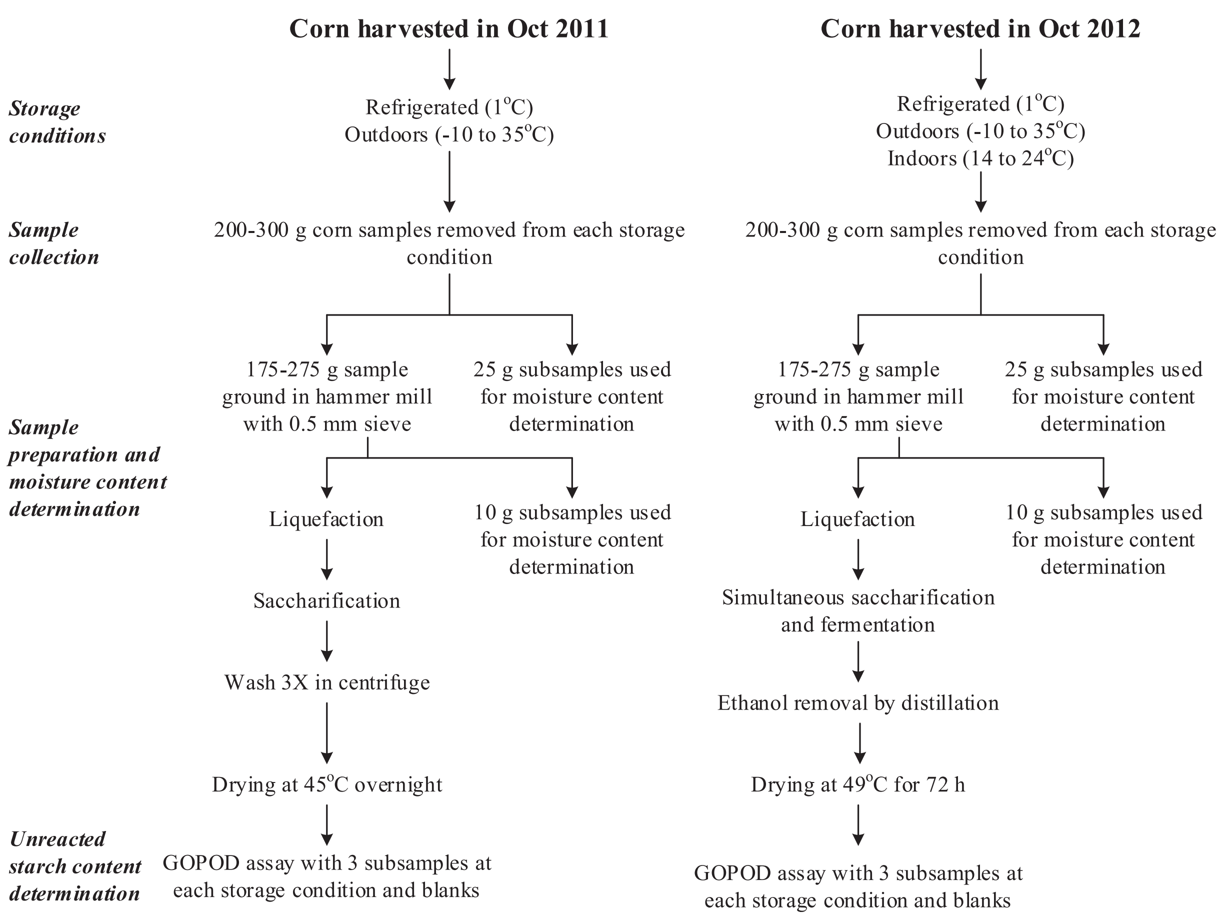

Fig. 1. Test procedure for monitoring *US* content in corn.