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Functional properties of starch from normal and mutant corn genotypes

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Abstract

The thermal and functional properties of starches from a wild-type corn, and *amylose extender25*, *dull39*, *sugary2* (*su2*), *and sugary1*(*su1*) corn mutants, all in the same (ExSeed68) genetic background were evaluated and related to their structural features obtained in a previous study. The onset temperature of gelatinization values of starches from all mutant lines ranged from 52.0 to 62.9 °C, temperatures that were all lower than that of the wild-type starch. The viscosity of the *su2* starch was relatively stable over the cooking process, showing only a small breakdown of the peak viscosity, suggesting high stability of starch granules against mechanical shear. The *su1* mutant starch formed the strongest gel among all starch-gel samples during measurements of both fresh and stored gel. Correlations were established between amylose percentage, chain-length distributions and pasting properties; Rapid Visco Analyser (RVA) and Differential Scanning Calorimeter (DSC) parameters; and DSC and texture analysis data.

Keywords: Corn starch; Structure-function; Starch pasting; Starch gels; Starch thermal properties; Starch gelatinization; Starch retrogradation; Starch texture; Corn mutants

1. Introduction

For new starches to be useful in food systems and other industrial applications, the functional properties, such as gelatinization, pasting, and retrogradation, should be fully understood. Starch functionality depends greatly on the molecular weight, size, and structure of the starch granule components, amylose (AM) and amylopectin (AP), which differ greatly in molecular-weight distribution and molecular structures. Variations in these molecular features influence pasting, retrogradation, viscoelastic, and rheological properties (Bahnassey & Breene, 1994; Morrison & Tester, 1991), which can have a major impact on the utilization of these starches in food products (Kobayashi, Schwartz, & Lineback, 1986; Yuan, Thompson, & Boyer, 1993). Starch structures differ within the same botanical source (Hizukuri, Takeda, Murata, & Juliano, 1989; Sanders, Thompson, & Boyer, 1990), but these differences are greater among starches from different botanical sources (Hizukuri, 1985, 1986; Lii & Lineback 1977; Whistler & Daniel, 1984). Differences among corn starches in granule swelling (onset of viscosity), peak temperature, peak viscosity, shear thinning during pasting, and gel firmness during storage, have been mostly attributed to differences in AP structure (Bahnassey & Breene, 1994; Doublier, Paton, & Llamas, 1987; Ring & Stainby, 1985), whereas differences in setback and final viscosity during pasting have been attributed to AM structure (Leloup, Colonna, & Buleon, 1991; Ott & Hester, 1965; Vasanthan & Hoover, 1992).

Some endosperm mutants of corn (*Zea mays* L.), such as *amylose-extender* (*ae*), *dull* (*du*), *sugary-1* (*su1*), and *sugary-2* (*su2*), impact the AM:AP ratio of the starch, the specific structures of AM and AP, and, potentially, the functional properties of the starch. For example, starch from amylomaize, a corn endosperm mutant containing the *ae* mutant gene, has an apparent AM content of up to 80% (Banks & Greenwood, 1975). In addition to the high apparent AM content, *ae* starches contain branched molecules with a higher proportion of longer chains (DP > 30) than is found in the AP of common corn starch

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(Klucinec & Thompson, 1998; Takeda, Takeda, & Hizukuri, 1993).

The relative AM content of starch in *du1* mutant kernels ranges from slightly to greatly higher than normal, depending on the genetic background (Shannon & Garwood, 1984). Starch granules from *du1* mutants seem to have normal structural and physical properties, although some abnormally shaped granules are found in the mutant endosperm (Shannon & Garwood, 1984).

The *su2* starch granules have a slightly greater percentage of apparent AM (29 vs 21%) and a lower gelatinization temperature than does normal, commercially available, corn starch (Kramer, Pfahler, & Whistler, 1958; Pfahler, Kramer, & Whistler, 1957; Li & Corke, 1999; Perera, Lu, Sell, & Jane, 2001; White, Pollak, & Johnson, 1994), and suitable pasting properties for application in starch-thickened acidic foods (White et al., 1994). The *su2* starches also retrograde less during storage than do normal starches (Campbell, White, & Pollak, 1994; Inouchi, Glover, Sugimoto, & Fuwa, 1991; White et al., 1994), and have less swelling power than does normal corn starch (Li & Corke, 1999). Also, *su2* starch has an improved nutritional quality as a result of its high susceptibility to α-amylase digestion; thus, its use has been suggested in improving animal feed value (Sandstedt, Strahan, Ueda, & Abbot, 1962).

The *su1* mutants of corn accumulate, in addition to starch, a novel form of water-soluble polysaccharide, termed phytoglycogen (Summer & Somers, 1944). The *su1* maize kernels are wrinkled, have reduced amounts of dry material, with the concentration of sugars being greater and the starch content much less than in normal corn (Creech, 1965). Yeh, Garwood, and Shannon (1981) reported widely different apparent AM percentages (0 and 65%) in the starches from *su1* mutants placed in corn of different backgrounds. The great differences, however, were likely caused not only by genetic background, but also by different environmental conditions during kernel development, kernel age, and methods of starch isolation and AM measurement during testing.

Although some structural features of the starch components for many corn endosperm mutants in a few genetic backgrounds have been characterized, and some functional features examined, variations in both structure and the related functional properties of these mutants, all in the same genetic background, have not been fully examined. Furthermore, the experimental corn line, ExSeed68, with mutants introduced, has had very little evaluation of these starch properties. Thus, the full impact of genetics on the corn-mutant starches is not known. Therefore, the objectives of this study were to characterize the thermal and functional properties of the starch from a wild-type (normal) corn starch and *amylose extender25*, *dull39*, *sugary2*, *and sugary1* corn mutants in the ExSeed68 genetic background and to relate these properties to the previously determined structural features of the starches.

2. Materials and methods

2.1. Starch

Corn (*Zea mays* L.) kernels from the ExSeed68 line [wild type (normal) and *dull*39 (*du39*), *amylose extender25* (*ae25*), *sugary2* (*su2*), *sugary1* (*su1*) genotypes] were provided by ExSeed Genetics, LLC (Ames, IA, USA). All corn endosperm mutants were developed from the normal corn and grown in summer 1999 under the same environmental conditions near Ames, IA, USA.

2.2. Starch isolation

Starch was extracted from the corn kernels by using the modified 100-g procedure previously described by Singh, Johnson, Pollak, Fox, and Bailey (1997). The extraction procedure was performed twice for all starch types, except for the *su1* mutant, which was available only in limited quantity; thus only one extraction of 50 g was performed.

2.3. X-ray diffraction analysis

X-ray diffraction patterns of the starches were obtained by using a Scintag XDS-2000 diffractometer with a 2.2 kW line-focus copper tube (Thermo ARL, Switzerland) and a KEVEX 4461 detector (KEVEX X-ray, CA, USA) according to Perera et al. (2001).

2.4. Differential scanning calorimetry analysis

Differential scanning calorimetry (DSC) was used to analyze thermal properties of the starches. Pyris software for windows package (V2.04, Perkin–Elmer, Norwalk, CT, USA) was employed by using procedures previously described (Seetharaman, Tziotis, Borras, White, Ferrer, & Robutti, 2001; White, Abbas, & Johnson, 1989). The samples were subjected to a temperature scan from 30 to 110 °C in aluminum pans (30–180 °C in stainless-steel pans for the *ae25* mutant starch to fully gelatinize this starch) at 10 °C min^{-1}. The *ae25* starch was cooled immediately to 30 °C and then rescanned under the same conditions as the first heating, allowing the determination of the AM–lipid complex, which overlapped (for the *ae25* starch) with the gelatinization of the AP peak during the first heating, but was formed alone during the second scan. Thus, Peak I, and all its properties, was defined as the difference between the peaks found during the first temperature scanning and the peak (Peak II) found during the immediate rescanning of the starch. To measure retrogradation properties, the gelatinized starch in the DSC pan was stored for 7 days at 4 °C, then equilibrated at 25 °C for 1.5 h before being reanalyzed in the DSC at a temperature range of 30–110 °C (30–180 °C for the *ae25* mutant starch) at 10 °C min^{-1}. Starch samples from duplicate extractions were analyzed in