Food Chemistry 179 (2015) 232–238

Contents lists available at ScienceDirect

Food Chemistry

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

Effects of waterlogging after pollination on the physicochemical properties of starch from waxy maize

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ARTICLE INFO

Article history:
Received 4 September 2014
Received in revised form 8 November 2014
Accepted 19 January 2015
Available online 24 January 2015

Keywords:
Crystallinity
Pasting
Swelling
Thermal
Waterlogging
Waxy maize starch

ABSTRACT

Waterlogging frequently occurs in Southern China in summer and significantly affects waxy maize growth. This study investigated the physicochemical properties of starch from six waxy maize varieties exposed to waterlogging for 1–7 days after pollination. Waterlogging decreased the starch granule size. Starch maximum absorption wavelength, iodine-binding capacity, crystallinity, and peak intensities in response to waterlogging depended on varieties. Swelling power and solubility in response to waterlogging increased in Wannuo5 and decreased in the other five varieties. Gelatinization and pasting temperatures were only slightly affected by waterlogging. Gelatinization enthalpy was unaffected in Nongkeyu301, increased in Guangbainuo5, and decreased in the other four varieties. Peak and breakdown viscosities decreased and retrogradation percentage increased when plants were subjected to waterlogging after pollination. In conclusion, waterlogging decreased starch granule size, crystallinity, swelling power, and solubility, resulting in deteriorated starch quality (i.e., low swelling, less sticky and easy to retrograde).

1. Introduction

Maize starch dominates nearly 80% of the global starch market (Jobling, 2004). Maize starch can be divided as waxy, normal, and high amylose based on amylose content (Singh, Sandhu, & Kaur, 2005). Among different maize types, waxy maize starch is composed of 100% amylopectin, which features high viscosity, easy digestion, good light transmittance, and low retrogrades (Lu & Lu, 2012).

The physicochemical properties of maize starch change with a growing environment. Ji et al. (2004) observed that the thermal properties of maize starch vary in different growth environments. Lenihan, Pollak, and White (2005) found that maize starch harvested in a warm environment has high gelatinization onset temperature and enthalpy, as well as a narrow gelatinization range. Oktem (2008) observed that water deficit decreases some mineral element (Fe, Cu, and Zn) contents but increases the protein content in sweet maize grains. Liu et al. (2013) observed that maize starch granule size and viscosities decrease and gelatinization temperatures increase under low irrigation levels. Our previous studies showed that high temperature, weak light, and drought after pollination significantly deteriorated the quality of waxy maize starch (Lu, Cai, Zhao, Shen, & Lu, 2015; Lu, Sun, Wang, Yan, & Lu, 2013; Lu et al., 2014). Several abiotic factors, including rainfall, sunlight, temperature, soil type, and growing conditions affecting the starch physicochemical properties of crops, may sometimes exhibit considerable influence than genotypic differences (Beckles & Thitisaksakul, 2014; Thitisaksakul, Jimenez, Abias, & Beckles, 2012; Wang & Frei, 2011).

Waterlogging is one of the most important abiotic factors and occurs frequently. Over 18% of the total maize production areas in South Asia and Southeast Asia are frequently affected by flooding or waterlogging, causing production losses of 25–30% annually (Zaidi, Maniselvan, Srivastava, Yadav, & Singh, 2010). Cairns et al. (2012) reviewed that waterlogging influences maize growth and development. However, no research has focused on the effects of waterlogging on the physicochemical properties of maize starch. In the present paper, we reported the physicochemical properties of waxy maize starch under normal and waterlogging conditions after pollination.

2. Materials and methods

2.1. Plant materials and experimental design

Six varieties of waxy maize, namely, Huainuo1, Nongkeyu301, Wannuo5, Meiyu16, YN525, and Guangbainuo5 were used in this

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http://dx.doi.org/10.1016/j.foodchem.2015.01.096
0308-8146/

study. These six varieties were provided by the Maize Regional Test Management Office of the China Ministry of Agriculture.

The experiment was conducted at the Yangzhou University Farm in 2013. Seeds were sown on March 15 and transplanted to a cement pit (2 m depth) on March 28. Plant density was 60,000/ha and plot area was 12 m^2. The plants were given a basal dressing of 500 kg/ha (commercial fertilizer, N:P_2O_5:K_2O = 15%:15%:15%) during transplantation and a top dressing of 326 kg/ha (commercial urea, 46% N) during the jointing stage.

The plants were grown under relative soil moisture content of approximately 75% before pollination. The plants were subjected to waterlogging (about 3 cm water above ground) after artificial pollination for 7 days. The soil moisture content of the control was 75–80%. The plants were covered with a transparent canopy that was 5 m high aboveground to avoid the effects of rainfall.

2.2. Starch isolation

The grains (100 g) were steeped in 500 ml of distilled water containing 1 g/l sodium hydrogen sulfite (1 g/l SO_2) for 48 h at room temperature. The starch was isolated according to a previously described method (Lu & Lu, 2012). The samples were rinsed with distilled water, and then ground using a blender for 2.5 min. The suspensions were passed through a 100-mesh sieve. The materials left on the screen were again homogenized for 1.5 min, and then passed through the same sieve. The starch–protein slurry was collected in a 1000 ml wide-neck flask and allowed to stand for 4 h. The supernatant was removed through suction and the settled starch layer was collected in 50 ml centrifuge tubes and centrifuged at 3000×*g* for 10 min. The upper non-white layer was scooped. The white layer was resuspended in distilled water and stirred for 30 min before centrifugation. The isolation procedures were repeated three times. The starch was then collected and dried in an oven at 40 °C for 48 h.

2.3. Granule size distribution

The particle sizes of the starch were analyzed using a laser diffraction particle size analyzer (Mastersizer 2000, Malvern, England). Instrument accuracy was verified using Malvern standard glass particles. The instrument was operated based on the principle of laser light scattering and could measure sizes between 0.1 and 2000 μm. The disperse phase was absolute ethyl alcohol. The size distribution was expressed in terms of the volume of equivalent spheres. The average granule size was defined as the volume weighted mean.

2.4. X-ray diffraction (XRD) pattern

The XRD patterns of starch were obtained using an X-ray diffractometer (D8 Advance; Bruker-AXS, Germany). The diffractometer was operated at 200 mA and 40 kV. The scanning region of the diffraction angle (2θ) ranged from 5° to 40° at a step size of 0.04° and a counting time of 0.6 s. Relative crystallinity (%) was calculated as the percentage of the total crystalline peak areas to that of the total diffractogram (total crystalline and amorphous peak areas) by using software (MDI Jade 6).

2.5. Iodine staining

The maximum absorption wavelength (λ_{max}) and iodine-binding capacity of starch were measured according to the method described by Fiedorowicz and Rebilas (2002), with minor modifications, as described by Lu et al. (2014). Starch (40 mg) was dispersed in 10 ml of DMSO containing 10% of 6 M urea. A 1.0 ml aliquot of each sample was placed in a 100 ml volumetric flash, to which 95 ml of deionised water and 2 ml of an aqueous I_2–K_I solution was added. The latter solution was prepared with 200 mg of I_2 and 2 g of K_I in 100 ml of distilled water. The mixture was made up to 100 ml with deionised water and mixed immediate. Blank solutions that were prepared identically did not contain starch. Spectra ranging from 500 to 700 nm were obtained from all of the samples using a UV–Vis spectrophotometer. The blue value of the samples was defined as the absorbance at 635 nm, and the λ_{max} was designated as the peak absorbance value over the range of wavelengths examined. The iodine-binding capacity of the starches was defined as the ratio of absorbance at 635 nm to that at 520 nm.

2.6. Swelling power and solubility

The swelling power and solubility of the starches at 90 °C was studied according to a previously described method (Lu & Lu, 2012). Samples (0.1 g) were weighed in a centrifuge tube with coated screw cap to which 10 ml distilled water was added. The tube was heated at 90 °C in a shaking water bath for an hour. The tube was cooled to room temperature in an iced bath and centrifuged at 4000×*g* for 20 min. The supernatant was discarded. The materials that adhered to the wall of the centrifuge tube were considered as sediments and weighed (W_1) and the sediments were dried to constant weight (W_2) in an air oven at 100 °C. The swell power and solubility were calculated as follows: swell power = W_1/W_2 (g/g) and solubility (%) × (0.1-W2)/0.1.

2.7. Pasting properties

The starch pasting properties (28 g total weight; 7%, w/w, dry basis) were evaluated using a rapid viscosity analyzer (RVA, Model 3D; Newport Scientific, Australia) following a previously defined method (Lu & Lu, 2012). A sample suspension was equilibrated at 50 °C for 1 min, heated to 95 °C at 12 °C/min, maintained at 95 °C for 2.5 min, cooled to 50 °C at 12 °C/min, and then maintained at 50 °C for 1 min. The paddle speed was set at 960 rpm for the first 10 s and then decreased to 160 rpm for the rest of the analysis.

2.8. Thermal properties

The thermal characteristics of the starch were studied using differential scanning calorimetry (Model 200 F3 Maia, NETZSCH, Germany) according to a previously utilized method (Lu & Lu, 2012). Each sample (5 mg, dry weight) was loaded into an aluminum pan (25/40 ml, D = 5 mm) and distilled water was added to achieve a starch–water suspension containing 66.7% water. Samples were hermetically sealed and allowed to stand for 24 h at 4 °C before heating in the DSC. The DSC analyzer was calibrated using an empty aluminum pan as a reference. Sample pans were heated at a rate of 10 °C/min from 20 to 100 °C. Thermal transitions of starch samples were defined as T_o (onset temperature), T_p (peak of gelatinization temperature) and T_c (conclusion temperature) and ΔH_{gel} referred to the gelatinization enthalpy. Enthalpies were calculated on a starch dry weight basis. After conducting thermal analysis, the samples were stored at 4 °C for 7 days for retrogradation studies. The sample pans containing the starches were reheated at the rate of 10 °C/min from 20 to 100 °C to measure retrogradation. The retrogradation enthalpies (ΔH_{ret}) were evaluated automatically and retrogradation percentage (%R) was calculated as %R = 100 × ΔH_{ret}/ΔH_{gel}.

2.9. Statistical analyses

The data reported in all tables are expressed as the average of two repeated observations. These data were subjected to ANOVA,