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Efficacy of potato resistant starch prepared by microwave–toughening treatment

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ABSTRACT

Potato starch was treated by microwaving, toughening, and low-temperature aging to prepare resistant starch (RS). The functional properties of the resultant RS were evaluated and the effects of this microwave–toughening treatment (MTT) on the amylose content, RS content, digestive properties, pasting properties, morphological observation, crystal structure, and thermal performance of potato starch were determined. The optimal MTT parameters were microwaving at 300 W for 100 s, toughening at 55 °C for 16 h, and low-temperature aging at 4 °C for 18 h. After MTT, the amylose and RS contents of potato starch had increased from 26.08% and 11.54% to 35.06% and 27.09%, respectively. Furthermore, the pasting temperature increased from 66.8 °C to 76.36 °C, while the peak viscosity, trough viscosity, and final viscosity decreased significantly. After MTT, the potato starch surface had also changed significantly, and the crystallinity had increased from 32.43% to 51.36%. MTT starch had beneficial effects on fasting blood glucose, body weight, and organ index in mice. Furthermore, it had a protective effect on subcutaneous abdominal fat and liver tissue.

1. Introduction

The potato is a widely cultivated cash crop and the most prevalent food crop worldwide, providing energy to about 15% of the global population (Karim, Holmes, & Orfila, 2016). Potatoes are generally used to make popular consumer products, such as potato chips and mashed potato (Kondo, Higashi, Iwama, Ishihara, & Handa, 2012). Potato storage is problematic owing to shortcomings in technology, facilities, and industrial structure (Heltoft, Wold, & Molteberg, 2017). Potatoes are nutritious, containing starch (9–20%), protein (1.5–2.3%), fat (0.1–1.1%), crude fiber (0.6–0.8%), polyphenols (0.0071–0.031%), and other trace components (Kurilich, 2013). The saponin found in potato green skin dry powder can be used to control hyperglycemia (Jecht, 2013). The main ingredient in potatoes is starch, of which ~80% is contained in the dry matter (Ciecko & Zolnowski, 2004). Potato starch is not only important in food, but also in pharmaceutical, chemicals, cosmetics, and textiles (Rodrigues & Emeje, 2012).

Starch is composed of amylose and amylopectin. Amylose is a linear D-glucopyranose chain connected by α-l,4-glycosidic bonds that is slightly branched (Takeda, Shitaozono, & Hizukuri, 1990), while amylopectin is a larger branched molecule with α-(1,4)- and α-(1,6)-linkages (Yuan, Wang, Chen, Zhu, & Cao, 2015). Starch can be divided into three types according to digestion rate, namely, rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst, Kingman, & Cummings, 1992). RDS can be completely digested and absorbed in the human small intestine, causing an increase in the blood glucose level (Pham & Nguyen, 2015). To control the sudden increase in blood sugar, pancreatic islets rapidly secrete insulin, causing the blood sugar levels to drop sharply. And long-term RDS intake can result in insulin resistance and type 2 diabetes (Kim & Lee, 2009). SDS is slowly digested in the human small intestine, which has potential health benefits for the blood sugar level and islets (Dong, 2012). RS is not digested, but fermented in the large intestine by human microflora to produce short-chain fatty acids. This causes a decrease in the intestinal pH value, which helps maintain intestinal peristalsis and protect intestinal mucosa (Fuentes-Zaragoza, Riquelme-Navarrete, Sánchez-Zapata, & Viuda-Martos, 2010). As RS has been shown to be effective at preventing diabetes and obesity, an increasing amount of research has focused on improving the RS content in functional foods (Patil, 2004).

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RS can be divided into four types according to their origin, namely, physical embedding starch (RS1), resistant starch granules (RS2), aging of regenerated starch (RS3), and chemically modified starch (RS4) (Maziarz et al., 2017). Chemical modification is the most common method for enhancing RS content. Recently, many techniques have been studied for enhancing the RS content in starch, including hydrothermal, enzymatic hydrolysis, acid hydrolysis, and ultrasound methods. Arns et al. (2015) increased the RS content of wheat starch to 42.1% using a heat treatment method, which was then modified by Sun et al. (2015) to achieve further improvements. This improved RS content was due to starch gelatinization and regeneration. When starch is hydrothermally treated, the amylose double helix is destroyed (hydrogen bond dissociation) and amylopectin detaches from the main chain (Tester, 1989). These events, collectively referred to as "gelatinization", are accompanied by a sharp increase in system viscosity, such as the gradual collapse of the grain structure (Yang & Rao, 1998). At low temperatures, recrystallization of the polymer chains causes degradation (Jang & Pyun, 1997). Mutungi, Rost, Onyango, Jaros, ànd Rohm (2009) improved the tapioca RS content from 21.4% to 67.3% by debranching with pullulanase, recrystallizing the linear dextran by incubation at 60 °C, and finally using heat-moisture treatment to broaden the endotherms and increased their enthalpies. Song, Park, and Shin (2015) increased the RS level by 114.5% through acid hydrolysis (pH 4.0) for 1 h under sonication. Sonication reduced the starch particle size and starch granules remained the same as in native starch, with a polygonal shape and A-type crystallinity after treatment.

Microwave treatment could replace the traditional heat treatment process. Microwaves can induce the swelling stage of starch gelatinization and then the low temperature can age the starch. The molecular chains recombine through hydrogen bonds to form new crystals (Sjöqvist & Gatenholm, 2005). The toughening of starch is a physical modification under the action of heat and water. It refers to the starch modified in excess moisture (> 60% w/w) or moisture (40%–55% w/w) and below starch gelatinization temperature of the initial temperature conditions for a period of time caused by changes in starch structure and properties. Toughening can reduce the degree of solubility and swelling, reduce the viscosity, and increase the paste temperature of starch, and does not produce harmful chemicals or cause genetic changes (Taguet, Bureau, Huneault, & Favis, 2014). During the toughening process, the starch crystals rearrange internally to increase the crystallinity, making them more resistant to enzymolysis (Yadav, Guleria, & Yadav, 2013).

Microwave and toughening methods are safe and easy to perform, but few studies have applied this method to resistant starch production. The present study aims to use to improve the RS content in potato starch, as the raw material, through microwave and toughening technology, and observe the effect of microwave toughening on the starch structure characteristics and efficacy. Changes in eating habits and food composition have resulted in the incidence of chronic diseases, such as diabetes and cardiovascular diseases, increasing in recent years, with more people tending to consume low-calorie high-fiber foods for health purposes. The microwave and toughening techniques, and products of potato starch obtained from this study, have broad market prospects. These raw materials could be used to prepare diabetes-specific staple foods, and inspire new applications and development of potato starch in functional foods. Furthermore, this technology could promote industrial restructuring and ease problems associated with potato storage.

2. Materials and methods

2.1. Materials

Potato starch (purity, 96.9%) was obtained from Gansu Mintian Food Co., Ltd. (Gansu, China). A blood glucose meter and blood glucose test strips was purchased from Roche Diagnostics GmbH (Mannheim, Germany). Amylose standard was purchased from Beijing Spectrum Analysis Technology Co., Ltd. (Beijing, China). Heat-stable α-amylase (1400 U/g) and amyloglucosidase (3300 U/g) were purchased from Sigma–Aldrich (St. Louis, USA). Maltose standard product was purchased from Aladdin Reagent Co., Ltd. (Shanghai, China).

2.2. Preparation of resistant starch

2.2.1. Preparation of microwave–toughening treatment (MTT) starch

Potato resistant starch (P-RS) was prepared according to methods of Yang, Yang, and Ding (2008) and Sharma, Yadav, Singh, and Tomar (2015) with some modifications. Potato starch (100 g) was gelatinized with distilled water (220 mL) by microwaving at 300 W for 100 s (microwave process conducted in water bath at 45 °C; final temperature of water–starch solution, 80.4 °C). The supernatant was removed by centrifugation (3000 rpm, 15 min) and the sediment was washed thoroughly three times with distilled water. The sample moisture content was then adjusted to 60% (w/v) by spraying with the appropriate calculated amount of distilled water. The starch and water were then thoroughly mixed, placed in sealed containers, and heated on a constant-temperature shaking table at 55 °C for 16 h. The containers were then cooled to ambient temperature, opened, and then stored in a refrigerator at 4 °C for 18 h. The obtained starch was dried at 45 °C for 24 h, ground, and passed through a 100-mesh sieve for further analysis.

2.2.2. RS determination

RS was determined according to the procedure of Goñi, García-Diz, Mañas, and Saura-Calixto (1996) with a slight modification. Treated potato starch (TPS) (0.5 g) was digested with excess amylase for 30 min. The reaction mixture was then centrifuged at 8000 rpm for 8 min. The resultant residue was collected and dispersed in 2 M KOH solution (6 mL) and stirred for 30 min at ambient temperature. The pH was adjusted to neutral using a citrate buffer solution and then adjusted to 4.4 using a 2 N HCl solution. Excess amyloglucosidase was added and the mixture was heated in a water bath at 60 °C for 45 min. The samples were centrifuged (8000 rpm, 8 min), and the supernatants were collected and made up to 100 mL using distilled water. The reducing sugar content was determined using the dinitrosalicylic acid (DNS) method.

2.3. Scanning electron microcopy (SEM)

The surface structures and cross-sections of treated potato starch (TPS) and potato starch (PS) fractions were observed using field-emission scanning electron microscopy (FESEM). Starch samples were mounted on circular aluminum stubs with double sided carbon tape, coated with a thin platinum film under vacuum, and examined using FESEM (Supra 55VP microscope, Carl Zeiss, Oberkochen, Germany) at an accelerating potential of 3 kV. A starch granule cross section was prepared using a stainless steel razor blade approximately 2-μm thick (ST 300, Dorco Co., Seoul, Korea).

2.4. X-ray diffraction

X-ray diffraction analysis was performed using an X-ray diffractometer (Model D5005, Bruker, Karlsruhe, Germany) operating at 40 kV and 40 mA producing CuK radiation with a wavelength of 1.54 Å scanning through the 2θ range of 3–30° and with a step time of 4 s. The relative crystallinity of the starches was calculated according to a previous report (Nara & Komiya, 1983) using peak-fitting software (Origin version 7.5, OriginLab, Northampton, MA, USA)

2.5. Differential scanning calorimetry–thermogravimetric analysis (DSC–TGA)

The gelatinization characteristics and thermogravimetric properties of the products were measured using DSC–TGA (SDT Q600, TA Instruments, USA). Anhydrous starch samples (approximately 5 mg)