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Effect of repeated heat-moisture treatments on digestibility, physicochemical and structural properties of sweet potato starch

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ABSTRACT

In the present study, the effects of repeated heat-moisture treatments (RHMT) on the *in vitro* digestibility, physicochemical and structural properties of sweet potato starch were investigated. The cycling times of RHMT ranging from 1 to 5 and heat-moisture treatment for 6 h were designated as RHMT-1, RHMT-2, RHMT-3, RHMT-4, RHMT-5 and HMT-6h, respectively. The results showed that as the cycling times of RHMT increased, the SDS content of starch samples increased gradually and reached the maximum (19.61%) by RHMT for 3 times, and the thermo-stable SDS content also increased and reached the maximum (14.46%) by RHMT-3, while the swelling power and solubility decreased gradually. Compared with the native starch, the gelatinization transition temperatures of modified starch samples were significantly increased, gelatinization enthalpy and gelatinization temperature range decreased markedly. The values of degree of gelatinization (DG) showed that RHMT caused some gelatinization of the starch granules. Moreover, the RHMT starch samples exhibited significantly increased pasting temperatures, reduced viscosities, and no longer exhibited traditional pasting profiles for the lack of a true peak viscosity and no breakdown, and the agglomerations of granules were found in them. The variation in infrared absorbance ratio of 1047 cm^{-1} and 1022 cm^{-1} of RHMT starch samples were consistent with that in relative crystallinity, and RHMT starch samples exhibited A type crystalline pattern. These results suggested that structural changes of sweet potato starch by RHMT significantly affected the digestibility and physicochemical properties.

1. Introduction

Sweet potato is one of the staple crops in China. It is highly easy to manage and cultivate and the potential supply of starch is large and cheap (Ramirez, 1992). Starch, the main component of sweet potato roots, accounts for around 50–80% of sweet potato roots on the basis of dry weight (Zhu, Yang, Cai, Bertoft, & Corke, 2010). Starch is the most abundant reserve carbohydrate of many plants and also a major source of carbohydrate in the human diet. It is an important source of nourishment and plays a very important role in supplying metabolic energy and nutrition for humans. According to the rate and extent of digestion or glucose release, starch is classified into three types: rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst, Kingman, & Cummings, 1992). RDS is the starch fraction that causes a rapid glucose release and absorption in the gastrointestinal tract, which leads to a sudden increase in blood glucose level after ingestion, whereas SDS is the starch fraction that causes glucose release and absorption in the gastrointestinal tract slowly but completely. RS has been defined as the starch portion that cannot be digested to release glucose, but it can be fermented by microorganisms in the large intestine into short-chain fatty acids that is beneficial to colonic health (Cummings, Beatty, Kingman, Bingham, & Englyst, 1996). Food rich in SDS tends to prolong the release of glucose and sustain glucose levels over time that may help control and prevent hyperglycemia-related diseases. Such foods may also be beneficial to satiety, mental performance, diabetes management (Lehmann & Robin, 2007). Therefore, as a new functional food component, SDS has attracted much attention in novel food development in recent years.

At present, many modification methods have been used to prepare SDS from various sources of starch. These methods include

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physical, chemical, and enzymatic modifications. Among these methods, physical modification is considered to be safe, non-toxic, and no by-products of chemical reagents. As a physical modification, heat-moisture treatment (HMT) involves heating of starch granules at a low moisture level (<35% w/w) and temperature of 84–120 °C for a certain period of time ranging from 15 min to 16 h (Hoover, 2010; Jacobs & Delcour, 1998). In addition, HMT is a method that is cost-effective and easy to be applied, and it has greater effect on the digestibility, physicochemical and structural properties of tuber starches than legume or cereal starches (Hoover & Vasanthan, 1994).

Recently, HMT has been widely applied to prepare SDS products from various sources of starch (Ahn et al., 2013; Chung, Liu, & Hoover, 2009; Lee, Kim, Choi, & Moon, 2012; Lee, Shin, Kim, Choi, & Moon, 2011; Shin, Kim, Ha, Lee, & Moon, 2005). HMT can cause some gelatinization or other damage of starch granules (Stute, 1992), because the exact moisture content at which HMT is conducted is not always considered when determining the time and temperature conditions (Moraes, Branzani, & Franco, 2014). It can also cause structural changes in amorphous and crystalline domains of the starch granules to different extent, which induce changes in swelling power and solubility, amylose leaching, gelatinization characteristics, X-ray pattern, crystallinity, retrogradation, thermal stability, and pasting properties (Hoover, 2010; Jacobs & Delcour, 1998; Varatharajan, Hoover, Liu, & Seetharaman, 2010; Zavareze & Dias, 2011). These changes of physicochemical and structural properties incurred during HMT may also affect the susceptibility of starch to enzymatic hydrolysis. Chung, Liu, et al. (2009) confirmed that HMT could increase thermo-stable SDS and RS contents of corn, pea, and lentil starches. Ahn et al. (2013) and Shin et al. (2005) reported that HMT could significantly increase the SDS content of sweet potato starch.

Furthermore, some researchers investigated the effects of single and dual hydrothermal treatments, using both the HMT followed by annealing (ANN) and the annealing followed by HMT, on the molecular structure and physicochemical properties of starches from corn, pea, lentil, and navy bean (Chung, Hoover, & Liu, 2009; Chung, Liu, & Hoover, 2010), and they found that HMT, ANN-HMT and HMT-ANN were more effective than ANN in increasing thermal stability and decreasing the extent of setback. Zeng, Ma, Kong, Gao, and Yu (2015) also reported that dual hydrothermal treatments (ANN-HMT and HMT-ANN) induced the decrease in the molecular weight and gelatinization enthalpy and the increase in gelatinization onset, peak, conclusion temperatures and resistant starch content of waxy rice starch compared with native starch. Moreover, Klein et al. (2013) evaluated the impact of single and dual heat-moisture treatments at 120 °C on physiochemical properties of rice, cassava and pinhão starches, and found that dual HMT caused the decrease in swelling power and solubility of rice starch and the increase in peak viscosity, breakdown, setback, final viscosity and gelatinization temperatures of rice and cassava starches compared with single HMT.

Although dual hydrothermal treatment and dual HMT have been reported to exert marked effects on physicochemical, structural properties and nutritional fractions of various botanical starches, few studies regarding the effects of repeated heat-moisture treatments on digestibility, physicochemical properties of sweet potato starch have been reported. Because HMT has been reported to significantly influence the properties of tuber starches in comparison with other botanical starches (Hoover & Vasanthan, 1994), we presume that repeated HMT may exert more significant effect on the properties of sweet potato starch compared with some traditional methods. To test the hypothesis, in the present study, we investigated the effects of repeated heat-moisture treatments on *in vitro* digestibility, physicochemical and structural properties of sweet potato starch.

2. Materials and methods

2.1. Materials

The sweet potato starch was provided by Anhui Tianlong Potato Industry Co., Ltd (Anhui, China). alpha-amylase type VI-B from porcine pancreas (EC 3.2.1.1, A3176) was purchased from Sigma–Aldrich Chemical Co. (St. Louis, MO, USA). Amyloglucosidase (EC 3.2.1.3) was purchased from Shanghai Yuanye Bio-Technology Co., Ltd (Shanghai, China). All other chemical reagents were of analytical grade.

2.2. Repeated heat-moisture treatment (RHMT) of sweet potato starch

Sweet potato starch (10 g) was weighed directly into the stainless steel container, and the moisture content was adjusted to be 30% by adding an appropriate amount of distilled water slowly with stirring (The moisture content of native sweet potato starch is 10.05% ± 0.06). After thorough mixing, the containers were sealed and equilibrated at room temperature for 24 h, and then placed in an air-drying oven at 100 °C for 2 h. Afterwards, the container were opened and the starch sample was dried in a drying oven at 45 °C for 24 h to reach final moisture content of around 10%, then milled and passed through a 100-mesh sieve. The dried and fine ground starch sample obtained by one cycle of heat-moisture treatment (HMT) was weighted and placed into the stainless steel container. After moisture content was adjusted to be 30% and complete mixing, the container was then sealed, equilibrated and heated as described above. After heating, the starch sample was dried, milled and passed through a 100-mesh sieve to perform two cycles of HMT. According to the procedures as mentioned above, sweet potato starch sample was treated successively to perform five cycles of HMT. The cycling times of HMT of the starch sample ranging from 1 to 5 were designated as RHMT-1, RHMT-2, RHMT-3, RHMT-4, and RHMT-5, respectively. The starch sample was treated with HMT at 100 °C and moisture content of 30% for 6 h, which was designated as HMT-6h.

The adjustment equation of moisture content of starch samples was listed as follows:

$$m_x(g) = [W\ (\%) - w_0\ (\%)] \times m_0\ (g)/[1 - W\ (\%)]$$

where, m_x indicates the amount of distilled water that was added in the starch samples; W indicates the moisture content after adjustment (30%); w_0 indicates the moisture content of native starch sample (10.04% ± 0.06) or other RHMT starch samples (about 10%); m_0 indicates the weight of starch sample (10 g).

2.3. Determination of in vitro digestibility of starch

The *in vitro* digestibility of the starch samples were determined on both “uncooked” and “cooked” basis according to the method described by Englyst et al. (1992) with a slight modification. Starch (200 mg) was weighed and placed into a centrifuge tube (50 ml) containing phosphate buffer (15 ml, pH 5.2) and seven glass balls. For “cooked” analyses, the centrifuge tubes were shaked in a boiling water bath for 20 min firstly, and then cooled to room temperature by vortexing prior to analysis. After all the centrifuge tubes (cooked and uncooked) were equilibrated in a water bath at 37 °C for 5 min, and 5 ml of enzyme solution (290 U/ml porcine pancreatic α-amylase and 15 U/ml amyloglucosidase) were added, followed by