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Slow digestion property of microencapsulated normal corn starch

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ABSTRACT

Starch is the main glycemic dietary carbohydrate, and its nutritional quality is associated with the amount of slowly digestible starch (SDS) that is beneficial to glycemic control. In the current study, a microencapsulation of normal corn starch by zein protein and its slow digestion property were investigated. A significant increase of SDS and RS was shown for starch capsules (weight ratio of zein to starch: 1:6) containing plasticizers of glycerol and oleic acid after high temperature (≥70 °C) treatment. Further studies showed a substantially decreased viscosity and the formation of an amylose–lipid complex after starch gelatinization. Thus, the hydrophobic physical barrier of the zein matrix and the amylose–lipid complex might together limit the water accessibility and starch swelling leading to a dense packing of starch materials with a high amount of SDS. The acceptable sensory property makes it an ideal ingredient for specialty food preparation and glycemic control.

1. Introduction

Starch, as the main component of cereal grains, is an important dietary carbohydrate providing energy for a series of physiological processes in which the brain is the major consumer of glucose (Fehm et al., 2006) for normal activity of the central nervous system such as cognition development (Gold, 1995). In the mean time, a prevalence of glucose metabolism related diseases such as type 2 diabetes indicates the supply of glucose to the body needs to be better controlled for glucose homeostasis (Le et al., 2013). Thus, the nutritional properties of starch that are expressed by the percentage of rapidly digestible starch (RDS), slowly digestible starch (SDS), and resistant starch (RS) (Englyst et al., 1992) need to be improved with a high amount of beneficial glycemic SDS (Lehmann and Robin, 2007), which is distinctly different from RDS that is a causative factor for many chronic diseases (Ells et al., 2005). Literature reports also showed that SDS epigenetically caused a shift of the gene expression peak of SGLT1 from the upper jejunum to ileum (Shimada et al., 2009) leading to an increased glucose transporter in the ileum (Woodward et al., 2012). High glucose content in the ileum after consuming SDS can result in sustained increase of an incretin hormone of GLP-1 (Wachters-Hagedoorn et al., 2006) that is important for body weight regulation and insulin sensitivity (Larsen, 2008). Thus, SDS not only generates a moderate postprandial glycemic response but also influences a variety of physiological processes that are essential to human health.

The scarcity of SDS, however, in regular food products (Bjorck et al., 2000) limits its practical applications, and techniques to produce SDS are critical to make its health benefit a reality. Based on our study, the native cereal starch is the ideal SDS made by nature (Zhang et al., 2006a), however, its slow digestion property almost completely disappeared once it is gelatinized (Zhang et al., 2008). Although there have been reports (Han and BeMiller, 2007; Venkatachalam et al., 2009) or patents on the preparation of SDS, most of them are either thermal sensitive or do not have a significant amount of SDS for noticeable health outcomes. Considering the slow digestion property of native cereal starch is an enzyme concentration-independent physical entity (Zhang et al., 2006b) that can resist the conditional regulation of the body, it would be the ideal SDS for consumption. However, the consumers are not willing to sacrifice the taste to accept the consumption of raw starch.

Microencapsulation is commonly used to mask the flavor of food materials, and microencapsulation of cereal starch granules to reduce their raw taste might be a possible way for consumers to accept the consumption of raw starches. Since normal corn starch is

Abbreviations: ENS, microencapsulated starch; ENSP, encapsulated starch containing plasticizer; GLP-1, glucagon-like peptide-1; GOPOD, glucose oxidase/peroxidase; NCS, non-encapsulated starch (or normal corn starch); RS, resistant starch; RVA, rapid visco analyzer; SDS, slowly digestible starch; SEM, scanning electron microscopy; SGLT1, Na(+)-D-glucose cotransporter.

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the most commonly used cereal starch, and zein protein has been widely used as shell materials for encapsulation (Parris et al., 2005), they were chosen as the core and shell materials to produce microencapsulated starch to mimic the natural forms of starch and protein in corn grains. The resulted digestion properties of microencapsulated starches were studied, and it is expected that specialty food focused on postprandial glycemic control could be prepared using the microencapsulated starch materials. The coexistence of corn starch and zein in corn flour might also be technologically advantageous to produce this type of encapsulated starch material.

2. Materials and methods

2.1. Chemicals

Zein protein (soluble in 80–92% ethanol) extracted and purified from corn protein powder was obtained from Wujiang City Bache Pharmaceutical Adjuvant Factory (Wu Jiang, China) with a moisture content of ~8.0%. The Kjeldahl test showed a nitrogen content of 15.0% (dry weight basis) that is equal to a purity of ~94% converted by a factor of 6.25. Glycerol (ACS reagent, ≥99.5%) and oleic acid (≥99%, GC) were purchased from Sigma–Aldrich (Shanghai, China). Low methoxyl pectin was from Quzhou Pectin Co., LTD., (Quzhou, China), and its degree of esterification is ~35%. Normal maize starch (amylose content: ~25%) was obtained from National Starch and Chemical Company (Shanghai, China). α-Amylase (EC 3.2.1.1, type VI-B from porcine pancreas, 19.6 U/mg) and AMG (EC 3.2.1.3, from Rhizopus mold, 21.1 U/mg) were purchased from Sigma Chemical Co. (Shanghai, China). The glucose oxidase/peroxidase (GOPOD) kit for D-glucose assay was from Megazyme International Ireland Ltd. (Wicklow, Ireland).

2.2. Low-temperature spray drying for starch encapsulation

A lab scale low-temperature spray dryer (Model yc-015A, Pilotech, Shanghai, China) was used to encapsulate normal corn starch. The slurry containing zein protein (dissolved in 80% ethanol) and starch granules with or without plasticizers of glycerol and oleic acid (20% based on zein weight in a ratio of 1:3) was stirred for 30 min at 60 °C. After homogenization at 30 Mpa, the sample was spray dried using the low-temperature spray drier with an entrance temperature of 120 °C and exit temperature of 90 °C at a flow rate of 15 mL/min. The dried sample was bottled for analysis.

2.3. Scanning electron microscopy (SEM) analysis

To analyze the morphological changes of starch granules after encapsulation, the encapsulated sample was first fixed by osmium tetroxide and sputter coated with platinum to a level of 250–500 nm. Scanning electron micrographs were then obtained with a Quanta 200 scanning electron microscope (FEI Co., Switzerland) under a vacuum of 13.33 Pa and an operating voltage of 20 kV.

2.4. Postprandial glycemic response measurement

Nine week-old male Kunmin (km) mice were purchased from Silaike Co. (Shanghai, China) and kept under an automatic light schedule of 07:00 a.m.–19:00 p.m. and a temperature at 22 ± 3 °C. The mice were conditioned by feeding ad libitum with a laboratory chow diet (Silaike Co. Shanghai, China) and drinking water. Experiments were performed one week later after an overnight fasting (10 mice per group). The postprandial glycemic response to zein-encapsulated starch was then measured by feeding the test samples (starch, 1 g/kg body weight [BW]) administrated via gavages. For all the samples, a 2.5% low methoxyl pectin solution was used to prepare the test samples (glucose, starch, encapsulated starch). Blood samples were taken from the lateral tail vein at 0, 15, 30, 45, 60, 90, and 120 min after gavages. The blood glucose concentration was measured using a glucose analyzer (Medisense, Abbott Park, IL) and expressed as the mean ± standard error (S.E.). All the procedures were approved by the Experimental Animal Review Committee at Jiangnan University of China.

2.5. Pasting property analysis

The pasting property of the encapsulated starch was measured by a rapid visco analyzer (RVA) (StarchMaster2, Perten instruments, Sweden) according to the standard method from the manual. In this procedure, the starch-based slurry (8%) with a final weight of 25.0 g by adding purified water was subjected to a temperature regime of increase from 50 to 95 °C, a holding period at 95 °C, and a decrease from 95 to 50 °C with a subsequent holding period at 50 °C. For zein-encapsulated starch samples, the amount used was based on the same starch content.

2.6. X-ray powder diffraction analysis

A Bruker D8-Advance diffractometer (Bruker AXS Corp., Nanjing, China) equipped with Cu Kα radiation at 40 kV and 40 mA was used to obtain the X-ray diffractogram of the encapsulated starch by scanning from 3° to 40° 2θ at a rate of 0.02°/3s.

2.7. In vitro starch hydrolysis

The standard Englyst method (Englyst et al., 1992) with minor modifications was employed to measure the starch fractions of RDS, SDS and RS. Briefly, 200 mg prepared starch samples in 5 mL buffer (100 mM NaOAC, pH 5.2, $CaCl_2$ 4 mM) with 6 glass beads (5 mm diameter)/tube was pretreated in a water bath for various temperatures (50, 60, 70, 80, 90, 100 °C) for 10 min with continuous shaking at 120 rpm. After all the tubes were cooled to 37 °C, 5 mL preheated (37 °C) dual enzyme solution (580 U/mL porcine pancreatic α-amylase, 12 U/mL amyloglucosidase) was added for digestion with continuous shaking at 120 rpm. An aliquot digestion sample (0.5 mL) was taken out at 20 and 120 min, and then 5 mL ethanol was added to stop the reaction. The released glucose was measured based on the procedure of GOPOD assay kit. The content of RDS, SDS and RS was calculated by taking a converting factor of 0.9 and expressed as the average and standard deviation.

2.8. Sensory evaluation

Ten professional sensory evaluators were chosen to evaluate the sensory properties of the samples focusing on the chewiness, graininess and overall acceptability. The chewiness refers to the rawness of the samples, and the graininess refers to the coarseness due to particles size of the encapsulated starch granules. A 7 point scale from 1 to 7 was used to represent categories from poor to excellent. For chewiness, 1 means the rawness is very strong, 2 means strong, 3 means less strong, 4 means mild, 5 means weak, 6 means weaker, and 7 means the weakest. For graininess, 1 means very coarse, 2 means less coarse, 3 means least coarse, 4 means mild, 5 means a little smooth, 6 means smooth, and 7 means the most smoothness. For acceptability, 1 means the weakest likeness, 2 means weaker likeness, 3 means weak likeness, 4 means mild, 5 means a little likeness, 6 means likeness, 7 means highest likeness. The sample for the sensory test was prepared by dissolving 30 g milk powder in 300 mL distilled water at 100 °C, and then a 20 g sample of encapsulated starch was added at 50, 60, 70 and 80 °C.