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Effects of non-starch polysaccharides on physicochemical properties and in vitro starch digestibility of rice starches

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ABSTRACT

The effects of non-starch polysaccharides (NSPs) on physicochemical properties and starch digestibility of waxy and non-waxy rice starches (WS and NWS) were investigated. The NSPs studied included guar gum (GG), xanthan gum (XG), carboxymethyl cellulose (CMC), tapioca fibre (Tap) and tamarind seed fibre (Tam). They were added to WS and NWS at the levels of 5, 10 and 15 g/100 g dry sample. The mixtures were examined for their in vitro starch digestibility, thermal properties by a DSC and textural properties by a texture analyser. Generally, it was found that all NSPs at the concentrations used in this study had little or no effect on starch digestibility. Glycaemic response parameters slightly decreased in the samples with added NSPs. No obvious effects on thermal properties were obtained. However, the NSPs affected the texture of rice starch gels as evidenced by changes in hardness and adhesiveness values. The textural changes were dependent on the type and concentration of the NSPs.

1. Introduction

As the primary dietary source of carbohydrates in over half of the world's population, rice plays an important role in meeting energy requirements and nutrient intake (Hu, Zhao, Duan, Linlin, & Wu, 2004; Wang et al., 2010). Starch, the major component in rice, undergoes hydrolysis as a result of the activity of amylolytic enzymes in the gastrointestinal tract (also in vitro). Hence it is regarded as a constituent rapidly and completely digested and absorbed in the small intestine in the form of glucose (Leszczyñski, 2004). According to the extent and rate of digestion, starch is generally classified as rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) (Englyst, Kingman, & Cummings, 1992). Overall, the rate of starch digestion and absorption is a determinant of the human metabolic response to a starchy meal (Araya, Contreras, Alvina, Vera, & Pak, 2002). RS has received much attention and is nowadays a focus of research, as it can be considered as functional dietary fibre; RS escapes from digestion in the small intestine and is fermented in the colon, producing short chain fatty acids (SCFAs) (Topping & Clifton, 2001). Due to its properties,

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RS positively influences the functioning of the digestive tract, the microbial flora, the blood cholesterol level, the glycaemic index (GI) and assists in the control of diabetes (Fuentes-Zaragoza, Riquelme-Navarrete, Sánchez-Zapata, & Pérez-Álvarez, 2010). Currently, RS is classified into four groups (RS1–4), according to its physical and chemical properties (Nugent, 2005).

Structurally, fibre can be sub-divided broadly into two forms, RS and non-starch polysaccharide (NSP). While both can be fermented in the colon, the exact site, rate of degradation and the nature of the SCFA produced can vary (Morita, Kasaoka, Hase, & Kiriyama, 1999), all these may affect insulin sensitivity and other metabolic parameters, either directly or indirectly. Indeed, a number of studies have reported that inclusion of fibre in the meal strategy (Giacco et al., 2000) or the use of either acute (Robertson, Currie, Morgan, Jewell, & Frayn, 2003) or chronic (Robertson, Bickerton, Dennis, Vidal, & Frayn, 2005) supplementation with RS does improve blood glucose control following a meal. It is less clear whether NSP is as effective as RS, however, and this is important because the former is the more prevalent form of fibre in Western diets (Lobley et al., 2013).

Physicochemical and metabolic properties of rice starch are influenced by numerous factors. One of these factors is amylose and amylopectin content (Behall, Scholfield, & Canary, 1988; Behall, Scholfield, Yuhaniak & Canary, 1989; Frei, Siddhuraju, & Becker, 2003). It has been well known that high amylose rice exhibits lower starch digestion rate. The amylose content of rice starch usually varies between 10% and 35%, although in high-amylose rice, it may reach even 70%, compared to the so-called "waxy" (high-amylopectin) rice in which amylose occurs in trace amounts (Leszczyński, 2004). Other factors such as granule size, architecture, crystalline pattern, degree of crystallinity, surface pores or channels, post-processing and storage conditions (recrystallisation), physical state and chemical modifications, degree of polymerisation and non-starch components also contribute to the metabolic properties (Biliaderis, 1982; Noda et al., 2008; Seneviratne & Biliaderis, 1991; Tester, Qi, & Karkalas, 2006).

Starch and NSP mixtures are often used to modify the texture of food products. Moreover, the interactions between starch and NSP have a nutritional impact on food products. The potential for altering starch digestibility by blending NSP has been a focus in current research studies, as NSP can modify food structure, texture, and viscosity, resulting in altered accessibility of enzymes to starch granules and processed starch materials (Brennan, 2005; Sasaki & Kohyama, 2011).

In views of the importance of NSP being used widely as food ingredients, the objective of this study was to investigate the effects of five different NSP including derivatives, namely guar gum (GG), xanthan gum (XG), carboxymethyl cellulose (CMC), tapioca fibre (Tap) and tamarind seed fibre (Tam), on the in vitro starch digestibility and physicochemical properties of rice starches.

2. Materials and methods

2.1. Preparation of samples

Waxy rice starch (WS) and non-waxy rice starch (NWS) were supplied by Cho Heng Rice Vermicelli Factory Co., Ltd. Amylose content of the WS and NWS samples were reported to be 1.48 ± 0.03 and 30.12 ± 0.02 g/100 g dry sample, respectively. Commercial NSPs (GG, XG and CMC) were purchased from Sigma-Aldrich, Singapore. They have been widely used in foods as thickener, stabiliser and emulsifier. GG is primarily the ground endosperm of the seeds from *Cyamopsis tetragonolobus* (L.) Taub., mainly consisting of high molecular weight polysaccharides composed of galactomannans; mannose:galactose ratio is about 2:1. XG is a high molecular weight polysaccharide gum produced by a pure-culture fermentation of a carbohydrate with *Xanthomonas campestris*, purified by recovery with ethanol or isopropanol, dried and milled, it contains D-glucose and D-mannose as the dominant hexose units, along with D-glucuronic acid and pyruvic acid, and is prepared as the sodium, potassium or calcium salt. CMS is the sodium salt of carboxymethyl ether of cellulose and prepared from cellulose by treatment with alkali and monochloro-acetic acid or its sodium salt. "Tap" in dry powder form was supplied by T-fibre Innovation Co., Ltd. It was isolated from the pulp of wet-milled tapioca after the isolation of starch. "Tam" was made from tamarind (*Tamarindus indica* L.) seeds by wet milling and drying at low temperature (50 °C) before use. A crude extract of tamarind seeds, was found to be rich in polysaccharide (~65–72%) (Kumar & Bhattacharya, 2008). These five NSPs were mixed with WS and NWS, each at 5, 10, 15 g/100 g dry sample. All samples were sieved through 100-mesh screen prior to analysis.

2.2. Total starch

Total starch content of the samples was determined enzymatically using the Megazyme assay kit (Megazyme International Ireland), following the approved AACC method 76.13 (AACC, 2009).

2.3. In vitro starch digestion and modelling of starch digestograms

The time-course starch digestion in the samples was determined using a rapid in vitro digestibility assay based on glucometry (Mahasukhonthachat, Sopade, & Gidley, 2010; Sopade & Gidley, 2009). About 0.5 g of ground sample was weighted and mixed with distilled water (1:1.5 w/w) and boiled at 100 °C for 20 min to obtain the gelatinised samples. To avoid the effect of retrogradation, immediately after cooking, the samples were treated with artificial saliva containing porcine α-amylase (Sigma A3176 Type VI-B) before pepsin (Sigma P6887; pH 2.0) was added and incubated at 37 °C for 30 min in a water bath operating under continuous shaking. The digesta was neutralised with NaOH before adjusting the pH to 6.0 (sodium acetate buffer) prior to the addition of pancreatin (Sigma P1750) and AMG (Novozymes AMG 300 L). The mixture was incubated for 2 h, during which the glucose concentration in the digesta was measured with Accu-Check® Performa® glucometer at specific periods (0, 10, 20, 30, 45, 60, 90 and 120 min). Digested starch per 100 g dry starch (DS) was calculated as in Eq. (1).

$$DS = \frac{0.9 \times G_G \times 180 \times V}{W \times S[100 - M]} \quad (1)$$