



Functional properties and starch digestibility of instant Jasmine rice porridges

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ABSTRACT

Ten instant rice porridges made from Jasmine rice mixed with other ingredients purchased from commercial outlets in Thailand were studied for their functional properties and starch digestibility. The starch contents of the samples varied from 59–84 g/100 g dry solids. Differential scanning calorimetry showed a single endothermic peak located around 56–82 °C for most samples, indicating that starch was partially gelatinized during processing. However, two samples did not show any transition enthalpy to suggest that they were completely gelatinized during processing. Rice porridge samples with similar ingredients exhibited different pasting properties because of significant effects of processing and possibly the type of ingredients, and differences in their hydration/swelling behaviours. From in vitro starch digestion, the rice porridge samples were high glycaemic index (GI) foods with calculated GIs ranging from 68 to 97. Generally, rice porridges that were completely gelatinized gave the highest GI values because gelatinization, in the absence of pronounced retrogradation and molecular reorganization, enhances digestibility. The present study demonstrated the importance of non-rice ingredients in the functional and digestion properties of rice porridge samples, and the need to understand how spices, animal and plant proteins, flavour enhancers (e.g. monosodium glutamate), and flavourings influence GI of rice porridges so as to guide processing and selection of ingredients.

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1. Introduction

Instant rice porridges have become more popular, as breakfast cereals in many Asian countries including Thailand. In 2008, the market in Thailand alone reached a value of \$22 million with total market growth of 13.5% (Viboonchart, 2008). Among many varieties of rice, Kao Dok Mali 105 (*Oryza sativa* L.) or the so-called Jasmine rice is the most popular variety in Thailand because of its aroma and tender texture. Jasmine rice is often used as the main ingredient for producing instant rice porridges in Thailand.

Physicochemical and metabolic properties of rice are influenced by numerous factors. One of these factors is amylose content, which is often used to predict starch digestion rate, blood glucose and insulin responses to rice. Starchy foods that are rich in amylose content are associated with lower blood glucose levels and slower emptying of human gastrointestinal tract compared to those with low levels of amylose (Behall, Scholfield, & Canary, 1988; Behall, Scholfield, Yuhaniak, & Canary, 1989; Frei, Siddhuraju, & Becker, 2003). In addition, Hu, Zhao, Duan, Linlin, and Wu (2004) reported that high-amylose rice exhibited lower glycaemic val-

ues than low-amylose varieties. However, Panlasigui et al. (1991) suggested that rice with similar amylose content could differ in starch digestibility and glycaemic responses. This is understandable because apart from amylose:amylopectin ratios, starch properties such as granule size, architecture, crystalline pattern, degree of crystallinity, surface pores or channels, degree of polymerisation, and non-starch components influence starch digestibility (Noda et al., 2008; Tester, Qi, & Karkalas, 2006). Regardless of the variability in starch digestibility, and hence, glycaemic index (GI), rice is generally known to have a relatively high GI compared to other starchy foods. It has been reported that GIs for rice ranged from 54 and 121 (Brand, Nicholson, Thorburn, & Truswell, 1985; Hu et al., 2004; Jaisut, Prachayawarakorn, Varanyanond, Tungtrakul, & Soponronnarit, 2008; Jenkins, Wolever, Jenkins, Josse, & Wong, 1984; Jenkins, Wolever, & Taylor, 1981; Miller, Pang, & Bramall, 1992). Thai Jasmine rice contains amylose in the range of 12–17% by weight, which is rather low compared to other rice varieties (Chitrakorn, 2003). Williams (2004) reported that Jasmine brown rice exhibits high GI of 74 which presents risk of type 2 diabetes.

The rate of starch digestion in foods, and consequently their GIs, can be altered by heat-moisture treatments as in many processing techniques (Jaisut et al., 2008; Jaisut, Prachayawarakorn, Varanyanond, Tungtrakul, & Soponronnarit, 2009; Rashmi & Urooj, 2003). The processing of rice porridges usually consists of

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Table 1
Ingredients of the rice porridges.

Samples	Ingredients
A	Jasmine rice 94%, soy bean flour 4%, iodized salt 2%
B	Jasmine rice 93%, soy bean flour 4%, pumpkin 2%, iodized salt 1%
C	Jasmine rice 93%, soy bean flour 4%, carrot 2%, iodized salt 1%
D	Jasmine rice 80%, red brown rice 18%, iodized salt 2%
E	Jasmine red brown rice 80%, soy bean flour 9%, seaweed 4%, salt 4%, sugar 2%, vegetables 1%
F	Jasmine brown rice 82%, soy bean flour 8%, soy sauce powder 5%, dried carrot 3%, dried cabbage 2%
G	Jasmine rice 61%, rice flour 10%, salt 6%, dried chicken meat 4.5%, sugar 4%, spices 1.35%, soy sauce powder 0.4%, monosodium glutamate and disodium 5'-ribonucleotides as flavor enhancers
H	Jasmine rice 60%, rice flour 10%, salt 6%, dried pork 4.5%, sugar 4%, pork extract 2%, spices 1.75%, dried shallot leaves 0.3%, monosodium glutamate and disodium 5'-ribonucleotides as flavor enhancers
I	Jasmine rice 74%, dried pork 8%, whole egg powder 2%, salt 6%, sugar 4%, monosodium glutamate as flavor enhancer
J	Jasmine rice 78%, dried fish meat 5%, soy bean protein 1%, salt 6%, sugar 4%

pre-cooking and then drying of the rice before mixing with other ingredients such as milk powder, salt and sugar. This process influences the properties of rice starch, and formation of complexes may affect starch resistance to enzyme digestion. In view of the popularity of Thai Jasmine rice in Asia, this research investigated the functional properties and starch digestibility of instant rice porridges made from the rice.

Table 2
The parameters (v/v, μm) of the particle size distribution of the rice porridges.^{a,b}

Samples	10th percentiles	50th percentiles	90th percentiles	Volume weighted mean
A	9.03f $\pm$ 0.24	312c $\pm$ 2.38	624b $\pm$ 4.09	301c $\pm$ 0.33
B	11.9d $\pm$ 0.02	328b $\pm$ 0.04	632b $\pm$ 0.00	315b $\pm$ 0.20
C	10.5e $\pm$ 0.05	207e $\pm$ 0.01	729a $\pm$ 0.14	368a $\pm$ 0.08
D	9.05f $\pm$ 0.07	374a $\pm$ 0.34	469d $\pm$ 0.21	214e $\pm$ 0.10
E	27.8b $\pm$ 0.29	168f $\pm$ 0.30	302g $\pm$ 0.71	165g $\pm$ 0.37
F	61.2a $\pm$ 0.26	225d $\pm$ 0.21	451e $\pm$ 0.40	241d $\pm$ 0.89
G	11.4d $\pm$ 0.04	140g $\pm$ 0.11	527c $\pm$ 0.28	218e $\pm$ 0.21
H	5.60g $\pm$ 0.01	38.9i $\pm$ 0.09	127i $\pm$ 0.70	54.0i $\pm$ 0.03
I	23.9c $\pm$ 0.10	126h $\pm$ 0.37	279h $\pm$ 0.00	141h $\pm$ 0.50
J	26.6b $\pm$ 0.56	140g $\pm$ 0.26	371f $\pm$ 0.85	173f $\pm$ 0.19

^a Values are means $\pm$ standard deviations.

^b Figures with the same letters in a column indicate that they are not significantly different ($p > 0.05$). These apply to all tables where they appear.

2. Materials and methods

2.1. Samples and preparation

Ten commercial brands of instant rice porridges, with at least three different date codes for each brand, were purchased locally in Thailand. All brands were made of Thai Jasmine rice as the main ingredient. The samples were coded (A–J), and the ingredients, as shown in the packets are listed in Table 1, while Fig. 1 shows the photographs of the samples.

The samples were ground with a disc mill (Laboratory Mill 3600, Perten Instruments, Sweden), and passed through a 1-mm sieve before they were stored refrigerated in air-tight containers prior to analysis.

2.2. Particle size analysis

Particle size distribution of the ground samples was determined by a Malvern Mastersizer 2000 equipped with Hydro 2000MU wet dispersion unit (Malvern Instruments Ltd., UK) using methanol as the suspension liquid. Each sample was analysed in duplicate. Particle size distribution parameters are summarized in Table 2.

2.3. Differential scanning calorimetry (DSC)

The moisture content of the ground samples (4.9–12.3%) was adjusted to about 70% by adding milliQ water prior to DSC, which was carried out in a Q2000 DSC equipped with refrigerated cooler RCS 90 (TA Instruments, New castle, DE, USA). The hydrated samples were kept in airtight containers overnight at room temperature



Fig. 1. Appearance of the rice porridges (from left to right and top to bottom, A–J).

to ensure that they were completely equilibrated (Srikaeo, Furst, Ashton, Hosken, & Sopade, 2005). The hydrated samples (20 ± 5 mg) were weighed into the Tzero aluminum DSC pans and hermetically sealed. An empty pan was used as the reference, and DSC analysis was done by equilibrating at 30°C , isothermal for 5 min and ramping at $10^\circ\text{C}/\text{min}$ to 120°C (Mahasukhonthachai, Sopade, & Gidley, 2010). The resulting thermograms were analysed (TA Universal Analysis) for the onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and transition enthalpy. Each sample was analysed in duplicate.

2.4. Rapid visco-analysis

Pasting properties were investigated using the Rapid Visco-Analyser (RVA-4D, Newport Scientific Pvt Ltd., Australia) following the approved method 61.02 (AACC, 2008). A 13-min RVA profile was used with 3.0 g ground samples (adjusted to 14% moisture content) in 25 mL distilled water. The RVA ThermoclineTM software (ver. 2.6) was used to obtain the pasting temperature, peak, trough, and final viscosities of the samples. Each sample was analysed in duplicate.

2.5. In vitro starch digestion

Time-course starch digestion in the rice porridge samples was determined using a rapid in vitro digestibility assay based on glucometry (Mahasukhonthachai et al., 2010; Sopade & Gidley, 2009). About 0.5 g of ground sample was treated with artificial saliva containing porcine α -amylase (Sigma A-3176 Type VI-B) before pepsin (Sigma P-6887; pH 2.0) was added and incubated at 37°C for 30 min in a reciprocating water bath (SWB20; Ratek Instruments Pvt. Ltd., Australia; 85 rpm). The digesta was neutralized with NaOH before adjusting the pH to 6 (sodium acetate buffer) prior to the addition pancreatin (Sigma P1750) and amyloglucosidase (Sigma A-7420). The mixture was incubated for 4 hr, during which the glucose concentration in the digesta was measured with an Accu-Check[®] Performa[®] glucometer at specific periods (0, 10, 20, 30, 45, 60, 90, 120, 150, 180, 210 and 240 min). Digested starch per 100 g dry starch (DS) was calculated as Eq. (1):

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

where G_G = glucometer reading (mM/L), V = volume of digesta (mL), 180 = molecular weight of glucose, W = weight of sample (g), S = starch content of sample (g/100 g sample), M = moisture content of a sample (g/100 g sample), and 0.9 = stoichiometric constant for starch from glucose contents.

2.6. Total starch content

Total starch content of the samples was analysed using a method derived from Megazyme (Megazyme International Ireland Ltd., Ireland). About 50 mg of sample was wetted with ethanol, heated (boiling water bath) in dimethyl sulphoxide (DMSO) and digested with thermostable α -amylase (Megazyme E-BLAAM) in MOPS (Sigma M-9381) buffer before sodium acetate buffer and amyloglucosidase (Megazyme E-AMGDF) were added and incubated as described before (Mahasukhonthachai et al., 2010; Sopade & Gidley, 2009). The glucose content was determined using an enzymatic glucose reagent (TR15104 Enzymatic glucose oxidase reagent; Microgenics Diagnostic Pvt Ltd., Australia), and the absorbance of the colouration was measured (Pharmacia LKB-Ultrospec III) at 505 nm. Each sample was analysed in duplicate.

Table 3
The starch content, and pasting (RVA) and gelatinization (DSC) parameters of the rice porridges.

Sample	Total starch (g/100 g dry solids)	RVA parameters		DSC parameters					
		Pasting temperature (°C)	Peak viscosity (RVU)	Trough viscosity (RVU)	Final viscosity (RVU)	T _o (°C)	T _p (°C)	T _c (°C)	ΔH (J/g sample)
A	83.2a ± 12	86.0b ± 0.57	296d ± 2.47	267c ± 3.75	468c ± 7.85	64.2b ± 0.28	69.3b ± 0.28	92.4b ± 0.28	0.62de ± 0.00
B	84.0a ± 8.4	84.8b ± 0.14	369c ± 8.41	274c ± 3.11	465c ± 4.17	64.6b ± 0.28	69.4b ± 0.71	79.8d ± 0.21	0.43f ± 0.01
C	78.9ab ± 1.2	84.7b ± 0.00	371c ± 9.90	323a ± 4.45	533a ± 4.81	64.1b ± 0.21	70.8b ± 0.28	92.2b ± 0.07	0.86c ± 0.02
D	82.9a ± 0.3	85.6b ± 0.07	424b ± 0.07	292b ± 1.98	494b ± 4.03	64.6b ± 0.14	70.2b ± 0.28	84.2c ± 0.21	0.67d ± 0.01
E	69.6abc ± 4.2	62.9c ± 0.07	619a ± 4.10	212d ± 1.77	347d ± 0.99	46.8d ± 0.14	56.6d ± 0.07	61.6f ± 0.21	2.15b ± 0.07
F	65.2bc ± 0.5	65.2c ± 3.46	77.7g ± 2.26	68.4g ± 1.27	91.1g ± 2.47	49.8c ± 0.14	60.4c ± 0.28	70.8e ± 0.21	2.94a ± 0.06
G	59.5c ± 4.6	90.8a ± 0.49	227e ± 7.35	212d ± 6.36	329d ± 9.40	77.4a ± 0.14	81.8a ± 0.28	95.4a ± 0.14	0.75cd ± 0.01
H	62.6bc ± 1.9	91.7a ± 0.42	200f ± 5.30	188e ± 4.38	330d ± 12.7	76.6a ± 0.35	81.6a ± 0.21	91.1b ± 0.14	0.52e ± 0.02
I	63.2bc ± 4.2	62.9c ± 0.00	287d ± 3.11	76.3f ± 0.71	123f ± 1.13	–	–	–	–
J	72.0abc ± 1.7	63.3c ± 0.57	288d ± 13.3	86.0f ± 0.42	150e ± 5.80	–	–	–	–

2.7. Modelling starch digestogram

A modified first-order kinetic model, Eq. (2), was used to describe (Mahasukhonthachat et al., 2010) the starch digestograms:

$$D_t = D_0 + D_{\infty-0}(1 - \exp[-Kt]) \quad (2)$$

where D_t (g/100 g dry starch) is the digested starch at time t , D_0 is the digested starch at time $t = 0$, D_{∞} is the digestion at infinite time ($D_0 + D_{\infty-0}$), and K is the rate constant (min^{-1}). The Microsoft Excel Solver® was used to compute the parameters of the model by minimising the sum of squares of residuals (SUMSQ) and constraining $D_{\infty} \leq 100$ g/100 g dry starch, and $D_0 \geq 0$ g/100 g dry starch. In addition to the coefficient of determination (r^2), the predictive ability of the models was assessed with the mean relative deviation modulus (MRDM) as described before (Mahasukhonthachat et al., 2010).

In order to calculate the glycaemic indices of the samples, the areas under the digestograms (AUC_{exp}) were computed with Eq. (3), which is the integral form of Eq. (1):

$$\text{AUC}_{\text{exp}} = \left[D_{\infty}t + \frac{D_{\infty-0}}{K} \exp(-Kt) \right]_{t_1}^{t_2} \quad (3)$$

The hydrolysis index (HI) of each sample was calculated by dividing (Goñi, Garcia-Alonso, & Saura-Calixto, 1997) the area under its digestogram by the area under the digestogram of a fresh white bread (≈ 6000 min g/100 g dry starch). From Goñi et al. (1997), single-point measurements of starch digestion at 90 min in samples and fresh white bread as a reference can also be used to calculate GI (H_{90}). Hence, using the parameters of the modified first-order kinetic model (Eq. (2)) for both the samples and fresh white bread, GIs of the samples were also calculated, and the average GI for each sample was defined as below (Eq. (4)):

$$\text{GI} = \frac{(39.21 + 0.803H_{90}) + (40.03 + 0.558\text{HI})}{2} \quad (4)$$

2.8. Statistical analysis

Analysis of variance (ANOVA) and test of significance were performed using Minitab® ver. 14 with confidence level of 95%. The samples were randomised for all the analyses described above.

3. Results and discussion

3.1. Starch content

Apart from differences in the ingredients (Table 1) and particle size distribution (Table 2) after ground, Table 3 also shows that the samples differed in their starch contents. This is expected because the proportion of Jasmine rice varied (60–94%) among the samples. These factors could manifest in differences in the functional and digestion properties of the samples.

3.2. Gelatinization behaviour

Apart from samples I and J, the rice porridge samples exhibited a single endothermic peak (not shown) with starch gelatinization peak temperatures located around 56–82 °C (Table 3). Most cereal flours/starches exhibit one endothermic peak (Normand & Marshall, 1989), but two endothermic transitions have been reported with rice and milled whole grain cereal samples (Jaisut et al., 2008; Nakazawa, Noguchi, Takahashi, & Takada, 1984; Normand & Marshall, 1989). In the absence of other food matrices, two endothermic transitions in cereals possibly result from gelatinization of the starch component and amylose–lipid transitions. However, thermograms of complex food matrices can be inconsistent due to thermal influences from non-starch components such as

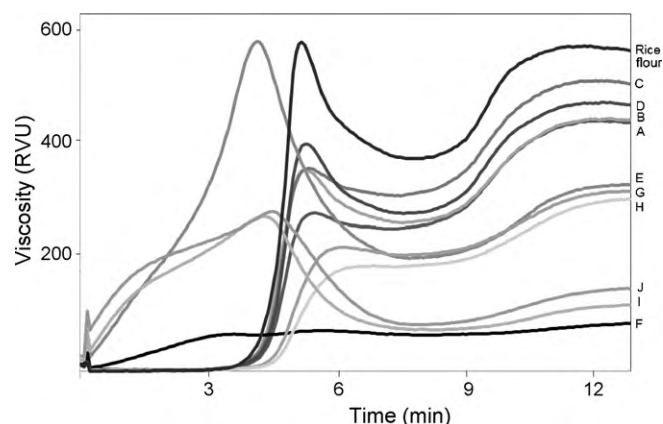


Fig. 2. Pasting (RVA) behaviours of the rice porridges and white jasmine rice flour.

proteins, lipids, and other carbohydrates (Parada & Aguilera, 2009; Srikaeo et al., 2005).

Generally, endothermic transition temperatures around 50–80 °C are usually due to starch gelatinization. Hence, the endothermic peaks found in samples A–H were judged to be associated with starch gelatinization. However, samples I–J, which showed no transition peak, indicated the absence of raw or non-gelatinized starch. It can, therefore, be inferred that the starch in these rice porridge samples (I and J) had been completely gelatinized during the processing. This is possible because the processing of rice porridges usually involves drum drying at high temperatures (120–140 °C) and water content (50–75%).

The gelatinization temperatures of samples E–F were significantly ($p < 0.05$) lower than the others (Table 3). These may be influenced by other components in the samples such as lipids and proteins (e.g. from dried meat ingredients). Mohamed and Rayas-Duarte (2003) reported that higher amounts of protein in starch–protein/gluten blend increased the onset and peak temperatures, and decreased enthalpy as measured by DSC. The presence of other components such as sugar and salt in starch–water systems has been found to inhibit gelatinization (Jang, Lee, Cho, & Pyun, 2001; Lund, 1984; Maauf, Che Man, Asbi, & Junainah, 2001; Perry & Donald, 2002). Kitabatake, Tahara, and Doi (1990) reported that DSC thermograms of soy bean protein, an ingredient in some rice porridge samples, developed two peaks at 93.3 and 76.5 °C because of the two dominant forms of the proteins, and these peaks shifted to higher temperatures with lower moisture content of the samples. Since the moisture contents of the porridge samples were adjusted to essentially the same level prior to DSC analysis, we do not believe the moisture factor played any roles in the measured thermal properties of the samples. Hence, as discussed above, the differences we measured could have been mainly due to the different ingredients used as well as possible varietal (or genotype $\times$ environmental) differences in the main ingredient (Jasmine rice) used for the samples.

3.3. Pasting behaviour

The hydration, swelling and viscosity developments in the rice porridge samples are depicted in Fig. 2 with Jasmine rice flour as a reference. Average RVA parameters of reference sample are: pasting temperature 83.1 °C, peak, trough and final viscosity 615, 396 and 599 RVU respectively. While some of the samples (e.g. sample D) exhibited an identical pasting profile with the Jasmine rice flour, some of the samples (e.g. sample E) showed profiles that suggested instantaneous swelling, and hence viscosity increases, on contact with water with and without heating. Moreover, some samples (e.g. sample F) did not completely swell during heat-

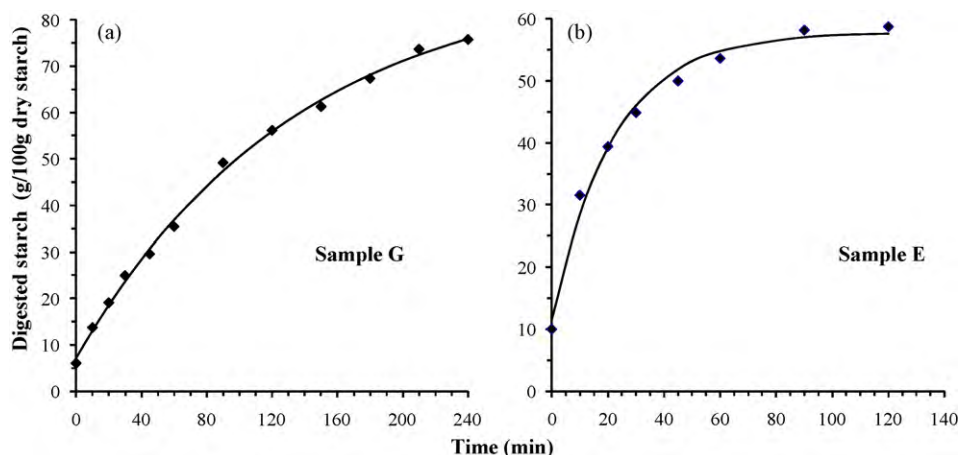


Fig. 3. Typical digestograms of the rice porridges showing the experimental (♦) and predicted (---) values: (a) low GI group and (b) high GI group.

ing to suggest the presence of impediments to swelling by the non-starch components of the sample. Shear-thickening pasting behaviours have been reported for sorghum, and the starch–protein interactions in sorghum was thought to impede starch swelling (Mahasukhonthachat et al., 2010). Although, sample F consisted of about 80% of Jasmine brown rice, it also had the highest amount of dried vegetable components (dried carrot 3% and dried cabbage 2%). This fibrous portion may retard starch swelling.

Table 3 shows the RVA parameters for the porridges. From the DSC data, samples I and J were suspected to be completely gelatinized. Although these samples increased in viscosity during pasting, it is doubtful if the viscosity developments were due to the gelatinization of the residual raw starch in the samples. We suspect the viscosity increased because of the hydration/swelling of the non-starch components. The other differences observed in the RVA profiles show that although the RVA is widely and extensively used in food research for starch behaviours, non-starch components in complex food matrices (Lim, Lee, Shin, & Lim, 1999) can hydrate, swell and increase the viscosity of their dispersions. Hence, in the presence of starch and non-starch components, RVA results need to be cautiously interpreted, and supportive data might be required to understand the pasting behaviours of complex food matrices.

3.4. In vitro starch digestion

Fig. 3 shows typical starch digestograms of the porridge samples. Irrespective of the ingredients and their proportions, the samples exhibited monophasic digestograms. Moreover, the modified first-order kinetic model was suitable ($r^2 = 0.962\text{--}0.997$; MRDM = 4–8%; SUMSQ = 6–80) in describing the digestograms. From Table 4, the GI of the samples ranged from 68–97. In terms of the GI, there

appears to be two groups; samples A–D, G and H (low group, <80) and samples E, F, I and J (high group, >80). Although there are minimal differences in the Jasmine rice contents of both groups, it is noteworthy that samples E and F contained Jasmine brown rice. Brown rice has high resistant starch content and, therefore, low digestibility (Nugent, 2005; Sajilata, Singhal, & Kulkarni, 2006). However, the reverse was measured with samples E and F. Generally, in the absence of retrogradation or structural changes, starch gelatinization enhances starch digestibility. Although samples E and F indicated the presence of raw starches as observed by DSC (Table 3), encapsulated and/or non-encapsulated, their high digestibility possibly resulted from the favourable effects of the non-starch components on starch digestion. Exogenous proteins have been reported to aid starch digestion, and mixtures of whey protein isolate and wheat starch were more digested than wheat starch (Sopade & Gidley, 2009; Yong, Chan, & Sopade, 2008). Moreover, in the rice porridge samples, the spices, flavour enhancers and flavourings differed with possibly different constituents that could have affected starch digestion. Reports exist on the effects of spices and herbs on digestion and health including GI or blood glucose and insulin response (Madar & Shomer, 1990; Srinivasan, 2008; Tuntipopipat, Zeder, Siriprapa, & Charoenkiatkul, 2009), and while some spices and herbs aid digestion, others inhibit digestion and absorption. Monosodium glutamate is a widely-used flavour enhancer in Asian cuisines, and has been shown to enhance digestion of protein-rich meals, while gastric emptying with carbohydrate-rich meals was not significantly affected (Zai et al., 2009).

Rice porridges are usually manufactured by drum drying, and market samples from different manufacturers could vary in the heat-moisture treatments due to different heat and moisture

Table 4

Model parameters, hydrolysis index (HI) and glycaemic index (GI) of rice porridge samples and white jasmine rice.

Samples	D_0 (g/100 g dry starch)	D_∞ (g/100 g dry starch)	K ($\times 10^{-3}$ min $^{-1}$)	H_{90}^a	HI	Average GI ^{b}
A	5.9 ± 0.26	85.0 ± 11.6	5.6 ± 2.63	35.5 ± 6.78	52 ± 9.7	68b ± 5.4
B	5.2 ± 0.77	71.1 ± 7.17	7.2 ± 0.30	36.8 ± 4.75	54 ± 7.1	69b ± 3.9
C	5.4 ± 0.06	78.4 ± 0.68	6.5 ± 0.30	37.6 ± 0.84	55 ± 1.3	70b ± 0.7
D	5.8 ± 0.16	73.3 ± 8.38	8.2 ± 1.31	40.6 ± 0.47	60 ± 0.1	73b ± 0.2
E	12.0 ± 0.71	60.8 ± 4.20	49.3 ± 5.38	60.2 ± 4.44	105 ± 8.9	93a ± 4.3
F	18.0 ± 3.52	64.8 ± 0.18	50.2 ± 1.37	64.3 ± 0.16	114 ± 1.0	97a ± 0.4
G	6.5 ± 0.88	89.3 ± 0.63	6.8 ± 0.95	44.2 ± 4.62	65 ± 7.2	75b ± 3.9
H	7.9 ± 0.13	94.2 ± 8.15	5.3 ± 0.65	40.6 ± 0.08	60 ± 0.1	73b ± 0.1
I	16.4 ± 0.89	62.9 ± 2.80	40.4 ± 6.42	61.6 ± 3.42	106 ± 70	94a ± 3.3
J	11.8 ± 2.76	56.4 ± 0.44	55.9 ± 9.14	56.1 ± 0.67	99 ± 2.1	90a ± 0.8

^a This is predicted digested starch at 90 min using the modified first-order kinetic model (Eq. (2)).

^b Average GI was calculated using Eq. (4).

regimes. While these will influence digestion and functional properties (Casiraghi, Brighenti, Pellegrini, Leopardi, & Testolin, 1993; Chung, Lim, & Lim, 2006; Jaisut et al., 2008), these properties will also depend on the types and quantities of major and minor ingredients used during manufacturing. The health concerns of high GI foods are well established, and while rice is a high GI food, the present study has shown that spices, herbs, flavour enhancers, and flavourings could influence GI of rice-based meals. Using a common base ingredient with identical processing, further studies are required to clearly establish the contributions of these minor but important ingredients to the extent and rate of starch digestion, and consequently GI. This would assist in formulating rice porridges of acceptable GI and desirable functional properties.

4. Conclusion

Rice porridges marketed in Thailand are essentially high GI (>70) products, which presents risk of type 2 diabetes. Heat-moisture treatments of rice such as in drum drying, which is used in the processing of instant rice porridges, change functional and digestion properties of rice porridges. With the 10 rice porridges marketed in Thailand investigated in the present study, the starch could be completely gelatinized as some samples did not show endothermic transitions akin to starch gelatinization during calorimetry, while most samples showed low gelatinization enthalpy to suggest they were highly partially gelatinized. Pasting and digestibility properties revealed significant effects of non-rice ingredients (salt, sugar, animal and plant proteins, spices, and flavour enhancers) of the instant rice porridges. While the present study revealed the compound effects of Jasmine rice and other ingredients on digestibility of rice porridges marketed in Thailand, the specific contributions of the non-rice ingredients need to be ascertained to help in formulating and processing of rice porridges with predicted GIs. This would be valuable for process design during the manufacture of Jasmine rice porridges, and for diabetic individuals.

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References

- AACC. (2008). Approved Methods of the American Association of Cereal Chemists. 10th edn., St. Paul, MN.
- Behall, K. M., Scholfield, D. J., & Canary, J. (1988). Effect of starch structure on glucose and insulin responses in adults. *American Journal of Clinical Nutrition*, 47, 428–432.
- Behall, K. M., Scholfield, D. J., Yuhaniak, I., & Canary, J. (1989). Diets containing high amylose vs amylopectin starch: effects on metabolic variables in human subjects. *American Journal of Clinical Nutrition*, 49, 337–344.
- Brand, J. C., Nicholson, P. L., Thorburn, A. W., & Truswell, A. S. (1985). Food processing and the glycemic index. *American Journal of Clinical Nutrition*, 42, 1192–1196.
- Casiraghi, M. C., Brighenti, F., Pellegrini, N., Leopardi, E., & Testolin, G. (1993). Effect of processing on rice starch digestibility evaluated by in vivo and in vitro methods. *Journal of Cereal Sciences*, 17, 147–156.
- Chitrakorn, S. (2003). Rice and the Thai way of life. In S. Lorlowhakorn (Ed.), *Science and Technology with Thai Rice*. Bangkok, Thailand: Thailand's National Science and Technology Development Agency, pp. 13–22.
- Chung, H. J., Lim, H. S., & Lim, S. T. (2006). Effect of partial gelatinization and retrogradation on the enzymatic digestion of waxy rice starch. *Journal of Cereal Science*, 43, 353–359.
- Frei, M., Siddhuraju, P., & Becker, K. (2003). Studies on the in vitro starch digestibility and the glycemic index of six different indigenous rice cultivars from the Philippines. *Food Chemistry*, 83, 395–402.
- Goñi, I., Garcia-Alonso, A., & Saura-Calixto, F. (1997). A starch hydrolysis procedure to estimate glycemic index. *Nutrition Research*, 17, 427–437.
- Hu, P., Zhao, H., Duan, Z., Linlin, Z., & Wu, D. (2004). Starch digestibility and the estimated glycemic score of different types of rice differing in amylose contents. *Journal of Cereal Science*, 40, 231–237.
- Jaisut, D., Prachayawarakorn, S., Varanyanond, W., Tungtrakul, P., & Soponronnarit, S. (2008). Effects of drying temperature and tempering time on starch digestibility of brown fragrant rice. *Journal of Food Engineering*, 86, 251–258.
- Jaisut, D., Prachayawarakorn, S., Varanyanond, W., Tungtrakul, P., & Soponronnarit, S. (2009). Accelerated aging of jasmine brown rice by high-temperature fluidization technique. *Food Research International*, 42, 674–681.
- Jang, J. K., Lee, S. H., Cho, S. C., & Pyun, Y. R. (2001). Effect of sucrose on glass transition and gelatinization, and retrogradation of wheat starch. *Cereal Chemistry*, 78, 186–192.
- Jenkins, D. J. A., Wolever, T. M. S., Jenkins, A. L., Josse, R. G., & Wong, G. S. (1984). The glycemic response to carbohydrate foods. *The Lancet*, 18, 388–391.
- Jenkins, D. J. A., Wolever, T. M. S., & Taylor, R. H. (1981). Glycemic index of foods: A physiological basis for carbohydrate exchange. *American Journal of Clinical Nutrition*, 34, 362–366.
- Kitabatake, N., Tahara, M., & Doi, E. (1990). Thermal denaturation of soybean protein at low water contents. *Agricultural and Biological Chemistry*, 54, 2205–2212.
- Lim, S.-T., Lee, J.-H., Shin, D.-H., & Lim, H. S. (1999). Comparison of protein extraction solutions for rice starch isolation and effects of residual protein content on starch pasting properties. *Starch/Stärke*, 51, 120–125.
- Lund, D. (1984). Influence of time, temperature, moisture, ingredients, and processing conditions on starch gelatinization. *CRC Critical Reviews in Food Science and Nutrition*, 20, 249–273.
- Maauf, A. G., Che Man, Y. B., Asbi, B. A., Junainah, A. H., & Kennedy, J. F. (2001). Gelatinization of sago starch in the presence of sucrose and sodium chloride as assessed by differential scanning calorimetry. *Carbohydrate Polymers*, 45, 335–345.
- Madar, Z., & Shomer, I. (1990). Polysaccharide composition of a gel fraction derived from fenugreek and its effect on starch digestion and bile acid absorption in rats. *Journal of Agricultural and Food Chemistry*, 38, 1535–1539.
- Mahasukhonthachai, K., Sopade, P. A., & Gidley, M. J. (2010). Kinetics of starch digestion in sorghum as affected by particle size. *Journal of Food Engineering*, 96, 18–28.
- Miller, J. B., Pang, E., & Bramall, L. (1992). Rice: a high or low glycemic index food? *American Journal of Clinical Nutrition*, 56, 1034–1036.
- Mohamed, A. A., & Rayas-Duarte, P. (2003). The effect of mixing and wheat protein/gluten on the gelatinization of wheat starch. *Food Chemistry*, 81, 533–545.
- Nakazawa, F., Noguchi, S., Takahashi, J., & Takada, M. (1984). Gelatinization and retrogradation of rice starch studied by differential scanning calorimetry. *Agricultural and Biological Chemistry*, 48, 201–203.
- Noda, T., Takigawa, S., Matsuura-Endo, C., Suzuki, T., Hashimoto, N., Kottarachchi, N. S., et al. (2008). Factors affecting the digestibility of raw and gelatinized potato starches. *Food Chemistry*, 110, 465–470.
- Normand, F. L., & Marshall, W. E. (1989). Differential scanning calorimetry of whole grain milled rice and mill rice flour. *Cereal Chemistry*, 66, 317–320.
- Nugent, A. P. (2005). Health properties of resistant starch. *BNF Nutrition Bulletin*, 30, 25–54.
- Panlasigui, L., Thompson, L. U., Juliano, B. O., Perez, C. M., Yiu, S. H., & Greenberg, G. R. (1991). Rice varieties with similar amylose content differ in starch digestibility and glycemic response in humans. *American Journal of Clinical Nutrition*, 54, 871–877.
- Parada, J., & Aguilera, J. M. (2009). In vitro digestibility and glycemic response of potato starch is related to granule size and degree of gelatinization. *Journal of Food Science*, 74, E34–E38.
- Perry, P. A., & Donald, A. M. (2002). The effect of sugars on the gelatinisation of starch. *Carbohydrate Polymers*, 49, 155–165.
- Rashmi, S., & Urooj, A. (2003). Effect of processing on nutritionally important starch fractions in rice varieties. *International Journal of Food Science and Nutrition*, 54, 27–36.
- Sajilata, M. G., Singhal, R. S., & Kulkarni, P. R. (2006). Resistant starch—A review. *Comprehensive Reviews in Food Science and Food Safety*, 5, 1–17.
- Sopade, P. A., & Gidley, M. J. (2009). A rapid in vitro digestibility assay based on glucometry for investigating kinetics of starch digestion. *Starch/Stärke*, 61, 245–255.
- Srikaeo, K., Furst, J. E., Ashton, J. F., Hosken, R. W., & Sopade, P. A. (2005). Wheat grain cooking process as investigated by modulated temperature differential scanning calorimetry. *Carbohydrate Polymers*, 61, 203–210.
- Srinivasan, K. (2008). Reason to season: spices as functional food adjuncts with multiple health effects. *Indian Food Industry*, 27, 36–46.
- Tester, R. F., Qi, X., & Karkalas, J. (2006). Hydrolysis of native starches with amylases. *Animal Feed Science and Technology*, 130, 39–54.
- Tuntipipat, S., Zeder, C., Siriprapa, P., & Charoenkiatkul, S. (2009). Inhibitory effects of spices and herbs on iron availability. *International Journal of Food Sciences and Nutrition*, 60(Suppl. 1), 43–55.
- Viboonchart, N. (2008). Unilever looks to enlarge market as Knorr's share falls. *The Nation*. February 14, 2008.
- Williams, P. (2004). The glycemic index. In *Extension of Utah State University*. Utah: Utah State University.
- Yong, L.-Z., Chan, C. H., & Sopade, P. A. (2008). Changes in digestibility and bioactivity of a model high-protein-low carbohydrate (HPLC) food as a result of extrusion. Presented, 41st Annual Conference of the Australian Institute of Food Science and Technology. 21–24 July, 2008.
- Zai, H., Kusano, M., Hosaka, H., Shimoyama, Y., Nagoshi, A., Maeda, M., et al. (2009). Monosodium L-glutamate added to a high-energy, high-protein liquid diet promotes gastric emptying. *American Journal of Clinical Nutrition*, 89, 431–435.