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Effects of amylose and resistant starch on glycaemic index of rice noodles

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ABSTRACT

Rice is generally high in glycaemic index (GI). Amylose and resistant starch (RS) play an important role in controlling the GI. The levels of amylose and RS in the mixed flours for rice noodle production (rice flours mixed with tapioca starch) were manipulated by adding high amylose maize starch. This resulted in the increase of amylose and RS from 32 to 50 and 0.4 to 16 g/100 g dry sample respectively. The mixed flour samples were used to produce rice noodles. Their GI values were estimated by an in-vitro enzymatic digestion assay and confirmed by an in-vivo method. It was found that the GI of rice noodles decreased as amylose and RS increased. However, high amylose and RS affected the texture as they reduced the tensile strength of the noodles.

1. Introduction

Rice is one of the most important cereal crops and is a staple food in Asia. However, it is generally known to have a relatively high glycaemic index (GI) compared to other starchy foods. It has been reported that GIs of rice ranged from 54 to 121 (Brand, Nicholson, Thorburn, & Truswell, 1985; Hu, Zhao, Duan, Linlin, & Wu, 2004; Jaisut, Prachayawarakorn, Varanyanond, Tungtrakul, & Soponronnarit, 2008, 2009; Jenkins, Wolever, Jenkins, Josse, & Wong, 1984; Jenkins, Wolever, & Taylor, 1981; Shobana et al., 2012).

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). Several investigators have reported that high-amylose rice exhibited lower GI values than low-amylose varieties (Denardin, Boufleur, Reckziegel, da Silva, & Walter, 2012; Denardin, Walter, da Silva, Souto, & Fagundes, 2007; Hu et al., 2004). Although, some investigators suggested that rice with similar amylose content could differ in starch digestibility and glycaemic responses (Panlasigui et al., 1991). 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; Parada & Aguilera, 2012; Tester, Qi, & Karkalas, 2006).

Apart from amylose, resistant starch (RS) has recently received much attention for both its health benefits and functional properties. It positively influences the functioning of the digestive tract, microbial flora, the blood cholesterol level, the GI and assists in the control of diabetes (Fuentes-Zaragoza, Riquelme-Navarrete, Sánchez-Zapata, & Pérez-Álvarez, 2010).

The rate of starch digestion in foods, and consequently their GIs, can be altered by several techniques. These may involve the modification of key functional ingredients (Finocchiaro et al., 2012; Srikaeo, Mingyai, & Sopade, 2011), using low or no calorie sugars (Whelan, Vega, Kerry, & Goff, 2008), formation of starch lipid complexes (Henry, Lightowler, Newens, & Pata, 2008; Thomsen et al., 1999; Thomsen, Storm, Holst, & Hermansen, 2003) or applying processing techniques e.g. heat-moisture treatments (Cham & Suwannaporn, 2010; Hormdok & Noomhorm, 2007; Jaisut et al., 2008, 2009; Rashmi & Urooj, 2003), extrusion (Brennan, Derbyshire, Tiwari, & Brennan, 2013; Mishra, Mishra, & Rao, 2012) or using less degree of polishing in milled rice (Panlasigui & Thompson, 2006; Shobana et al., 2012, 2011).

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Rice noodle is the potential rice product that can be formulated to exhibit lower GI values than other rice products. It is usually made of high amylose rice as this promotes better noodle texture (Fu, 2008; Yoenyongbuddhagal & Noomhorm, 2002). Its processing also applies steaming of rice flour slurry and tempering of steamed rice sheets. These may increase RS or slowly-digestible starch portion and consequently lower the GI by means of hydrothermal treatment (Guha, Umesh, Reddy, & Malleshi, 2011) and starch retrogradation (Zhang, Hu, Xu, Jin, & Tian, 2011). Our previous study has found that high RS ingredients produced noodles that showed lower GI values (Srikaeo et al., 2011). This study further investigates the mechanistic effects of amylose and RS on GI of rice noodles. The findings could be useful as the example for healthy rice product formulations. This helps rice processing industry to expand the products that suit the increasing markets of functional foods.

2. Material and methods

2.1. Sample preparation

The rice noodle mixtures (control sample) composed of rice flour and tapioca starch at the ratio of 7:3 by weight. This mixture is commonly used as the flour mixture for rice noodle production in Thailand. Commercially available rice flour and tapioca starch purchased in Thailand were used. Amylose and RS of the mixtures were manipulated by adding high amylose maize starch (Hi-maize™ 260) which was purchased from National Starch and Chemical (Thailand) Co., Ltd. The supplier labelled a minimum of 60 g/100 g dry sample of total dietary fibre. Total starch, RS and amylose content were found to be 84.25 ± 1.24, 27.81 ± 0.78 and 76.05 ± 0.75 g/100 g dry sample, respectively. The maize starch was added to the control mixtures at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample. They were identified as control, M10, M20, M30, M40, M50 and M60 respectively. These samples were used for the analysis of starch composition, amylose content and gelatinisation properties. They were also used for the production of rice noodles.

Rice noodles were produced in the laboratory for precise control. The water was added to the mixtures to give the mixed flour slurry at the same specific gravity (1.15 Baume). The same amount of slurry was poured into the nonstick trays to give the final rice sheet thickness at approximately 1 mm. The slurry was steamed for 10 min in the steamer at 95 °C to obtain cooked rice sheets. The cooked rice sheets were tempered at room temperature for 3 h before being cut to 7 mm width and dried at 50 °C until the final moisture content was about 10–13 g/100 g dry basis. The samples were analysed for both in-vitro and in-vivo starch digestion assays and textural properties.

2.2. Starch composition

Starch composition was determined enzymatically using the Megazyme RS assay procedure (KRSTAR test kit, Megazyme International, County Wicklow, Ireland). Briefly, 100 mg of milled sample were incubated in a shaking water bath with thermo-stable pancreatic α-amylase and AMG for 16 h at 37 °C. During this incubation the non-resistant starch (non-RS) is solubilised and hydrolysed to glucose by the two enzymes. The reaction was terminated by the addition of equal volume of ethanol and the RS was recovered as a pellet on centrifugation (3000 g) for 10 min. The supernatants of this centrifugation and those of two consecutive washings were removed by decantation and stored. RS pellets were dissolved in 2 mol/L KOH and stirred for 20 min in an ice/water bath over a magnetic stirrer. Sodium acetate buffer (1.2 mol/L, pH 3.8) was added, the starch was quantitatively hydrolysed to glucose with AMG. The absorbance of the released glucose was spectrophotometrically determined at 510 nm using glucose oxidase--peroxidase reagent (GOPOD) method (GOPOD Format Assay Kit, Megazyme International, County Wicklow, Ireland). Glucose release of non-RS was equally determined by previously pooling the supernatant and the two washings and adjusting the volume to 100 mL. Total starch was calculated as the sum of RS and non-RS.

2.3. Amylose content

Amylose content of the samples was determined by colorimetric measurement of the blue amylose–iodine complex (Juliano, 1971). In summary, 100 mg of sample were weighed into a 100 mL volumetric flask and mixed with 1 mL ethanol and 9 mL of 2 mol/L NaOH. The samples were diluted and the iodine solution was added. After 10 min incubation at room temperature, the absorbance at 620 nm was analysed with a spectrophotometer and the amylose content was calculated based on the standard curve.

2.4. Differential scanning calorimetry (DSC) gelatinisation properties

The moisture of the samples was adjusted to 70 g/100 g wet basis by the addition of distilled water. The DSC (DSC 1, Mettler Toledo (Thailand), Bangkok, Thailand) equipped with a refrigerated cooler was used. The hydrated samples were weighed (25 ± 5 mg) into aluminium DSC pans (120 μL) and hermetically sealed. The DSC analysis was run by scanning from 25 to 120 °C, ramping at 10 °C/min and a hermetically sealed empty pan was used as a reference. Nitrogen was used as a purging gas. The software used for the analysis of the resulting thermograms was Star^e software (ver. 9.20, Mettler Toledo). The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and transition enthalpy (ΔH) were determined.

2.5. In-vitro starch digestibility and modelling of starch digestograms

Time-course starch digestion 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 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 reciprocating water bath (85 rpm). The digesta was neutralised with NaOH before adjusting the pH to 6 (sodium acetate buffer) prior to the addition of pancreatin (Sigma P1750) and AMG (Novozymes AMG 300 L). The mixture was incubated for 4 h, during which the glucose concentration in the digesta was measured with an Accu-Check® Performa® glucometer (Roche Thailand Ltd., Bangkok, Thailand) at specific periods (0, 30, 60, 90, 120, 150, 180, 210 and 240 min). Digested starch per 100 g dry starch (DS) was calculated as in Eqn. (1):

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

where G_G = glucometer reading (mmol/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.

The digestogram (digested starch at a specific time period) of each sample was modelled using a modified first-order kinetic model, Eqn. (2), as described before (Mahasukhonthachat et al., 2010).

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

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}). $D_{\infty-0}$ was estimated from $t = 0$–240 min.

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 elsewhere (Mahasukhonthachat et al., 2010).

In order to calculate the estimated GIs of the samples, the areas under the digestograms (AUC_{exp}) were computed with Eqn. (3):

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

Estimated GI values were determined using the method proposed by Goñi, Garcia-Alonso, and Saura-Calixto (1997) with some modifications (Mahasukhonthachat et al., 2010; Srikaeo et al., 2011). The hydrolysis index (HI) of each sample was calculated by dividing the area under its digestogram by the area under the digestogram of a fresh white bread, which was calculated in our laboratory to be about 24,000 min g/100 g dry sample (from 0 to 240 min). Using the parameters of the modified first-order kinetic model for both the samples and fresh white bread, estimated GI (average) (GI_{AVG}) for each sample was calculated using Eqn. (4):

$$GI_{AVG} = \left[\frac{((39.21 + 0.803\,H_{90}) + (39.51 + 0.573\,HI))}{2}\right] \quad (4)$$

2.6. In-vivo glycaemic response

The in-vivo glycaemic response was conducted in according to the method recommended by FAO/WHO (1998). Ten healthy volunteers (five females, five males; 25.3 ± 5.1 years; 1.64 ± 0.12 m height; 58.8 ± 5.6 kg weight) were recruited for the study. Noodle samples (equivalent to 50 g of starch) were prepared by cooking with boiling water for 15 min. Blood glucose concentration (postprandial response) was monitored for 120 min after consumption (0, 15, 30, 45, 60, 90 and 120 min), and the maximum blood glucose concentration after meal (C_{max}) and area under curve after meal (AUC) were calculated from the incremental curves. The GI was calculated as the percentage of AUC of the test food divided by the AUC of the reference food (bread). The blood glucose concentration was also measured 5 and 10 min before ingestion, and the average value taken as the base line. Blood was obtained by finger prick using Accu-Chek® Softclix® Lancet Device (Roche Thailand Ltd., Bangkok, Thailand). Blood glucose was measured using Accu-Check® Performa® glucometer (Roche Thailand Ltd., Bangkok, Thailand), and controlled following the specific instructions of the manufacturer. Numerical results are averages of three independent replicates obtained in 3 different days. As all samples were assessed by in-vitro method, we selected only three samples for confirmation by in-vivo method (control, M30 and M60). Notably that variability of the in-vivo glycaemic response among individuals is known to be larger than that within individual subjects. Thus, the result in this study has the objective of getting preliminary data that may justify larger experiments with humans.

To differentiate between the GIs obtained from in-vitro and in-vivo methods, the terms "estimated GI" was used for the in-vitro results and "GI" was used for the in-vivo results.

2.7. Textural properties

The texture quality of the cooked noodles was determined by measuring the tensile strength and break distance (extensibility) using a TA-XT$_2$ Texture Analyser (Stable Micro Systems Ltd., Surrey, UK) (Chung, Cho, & Lim, 2012; Inglett, Peterson, Carriere, & Maneepun, 2005). Briefly, dried noodles were soaked in water for 15 min to rehydrate and cooked in boiling water for 3 min. Five strands of cooked noodle were fixed to the arms of tensile grips. Force (tensile strength) at the break point was measured at a speed of 1.0 mm/s. Tensile strength and break distance were recorded using the Exponent software (ver. 6, Stable Micro Systems Ltd.).

2.8. Statistical analysis

Analysis of variance (ANOVA) and test of significance were performed using SPSS® ver. 17 with confidence level of 95%. The samples were randomised for all the analyses described above.

3. Results

3.1. Starch composition and amylose content

Starch composition and amylose content are shown in Table 1. The flour mixture used for the production of rice noodles (control sample) had initial amylose content of 32.05 g/100 g dry sample and it increased up to 50.12 g/100 g dry sample when high amylose maize starch was added. RS also increased from 0.41 to 16.41 g/100 g dry sample. The total starch of the mixtures was in the range of approximately 73–88 g/100 g dry sample.

3.2. DSC gelatinisation properties

All mixture samples exhibited a single endothermic peak localised around 77–80 °C (Table 2). These are the gelatinisation temperatures of native starches contained in the mixtures. Generally, gelatinisation temperatures did not differ much among all the samples. However, gelatinisation enthalpies (ΔH) of the control sample are significantly higher than those of the added samples. This study found no energy transition for high amylose maize starch as investigated by DSC (data not shown). Thus, changes of starch granule molecular order and structures of the high amylose maize starch could have been made by its production processes. The addition of the maize starch to the control sample caused the decrease of gelatinisation enthalpies in the added samples. Also, peak temperature (T_p) of the samples slightly decreased as more maize starches were added.

Table 1
Starch composition and amylose content of the flour mixtures (g/100 g dry sample).[a,b]

Samples[c]	Non-resistant starch	Resistant starch	Total starch	Amylose
Control	73.23 ± 0.01b	0.41 ± 0.01f	73.46 ± 0.11c	32.05 ± 1.16e
M10	81.08 ± 1.42a	2.86 ± 0.36e	83.94 ± 1.78 ab	36.79 ± 0.98d
M20	80.86 ± 1.44a	6.17 ± 1.36d	87.03 ± 0.08a	38.45 ± 0.08d
M30	71.96 ± 2.57bc	8.92 ± 0.28c	80.88 ± 2.85b	43.42 ± 0.86c
M40	67.27 ± 1.03c	13.29 ± 0.75b	80.56 ± 1.79b	45.89 ± 0.44b
M50	72.19 ± 0.37b	14.36 ± 0.99b	86.55 ± 1.34a	47.10 ± 0.72b
M60	71.19 ± 3.69bc	16.41 ± 0.09a	87.60 ± 0.85a	50.12 ± 0.06a

[a] Values are means ± standard deviations ($n = 3$).
[b] For each parameter (column), values with the same letters are not significantly different ($P > 0.05$).
[c] M10, M20, M30, M40, M50 and M60 are the flour mixtures which have been added with high amylose maize starch at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample respectively.

Table 2
The onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and transition enthalpy (ΔH) of the flour mixtures as determined by the DSC.[a,b]

Samples[c]	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g dry sample)
Control	69.46 ± 0.57b	80.06 ± 0.60a	88.30 ± 0.43a	3.14 ± 0.25a
M10	73.32 ± 1.19a	79.70 ± 0.18a	85.99 ± 0.46b	1.07 ± 0.02b
M20	74.68 ± 0.52a	79.87 ± 0.10a	86.37 ± 0.48b	0.89 ± 0.16b
M30	74.21 ± 0.69a	78.52 ± 0.76b	83.31 ± 1.21c	0.51 ± 0.17c
M40	73.39 ± 1.41a	77.97 ± 0.80b	82.45 ± 1.22cd	0.51 ± 0.06c
M50	74.32 ± 0.86a	77.77 ± 0.24b	82.01 ± 0.13cd	0.49 ± 0.10c
M60	74.25 ± 2.22a	77.48 ± 0.73b	81.64 ± 0.58d	0.58 ± 0.10c

[a] Values are means ± standard deviations ($n = 3$).
[b] For each parameter (column), values with the same letters are not significantly different ($P > 0.05$).
[c] M10, M20, M30, M40, M50 and M60 are the flour mixtures which have been added with high amylose maize starch at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample respectively.

3.3. In-vitro and in-vivo starch digestibility

Model parameters and the estimated GI values of the rice noodles produced from the mixtures are shown in Table 3 (in-vitro method). The modified first-order kinetic model showed suitable in describing the digestograms (r^2 = 0.97–0.99; MRDM = 2–20%; SUMSQ = 6–172). It is clearly seen that the estimated GI values decreased in accordance with the increase of maize starches. The rate of the digestion as determined by constant K value also correlated well with the GI values. Therefore, amylose and RS in the mixtures affected the starch digestion in rice noodles. The more amylose and RS the lower the GI values.

From in-vitro method, the trend of the GI values was obtained. We confirmed the values with the in-vivo method. The results are shown in Fig. 1 and Table 4. The results from in-vivo method confirmed the results from in-vitro method. The more amylose and RS the lower the GI values. The GI values obtained from in-vivo method were generally lower than those obtained from in-vitro method (Fig. 2). In this study, rice noodles could be classified as low GI food (GI < 55) when the ingredient mixture was added with the maize starch at the level of 60 g/100 g dry sample, representing the RS and amylose content of 16.41 and 50.12 g/100 g dry sample respectively. This would lower the GI value as obtained by in-vivo method to 51.84.

3.4. Textural properties

The addition of high amylose maize starch induced the changes in textural properties of rice noodles. The tensile strength and break distance of rice noodle samples are shown in Figs. 3 and 4 respectively. Generally, the tensile strength and break distance of rice noodle samples decreased as amylose and RS increased.

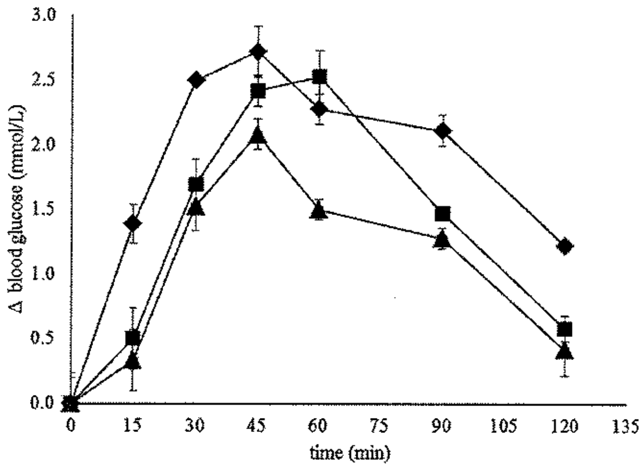

Fig. 1. Glycaemic response, the change from basal blood glucose concentration, of the rice noodle samples (◆ control, ■ M30, ▲ M60); M30 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 30 and 60 g/100 g dry sample respectively. (Average values and standard deviation bars, $n = 10$).

Therefore, amylose and RS affected the final product textures. The noodles with low tensile strength and break distance would provide low extensibility. This affected cooking and eating qualities of rice noodles.

4. Discussion

From the results, it is clear that the addition of high amylose maize starches affected the properties of rice noodles mixtures and consequently the final rice noodle products. The maize starch was found to be able to manipulate the RS and amylose content in the mixtures. The increase of amylose and RS in the mixtures influenced the properties of the mixtures. Though DSC gelatinisation temperatures did not differ much, slight increase of peak temperatures was observed with the increase of amylose. However, gelatinisation enthalpies decreased with the increase of the maize starch in the mixtures (refers Table 2). Since no energy transition was found in pure high amylose maize starch when assessed by DSC, the energy transitions found in the mixture samples were primarily from the rice and tapioca, not the added maize starch. Several studies suggested that increasing dietary fibre or RS showed positive linear correlation with the gelatinisation temperatures (Morita, Ito, Brown, Ando, & Kiriyama, 2007). Also, as amylose content increased, gelatinisation temperatures increased while enthalpies decreased (Chung, Liu, Lee, & Wei, 2011). Waxy rice (low amylose but high amylopectin) is known to have larger

Table 3
Model parameters, hydrolysis index (HI) and estimated glycaemic index (GI) of the rice noodle samples (in-vitro method).[a,b]

Samples[c]	D_0 (g/100 g dry starch)	D_∞ (g/100 g dry starch)	$K \times 10^{-3}$ (min^{-1})	Estimated GI_{H90}	Estimated GI_{HI}	Estimated GI (average)
Control	1.80 ± 1.08c	100 ± 0.78a	11.30 ± 0.42a	91.00 ± 1.40a	108.00 ± 1.40a	99.00 ± 1.40a
M10	4.86 ± 0.53a	100 ± 0.47a	8.10 ± 0.06b	82.61 ± 0.40b	99.43 ± 0.45b	91.02 ± 0.42b
M20	4.80 ± 1.07a	100 ± 0.52a	7.49 ± 0.17c	80.53 ± 0.58b	97.14 ± 0.64b	88.83 ± 0.61b
M30	5.47 ± 0.58a	98.8 ± 0.71a	6.11 ± 0.17d	75.72 ± 0.93c	91.59 ± 1.10c	83.66 ± 1.02c
M40	4.01 ± 0.41 ab	97.6 ± 0.41a	4.67 ± 0.15e	68.87 ± 0.67d	83.16 ± 0.84d	76.01 ± 0.76d
M50	1.86 ± 1.37c	94.7 ± 0.57b	4.11 ± 0.27e	65.08 ± 0.21e	78.36 ± 0.43e	71.72 ± 0.32e
M60	2.14 ± 0.37bc	94.1 ± 0.83b	3.30 ± 0.00f	61.07 ± 2.27f	72.89 ± 3.10f	66.98 ± 2.68f

[a] Values are means ± standard deviations ($n = 3$).
[b] For each parameter (column), values with the same letters are not significantly different ($P > 0.05$).
[c] M10, M20, M30, M40, M50 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample respectively.

Table 4
Area under curve (AUC), maximum blood glucose concentration (C_{max}) and glycaemic index (GI) of the rice noodle samples (in-vivo method).[a,b]

Samples[c]	AUC (mmol × min/L)	C_{max} (mmol/L)	GI
Control	232 ± 24 ab	7.55 ± 0.20a	87.23 ± 9.08a
M30	169 ± 12bc	7.95 ± 0.43a	63.62 ± 4.69b
M60	138 ± 5c	7.50 ± 0.08a	51.84 ± 1.95b

[a] Values are means ± standard deviations (obtained from ten healthy volunteers).
[b] For each parameter (column), values with the same letters are not significantly different ($P > 0.05$).
[c] M30 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 30 and 60 g/100 g dry sample respectively.

gelatinisation enthalpy since starch with higher amylopectin content has more crystalline and less amorphous regions (Jane et al., 1999). This variation is understandable as most previous studies investigated natural flour and/or starch samples which are different from the mixtures in this study. Also, gelatinisation temperatures of the starchy samples can vary due to factors that include genetic origin, environmental conditions and age of the parent plant (Biliaderis, Maurice, & Vose, 1980; Jane et al., 1999, 1992). In this study, low enthalpies were found in the mixture samples with high amylose and RS, suggest that they are easier to cook. Thus, this could be beneficial for industrial application in terms of energy and processing time saving.

The key benefit of adding high amylose maize starches in this study was that it can lower the GI values in the final rice noodle products. It has been known that rice is high in GI and most rice products are also high in GI. The production of low GI rice products would be challenging for industry. Rice is a choice for people who suffer from coeliac disease, formulating rice products with low GI would provide more extra benefits.

Low GI foods are valuable in lowering insulin response, and greater use of stored fat is expected. These, as well as the fact that RS has been studied for its potential health benefits, make high RS and low GI foods important for obesity, diabetes and its dietary management (Nugent, 2005; Sajilata, Singhal, & Kulkarni, 2006). The present study confirmed that starch digestibility could be improved by manipulating the level of amylose and RS content in the ingredients. This study used high amylose and high RS maize

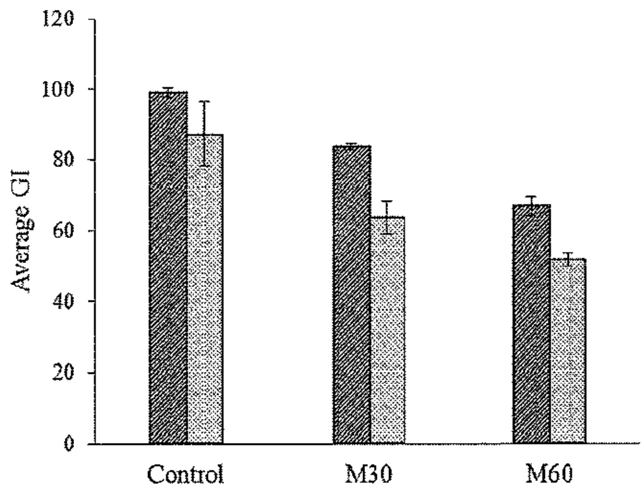

Fig. 2. Comparison between (▨) in-vitro and (▤) in-vivo GI values of the rice noodle samples; M30 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 30 and 60 g/100 g dry sample respectively. (Bar with standard deviations).

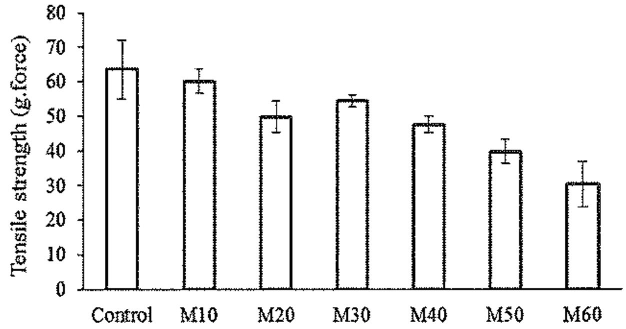

Fig. 3. Tensile strength of rice noodle samples; M10, M20, M30, M40, M50 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample respectively. (Bars with standard deviations, $n = 10$).

starch. Other sources of ingredients with similar functional properties could also be able to use. 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 et al., 1988, 1989). Amylose content was reported to have an obvious impact on GI values and RS content. The contents of RS were increased with the increasing amylose as studied in several food systems (Choi, Lee, Cho, Choi, & Moon, 2010; Hu et al., 2004; Marangoni & Poli, 2008; Morita et al., 2007; Yadav, Sharma, & Yadav, 2010). In this study, the GI values of rice noodles produced from the mixtures which contained 60 g/100 g dry sample of the maize starch were lower than 55 (in-vivo method) and thus they could be declared as low GI food (refers Tables 3 and 4). Notably that the GI values obtained from in-vivo method are generally lower than those from in-vitro method. The in-vitro method has been proposed as an alternative method for classifying carbohydrates with some studies showing correlation of results with in-vivo GI testing (Araya, Contreras, Alvina, Vera, & Pak, 2002; Englyst, Englyst, Hudson, Cole, & Cummings, 1999; Granfeldt, Bjorck, Drews, & Tovar, 1992). In-vitro methods are still being developed, there is no standard protocol for testing, and different models are used to predict GI (Garcia-Alonso & Goni, 2000; Granfeldt et al., 1992; Leeman, Barstrom, & Bjorck, 2005). Generally, in-vitro methods normally provide higher rate of starch digestion and consequently higher GI values than in-vivo methods (Araya et al. 2002; Brouns et al., 2005). Apart from methodology difference, GI values also depend on various factors such as starch granule morphology, amylose to amylopectin ratio, molecular structure, degree of branching in terms of steric hindrance, and

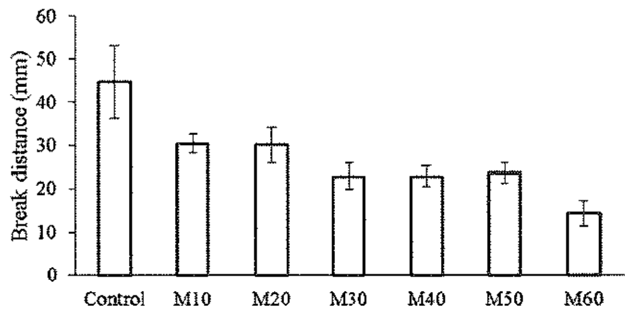

Fig. 4. Break distance of rice noodle samples; M10, M20, M30, M40, M50 and M60 are the noodles produced from the flour mixtures which have been added with high amylose maize starch at the level of 10, 20, 30, 40, 50 and 60 g/100 g dry sample respectively. (Bars with standard deviation, $n = 10$).

consequently mass transfer resistance (Fuentes-Zaragoza et al., 2010; Singh, Dartois, & Kaur, 2010). In addition, the other constituents in the rice flour could also have impact on the rate of starch digestion and GI (Srikaeo & Sopade, 2010).

In terms of texture, it has been known that rice with high amylose content provides dry and fluffy textures while low amylose rice gives moist, chewy and clingy textures after cooking. The proportion of amylose and amylopectin affected the hardness of rice starch gel (Hibi, 1998). Generally, high-amylose rice varieties give high hardness (Lu et al., 2009). Hardness usually showed a negative correlation with adhesiveness and therefore amylose (Yu, Ma, & Sun, 2009). Thus, rice noodles made from high amylose mixtures gave high hardness and fluffy textures. Consequently, their tensile strength and break distance (extensibility) values were low. This is clearly seen in the results from this study (Figs. 3 and 4). Texture is the important factor for considering by industry in producing starchy foods. In Thailand, high tensile strength and high extensibility rice noodles are preferred. However, this may be different in other countries. Moreover, other components in the mixtures e.g. proteins from rice flour could also influence the textures of the products (Hager et al., 2012; Singh, Pal, Mahajan, Singh, & Shevkani, 2011).

5. Conclusions

Rice and rice products are normally high in GI. Rice noodle which is the potential rice product could be formulated as a low GI food by manipulating its amylose and RS content. High amylose and RS rice noodles exhibited low GI values. This paper demonstrated that the addition of high amylose maize starch to the ingredients at the certain levels can lower the GI of rice noodle to lower than 55 at which it can be declared as low GI food. This technique could be applied to other similar starchy foods. Though cares should be taken as high amylose and RS affected the textures of the products.

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