International Food Research Journal 22(3): 923-929 (2015)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effects of sugarcane, palm sugar, coconut sugar and sorbitol on starch digestibility and physicochemical properties of wheat based foods

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Article history

Received: 3 September 2014
Received in revised form: 22 November 2014
Accepted: 24 November 2014

Keywords

Palm sugar
Coconut sugar
Sweetener
Starch digestibility
Wheat

Abstract

Wheat flours mixed with four types of sweeteners; sugarcane, palm sugar, coconut sugar and sorbitol were evaluated for their in vitro starch digestibility, estimated glycemic index (GI) and physicochemical properties. It was found that sorbitol which is a sugar alcohol gave the best starch digestibility results providing the lowest estimated GI values. Palm and coconut sugars provided better starch digestion rate and lower estimated GI values than those of sugarcane, indicating their nutritional quality over the sugarcane. All the studied sweeteners influenced the physicochemical properties of wheat flour and sweetener mixtures as examined by the DSC, RVA and texture analyzer. The addition of sweeteners increased gelatinization temperatures, decreased viscosities and altered the gel textures. The studied sweeteners were used as an ingredient to produce the breads. The appearances of the products were similar but physicochemical properties and estimated GI values were varied according to the sweeteners used. The use of palm and coconut sugars in breads provided lower GI values than those of sugarcane.

Introduction

Palms are a tree crop which benefits the environment ecologically as they restore damaged soil requiring very little water in the process. Many palm species have been tapped especially in the South and South-east Asia in order to produce fresh juice, fermented drinks, syrup and sugars. Under proper management, the main tapped palm species (*Arenga pinnata*, *Borassus flabellifer*, *Cocos nucifera* and *Nypa fruticans*) produce sugar yields that is higher than sugarcane production. Most tapped palm trees do not only produce sap but are multipurpose e.g. edible fruits, building materials, fibers, polymers etc. (Mogea *et al*., 1991; Ishak *et al*., 2013). Hence, their socio-economic importance can be critical for the rural poor.

For the traditional production of palm sugar, a large volume of filtered palm sap is transferred into a big wok, where the filtered palm saps are heated on the wood fired stove for a few hours at about 100ºC until it becomes concentrated to obtain a typical aroma. Mainly, two major reactions occur during the heating process of palm sap, Maillard reaction and caramelization. After the heating process, the palm sap liquid is poured into bamboo moulds to form pure solid palm sugar which is ready for consumption (Ho *et al*., 2007; 2008).

Palm sugar has been used as a traditional sweetener for thousands of years in Asia. It is now gaining popularity globally because of its natural, minimal processed and healthy. One of the major health claims is its glycemic index (GI).

The GI is the indexing of the glycemic response of a fixed amount of available carbohydrate from a test food to the same amount of available carbohydrate from a standard food consumed by the same subject. Initially, the standard "food" was glucose, but more recently it has been white bread. Hence, GI ranks foods based on the postprandial blood glucose response compared with a reference food. GI values can be categorized into three categories: low (GI of 55 or less), moderate (GI of 56 – 69) and high (GI of 70 or higher). Low GI foods play an important role in the dietary management of diabetes, weight reduction, peak sport performance and the reduction of risks associated with heart disease and hypertension (Jenkins *et al*., 1981; Foster-Powell and Miller, 1995; Foster-Powell *et al*., 2002; Jenkins *et al*., 2002). Since the GI concept was proposed in 1981 (Jenkins *et al*., 1981), several hundred scientific articles and numerous popular diet books have been published on the topic. In 1997, a committee of experts was brought together by the Food and Agriculture Organization (FAO) of the United Nations and the World Health Organization (WHO) to review the available research evidence

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regarding the importance of carbohydrates in human nutrition and health. The committee endorsed the use of the GI method for classifying carbohydrate-rich foods and recommended that the GI values of foods be used in conjunction with information about food composition to guide food choices (FAO, 1998).

Palm sugars were normally marketed as low GI foods, though only few published papers were evidenced. The recent work has published that the GI of coconut sap sugar was reported to be in low category, 35±4 and 42±4 (Trinidad *et al*., 2010). Recently, there are many sweeteners available commercially, though sucrose (sugarcane) remains the widely used sugar. With the demand of reduced-sugar foods, low-calorie sugars e.g. acesulfame K, aspartame, neotame, saccharin, sucralose, are of interest. A variety of polyols (sugar alcohols) e.g. sorbitol, mannitol, xylitol, and other bulk sweeteners are also accepted for use in foods (Kroger *et al*., 2006). However, these are costly and highly processed ingredients.

As the published papers on the glycemic response of natural palm sugars are limited, this paper examined the effects of palm sugars derived from Borassus flabellifer and Cocos nucifera on the in vitro starch digestibility of wheat flour in comparison with common sugarcane and a sugar alcohol (sorbitol). Their effects on physicochemical properties of wheat based foods were also determined.

Materials and Methods

Materials

Wheat flour with the protein content of 9.04 ± 0.11 g/100 g dry sample was obtained from UFM Food Centre Co., Ltd. (Thailand). Four types of sugars were studied. Palm sugars from *Borassus flabellifer* (palm sugar) and *Cocos nucifera* (coconut sugar) were obtained from Suttiphuan Coconut Palm Sugars (Thailand). Sugarcane was obtained from Mitr Phol Sugar Corp., Ltd (Thailand). Sorbitol was obtained from Siam Sorbitol Co., Ltd. (Thailand). All the chemicals used for experiments were AR grade.

The flour was analyzed for the starch composition. It was then mixed with each type of sugar at the same sweetness level. The sweetness level for palm and coconut sugars is 1.0 while the sorbitol is 0.6 (Whelan *et al*., 2008). Sugarcane, palm and coconut sugars were used at 30 g/100 g dry solid. Therefore, sorbitol was used at 50 g/100g dry solid. The calories of sorbitol are 2.6 kcal/g while the calories of sugarcane, palm and coconut sugars were approximately 4.0 kcal/g (Burt, 2006). The samples were mixed freshly before analysis. The mixtures were analyzed for starch composition, starch digestibility and physicochemical properties as described below.

Starch composition and digestibility

Starch composition including total starch (TS), resistant starch (RS) and non-resistant starch (Non-RS) were determined enzymatically using the test kit from Megazyme International (Ireland), following the approved AACC Method 32-40. The rapid in vitro digestibility assay based on glucometry was used for the digestion and modelling of starch digestograms (Sopade and Gidley, 2009). Briefly, 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 (85 rpm). The digesta was neutralized with NaOH before adjusting the pH to 6 (sodium acetate buffer) prior to the addition of pancreatin (Sigma P1750) and AMG (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 was calculated and the digestogram (digested starch at a specific time period) was modeled using a modified first-order kinetic model, Equation (1), as described elsewhere (Mahasukhonthachat *et al.*, 2010).

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

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 apparent 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 per 100 g dry starch, and $D_0 \geq$ 0g per 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).

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 (Goñi *et al*., 1997), which was calculated to be about 13,000 min g/100 g dry starch from 0 – 240 min. The single-point measurement of starch digestion at

90 min (H90) in the samples was also used to calculate estimated GI. The average estimated GI (GI_{AVG}) for each sample was defined as the average of GI_{H90} and GI_{HI}. Each sample was analyzed in triplicate.

Physicochemical properties

Physicochemical properties included thermal properties by a Differential Scanning Calorimetry (DSC), pasting properties by a Rapid-visco Analyser (RVA) and the gel texture by a Texture Analyser. Each sample was analyzed in triplicate. DSC was conducted using the DSC 1 (Mettler-Toledo, USA) equipped with a Huber TC100 (Germany) cooling device. To avoid the interference from different moisture content, all mixture samples were adjusted to reach 70% (w/w) of moisture content by adding distilled water and kept overnight to ensure they were completely equilibrated prior to analysis. The hydrated samples (25±5 mg) were weighed accurately into aluminum DSC pans and hermetically sealed. A sealed empty pan was used as a reference. Thermal scans were performed from 30 -120ºC at a heating rate of 10ºC/min. DSC parameters including onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and transition enthalpy (ΔH) were quantified using the Stare Software (Mettler-Toledo, USA).

Pasting properties were investigated using the RVA (RVA-4D, Newport Scientific Pvt Ltd., Australia) following the approved method 61.02. 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 RVA profiles and pasting characteristics.

For gel texture, the samples were mixed with distilled water to prepare 30 g of paste (30% w/w) in a 50 mL cylindrical glass jar, followed by 30-min heating under continuous stirring using a magnetic stirrer for gelatinization and then cooling at 4ºC for another 30 min. To avoid the effects of starch retrogradation, the samples were immediately measured for textural properties (Lu *et al*., 2011) using a Texture Analyzer (TA-XT2, Stable Micro Systems, England) equipped with a 5 mm diameter cylinder probe and compression platens. The parameters were set as follows: pretest speed 2.0 mm/s, test speed 1.0 mm/s, posttest speed 2.0 mm/s, trigger force 15 g, distance 5 mm. The resulting force-time curves were then analyzed with the Exponent software (Stable Micro Systems, England) for sample texture characteristics including hardness and adhesiveness. Hardness was defined as the maximum compressive force that displays substantial resistance to deformation. Adhesiveness was defined as the negative force area after the first compression, representing the work necessary to pull the compressing plunger away from the sample. For gel texture, at least ten measurements were conducted for each sample.

Substitution of the investigated sugars in breads

Breads were produced from wheat flours using different types of sugars as investigated in this study. The control sample contains 200 g of wheat flours, 100 g of water, 5 g of dried yeast and 30 g of sugarcane (sucrose). The sugarcane was substituted with palm sugar, coconut sugar and sorbitol at the same sweetness level. The sweetness level for palm and coconut sugars is 1.0 while the sorbitol is 0.6 (Whelan *et al*., 2008). The ingredients were mix to form the dough and the bread dough was baked in the same condition for all samples.

The breads were then examined for their appearance using image analysis technique as described earlier (Srikaeo *et al*., 2011), physical properties and starch digestibility including estimated GI values. Starch digestibility was analyzed using the method as described above.

Statistical analysis

Analysis of variance (ANOVA), test of significance and comparison of means, using the Tukey's test were performed using Minitab® ver. 16 with confidence level of 95%. The samples were randomized for all the analyses described above.

Results and Discussions

Starch composition and digestibility

RS, Non-RS and TS of the wheat flour sample were found to be 3.91±0.06, 91.99±0.93 and 96.80±0.62 g/100 g dry sample, respectively. The flour sample used in this study had considerably high TS, indicating the good quality wheat flour. The flour contained small amount of RS which is common for general plain flour.

In terms of starch digestibility, the digestograms or digested starch over the time (figure not shown), suggested that starch digestion rate of sorbitol is lower than those of coconut, palm and sugarcane respectively. This was confirmed by the numerical data and model parameters as shown in Table 1. The modified first-order kinetic model proved suitable in describing the digestograms (r^2 = 0.96 – 0.99; MRDM = 8.24 – 31.67%; SUMSQ = 11.48 – 70.91).

From Table 1, it can be seen that the addition of sugars (except sorbitol) into wheat flour increased the estimated GI values. Comparing among all the

Table 1. Starch digestion rate constant (K), hydrolysis index (HI) and average estimated glycemic index (GI_{AVG}) of the wheat flour and sweetener mixtures

Samples	K x10^{-3} (min^{-1})	HI	GI_{AVG}
Wheat flour (WF)	1.86±0.13b	46.4±2.75b	58.78±1.17b
WF+Sugarcane	3.32±0.04a	84.15±0.92a	75.44±0.41a
WF+Coconut sugar	1.83±0.19b	49.66±1.29b	60.72±0.73b
WF+Palm sugar	1.86±007b	51.01±1.93b	60.89±0.84b
WF+Sorbitol	0.48±0.06c	13.36±1.67c	44.87±0.69c

Values are mean ±standard deviation (triplicate).
For each parameter (column), values with the same letters are not significantly different (p>0.05)
These apply to all tables at where they appear

Table 2. DSC parameters; onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c) and transition enthalpy (ΔH), of the wheat flour and sweetener mixtures

Samples	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g dry sample)
Wheat flour (WF)	57.84±0.37d	64.27±0.27c	70.57±0.48c	1.27±0.02c
WF+Sugarcane	63.26±0.13b	64.04±0.97c	76.24±0.40a	2.98±0.07a
WF+Coconut sugar	65.25±0.62a	69.38±0.39a	73.76±0.46b	1.59±0.23b
WF+Palm sugar	65.51±0.36a	69.38±0.63a	73.15±0.40b	1.05±0.05c
WF+Sorbitol	60.08±0.08c	67.30±0.32b	73.71±0.29b	1.18±0.02c

sugars, as expected, sorbitol which is a sugar alcohol gave the lowest GI values of the mixtures (about 45). Sugarcane raised the GI of the mixtures to about 75 while coconut and palm sugars raised the GI to about 61. Notably that the estimated GI values of wheat flour, wheat flour mixed with palm and coconut sugars are not statistically different.

The GI of sorbitol has been reported to be 7±2 (Whelan *et al.*, 2008). Sorbitol has been widely used as a sugar substitute especially in chewing gums because of their anticaries properties (Edgar, 1998). Diabetics often consume dietetic foods with sorbitol as the sweetener although it might cause diarrhea due to sorbitol intolerance (Badiga *et al.*, 1990). Sugar alcohols, including sorbitol, have been approved by the Food and Drug Administration as generally recognized as safe or as food additives and are used by food manufacturers to fully or partially replace added sugars in foods, as well as to serve as bulking agents. In studies (generally one meal type) comparing sugar alcohols to similar amounts of fructose, sucrose, or glucose in individuals with diabetes, the sugar alcohols produce significantly lower postprandial glucose responses (Wheeler and Pi-Sunyer, 2008).

This research highlighted the findings from coconut and palm sugars. As mentioned earlier, very few published works have proved that palm sugars were low in GI values and suitable for low GI foods. Only one recent published work has reported that the GI of coconut sap sugar was in low category, 35±4 and 42±4 (Trinidad *et al.*, 2010). The estimated GI values of wheat flour and coconut/palm sugar mixtures in this study were found to be about 61 as evaluated by an in vitro method. This was lower than the estimated GI of wheat flour mixed with sugarcane.

The average GI values of sucrose were 68±5 (glucose =100) and 97±7 (bread=100) (Foster-Powell *et al.*, 2002). The major components of palm sugars are sucrose (~70-80%) with glucose (~3-9%) and fructose (~3-9%). These may vary depending on botany sources and environmental conditions (Purnomo, 1992). Although, the major sugar component in palm sugars are sucrose, similar to sugarcane, but the starch digestion rate and GI values were found to be lower than those of sugarcane. Palm sugars are minimal processed and their natural forms are complex and contain other ingredients rather than sugars. Palm sugars were reported to contain significant amount of dietary fiber, especially inulin (Trinidad *et al.*, 2010; Vayalil, 2012). These could play an important role in lowering the GI values of palm sugars when compared to refined sugarcane which contain almost 100% of sucrose. Fibers can be fermented in the colon by bacteria, producing beneficially digestive short chain fatty acids. These affect insulin sensitivity and other metabolic parameters, either directly or indirectly (Bernabé *et al.*, 2011). Indeed, it has been well accepted that inclusion of fiber in the meal strategy or the use of either acute or chronic supplementation with fiber does improve blood glucose control following a meal.

As palm species were proved to be the multipurpose trees from which many food and non-

Table 3. RVA parameters of the wheat flour and sweetener mixtures

Samples	Peak (RUV)	Trough (RUV)	Breakdown (RUV)	Final (RUV)	Setback (RUV)
Wheat flour (WF)	86.25±1.30a	53.30±1.59a	31.96±1.12a	134.17±0.59a	77.38±2.76a
WF+Sugarcane	34.13±0.77b	24.59±1.89b	10.54±0.30b	53.67±0.71b	27.59±0.94b
WF+Coconut sugar	16.96±0.06d	12.67±0.23d	4.30±0.18c	27.05±0.18c	14.38±0.06c
WF+Palm sugar	17.96±1.36c	13.27±0.80c	4.80±0.88c	27.55±0.53c	14.59±0.64c
WF+Sorbitol	2.42±0.12e	2.21±0.18e	0.21±0.06d	4.38±0.18d	2.17±0.35d

Table 4. Physical properties and average estimated glycemic index (GI_{AVG}) of the breads produced using different sweeteners

Samples	Color L*	Color a*	Color b*	a_w	Firmness (g)	GI_{AVG}
Control (Sugarcane)	65.40±0.71a	3.15±0.07b	19.55±0.21b	0.94±0.01a	857.71±1.03b	81.34±0.96a
Coconut sugar	61.60±0.42c	3.60±0.14a	20.55±007a	0.92±0.00b	812.66±8.07d	65.67±0.12b
Palm sugar	60.65±0.07c	3.70±0.00a	20.40±0.00a	0.89±0.01c	884.88±7.87a	63.92±1.27b
Sorbitol	62.45±0.64b	3.50±0.00a	19.55±0.07a	0.87±0.00d	833.18±5.55c	55.78±0.14c

food products can be produced (Mogea *et al*., 1991; Ishak *et al*., 2013). The functional properties of palm sugars in terms of their ability to improve the GI values in foods would add an extra benefit. The palm sugars are also natural and do not contain any additive or artificial coloring and can last for years under proper storage conditions.

Physicochemical properties

DSC

The DSC results showing the starch gelatinization temperatures are shown in Table 2. Generally, the addition of sugars (all types) into wheat flour increased gelatinization temperatures. Inconsistent results were found for transition enthalpies. Wheat flour with sugarcane gave the highest Tc values while palm and coconut sugars gave the highest Tp.

Sugars were found to increase temperatures of starch gelatinization as studied by a DSC. The exact effects depend on the nature of sugar and water content of the systems. Two hypotheses have been proposed for explaining this effect, the activity of sugars to compete for water with starch and thereby reduce water activity and the sugar-starch interaction (Chevallier *et al*., 2000; Baek *et al*., 2004). Notably that high gelatinization temperature starches will require longer time to be fully cooked.

RVA

The RVA results showing the pasting properties of the mixtures are shown in Table 3. It was found that all sugars altered pasting properties of the mixtures resulting in the decreased viscosities. The effect of sugars on starch showing different behaviors depends on types of starch and saccharide, concentration and preparation methods (Rojas *et al*., 1999; Baek *et al*., 2004). Sugars were added to starch mixtures in order to increase the gelatinization temperature and the paste viscosity by decreasing the availability of water (Spies and Hoseney, 1982). Moreover, sample preparation e.g. milling method can exert a significant effect on the RVA for both raw and processed cereal samples, even if measurements are made on a defined sieve fraction (Becker *et al*., 2001). In this study, it should be noted that sorbitol provided the lowest RVA parameters of the mixtures than those from the other sugars. Sugars affect the physical and mechanical properties of starch gels by promoting polymer – polymer association. The effectiveness of promoting conformational ordering and intermolecular association depends on the type of sugar molecule (Evageliou *et al*., 2000). Polyols, both sugar (e.g. sorbitol) and non-sugar polyols, have less impact on promoting conformational ordering and intermolecular association than general sugars such as sucrose and glucose (Gunaratne *et al*., 2007).

Texture

Textures as defined by hardness and adhesiveness of the mixture gels were reported in Figure 1. Generally, the hardness and adhesiveness of the mixtures decreased when compared to the control samples (without sugar). It is well known that textural properties of dough and baked products are greatly affected by flour composition, processing parameters and ingredients. Dough without sugar usually has solid and elastic texture, with a higher resistance to tensile forces, while the presence of bulk sugars determined a softer and more viscous texture (Mariotti and Alamprese, 2012). In this study, palm sugars and sorbitol gave different starch gel

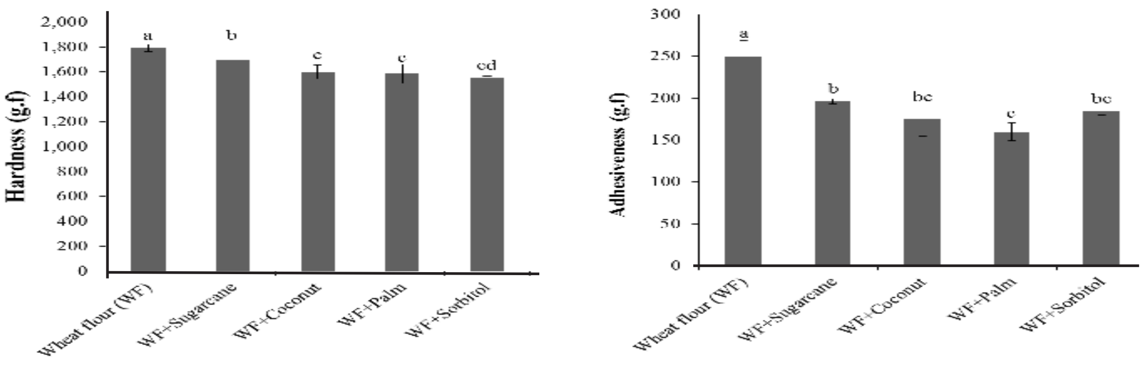

Figure 1. Textural properties, (a) hardness and (b) adhesiveness of the wheat flour and sweetener gels

textures as examined by hardness and adhesiveness when compared to sugarcane. The use of these sugars could affect the texture. For industrial application, other bulking agents should be added to compensate sucrose functionalities.

Breads

The physical properties of the breads are also shown in Table 4. From images analysis results, the appearances as determined by image analysis techniques gave acceptable results. The porosity as indicated by percentages of the white pixels in the images was found to be 57.14±0.91%, 57.41±1.23%, 56.03±2.21% and 56.92±1.61% for the breads made with sugarcane, coconut, palm and sorbitol respectively (values are not statistically significant different). Therefore, it can be concluded that the breads produced using different sugars were in similar appearance. However, the color and texture including water activity changed in according to the sugars used. The key benefit of using palm and coconut sugars, found in this study, is that they can reduce the estimated GI values of the baked products. The estimated GI values of breads made with palm and coconut sugars were found to be lower than the GI values of breads made with sugarcane. This confirmed the results as determined in wheat sweetener mixtures, shown earlier.

Conclusion

Sweeteners influenced the physicochemical properties and starch digestibility of wheat based food products. Sugarcane remains the widely used sugar but it may contribute to health problems. Sugar alcohols such as sorbitol provided low calories but it is costly and highly processed ingredient. This paper highlighted that palm and coconut sugars could be the alternative healthy sweeteners as they provided benefits in terms of GI values. In this study, palm and coconut sugars produced acceptable bread qualities when compared to conventional breads made using sugarcane.

Acknowledgements

This research was financially supported by the Thailand Research Fund (TRF) – Grant No. MSD56I0142. The cooperation from the industry partner is greatly acknowledged.

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