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Effects of microwave heat-moisture treatment on properties of waxy and non-waxy rice starches

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Abstract

Waxy and non-waxy rice starches adjusted to 20% moisture (wet basis, w.b.) were heat-moisture treated in a microwave oven to determine the effects of the microwave heating characteristics on digestibility, pasting, and morphological properties of the heated starches. Microwave heating produced only minimal changes in digestibility as well as the physical characteristics of heated starches. Significant changes in viscosity properties after microwave heat treatment were observed for both waxy and non-waxy starches heat-treated in a microwave oven, relative to non-treated samples. Non-waxy starch heated in microwave oven showed an increase in breakdown viscosity from 29.8 RVU (non-treated starch) to 35.8 RVU after heating for 60 min. However, for waxy starch, breakdown viscosity decreased from 112.7 to 35.9 RVU after 60 min of microwave heat treatment, reflecting an increased stability of microwave heat-treated starch under cooking. The data obtained in this study indicate that there was much higher re-aggregation of starch granules in waxy starch after microwave heat treatment than occurred in non-waxy starch, suggesting a re-association of amylopectin branch chains in the heat-treated waxy starch.

Keywords: Microwave; Heat-moisture; Waxy starch; Non-waxy starch

1. Introduction

Starch properties can be modified through the controlled application of heat and moisture which produces physical modifications within the starch granules. Gelatinization and damage to the starch granules with respect to size, shape or birefringence do not occur due to the controlled application of heat/moisture (Stute, 1992). The modified starches can be beneficial for nutritional purposes in view of the decreased digestibility as a result of the heat-moisture treatment. For example, such heat-moisture treatment can be used to produce modified starches such as resistant starch, which are formed as a result of food processing (Sievert & Pomeranz, 1989). Foods containing resistant starch, which is digested and absorbed slowly, may be useful in the control of diabetes and obesity, by reducing the increase in blood glucose levels after a meal (Anderson, Guraya, James, & Salvaggio, 2002).

Traditionally, heat-moisture treatment of starch has been carried out using conventional air ovens or other treatment methods, following the pioneering work of Sair (1964). For example, Xue, Newman, and Newman (1996) studied the effects of autoclave heat treatment of barley starches on digestibility and glucose responses in rats. Methods involving boiling and pressure cooking (Sagum & Arcot, 2000), baking, slow-cooking, and frying (Kingman & Englyst, 1994), and flaking, steam-cooking and popping (Holm, Björck, Asp, Sjöberg, & Lundquist, 1985) have all been used to heat-moisture treat starches in order to study the

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effect of the heat treatment method on the digestibility and starch availability both in vivo and in vitro. However, there is an increasing trend toward the use of microwave applications in food processing due to the fact that microwave energy is more efficient than the traditional heating process since it ensures homogenous operation in the whole volume of substance, greater penetrating depth, and selective absorption (Rajkó, Szabó, Vidal-Valverde, & Kovács, 1997). Microwave energy effects on various food components could differ significantly from those of conventional cooking (Daglioglu, Tasan, & Tuncel, 2000), and has long been applied for pasteurizing food products (Tajchakavit & Ramaswamy, 1997). The unique heating ability makes microwave energy advantageous for both home and industrial food applications such as baking, cooking, thawing, blanching, dehydration, pasteurization, sterilization, and tempering (Daglioglu et al., 2000).

Studies have been conducted on the effect of microwave heating on a variety of food substances. Khraisheh, McMinn, and Magee (2004) evaluated the quality and structural changes in starchy foods during microwave and convective drying and reported a reduced vitamin C destruction but a higher rehydration potential in microwave dried samples. Tajchakavit and Ramaswamy (1997) also used microwave heating process to study the inactivation kinetics of methyl esterase in orange juice. Similar research has been reported on the effects of microwave baking on oxidative stability of pastry (Daglioglu et al., 2000) and the reduction of antinutritive agents in soybean by microwave energy (Rajkó et al., 1997). Microwave energy applications in the study of heat-moisture treatments of cereal starches has not been commonly studied. The objective of this study was to apply microwave heating to heat-moisture treat rice starches in order to evaluate the effect of the heating characteristics of the microwave on the digestibility, pasting and microstructural properties of the heated starches.

2. Materials and methods

2.1. Materials

Waxy and non-waxy rice starches were obtained from A&B Ingredients, Fairfield, NJ. Moisture content of the starches was adjusted to 20% (wet basis) and stored in glass containers at room temperature until further use. Porcine pancreatic α-amylase, Type VI-B from porcine pancreas (29 units of α-amylase/mg of solid at pH 6.9, 1 unit liberating 1 mg of maltose from soluble starch in 3 min), was purchased from Sigma Chemicals, St. Louis, MO.

2.2. Heat-moisture treatment in microwave oven

Moisture-adjusted starch sample (10.5 g) was placed in a moderate pressure microwave digestion vessel (OI Analytical, College Station, TX) and placed in an Amana Model RC27 commercial microwave oven. A fiber optic thermometer attached to a universal multichannel instrument (Fiso Technologies, Quebec, Canada) was inserted into the starch sample to monitor temperature of sample during heating. The starch sample was heated slowly to a previously determined temperature of melt (T_m) of the starches, (±0.5 °C), and maintained at that temperature by manual control. The time it took for the sample to reach the target T_m at each power setting of the microwave oven was noted and designated as the come-up-time (CUT). Starch sample was then heated at this temperature for 60 min, followed by air-cooling to room temperature. Sample was further ground with a mortar and pestle and sieved through a 60-mesh screen.

2.3. In vitro starch hydrolysis of microwave heat-treated starches

In vitro digestibility of treated and non-treated starches was determined according to the method of Singh, Kherdekar, and Jambunathan (1982) by measuring the digestibility of the starches by 1% porcine α-amylase reconstituted in 0.9% NaCl. The hydrolysis product of α-amylase was mixed with 3,5-dinitrosalicylic acid (DNSA) and the reaction product of maltose–DNSA was measured spectrophotometrically at 540 nm. Maltose concentration was determined from a standard curve of maltose vs. absorbance and was expressed as mg maltose released per gram of starch sample.

2.4. Pasting properties

Pasting properties of heat-treated and native starch dispersions were measured using the Rapid Visco Analyser (RVA) model 3D (Newport Scientific, Warriewood, Australia) interfaced with a personal computer equipped with Thermocline software. Starch (3 g, 12% moisture basis) was added to 25 ml deionized water in a RVA aluminum test canister to achieve a total weight of 28 g, stirred for 10 s at 160 rpm and then at 960 rpm for the remainder of the test. The starch slurry was equilibrated at 50 °C for 1 min, raising the temperature to 95 °C at a rate of 11.8 °C/min, holding at 95 °C for 2.5 min, lowering the temperature to 50 °C in 3.8 min, and holding for 1.4 min for the remainder of the run. The total run time was 12.4 min. Parameters measured from the pasting profiles were the peak viscosity (PV), hot paste viscosity (HPV), and final viscosity (FV) from which the breakdown and setback viscosities were determined. At least three RVA profiles were obtained for

each sample, and the results from two duplicates were averaged.

2.5. Scanning Electron Microscopy (SEM)

Dried and finely ground heat-moisture treated and native waxy and non-waxy starches were mounted on aluminum specimen stubs with double-sided adhesive tape. Samples were sputter-coated in vacuo with a thin film of gold–palladium in a Hummer II Versatile DC Sputtering system (Technics, Alexandria, VA). Coated samples were viewed in a Hitachi S-510 scanning electron microscope operating at an accelerating voltage of 5 kV. Images were photographed at 3000 magnification on a Polaroid type 55 film.

3. Results and discussion

3.1. General

Fig. 1 shows that come-up-time (CUT) was different for waxy and non-waxy starches. Come-up-time was defined as the time needed for a starch sample to heat to its T_m during microwave heating. At all microwave powers settings tested, CUT was shorter in waxy starch than in non-waxy starch, indicating that the rate of heat transfer was higher in waxy starch than in non-waxy starch. Waxy starches are 100% amylopectin comprising of 1,6-α-glucosidic linkages in addition to 1,4-α-glucosidic linkages involved in the linear portion of the molecule. This spatial arrangement confers a more bulky structure to the amylopectin molecules, which facilitates rapid enzyme hydrolysis and makes waxy starches more susceptible to enzyme attack than non-waxy starches.

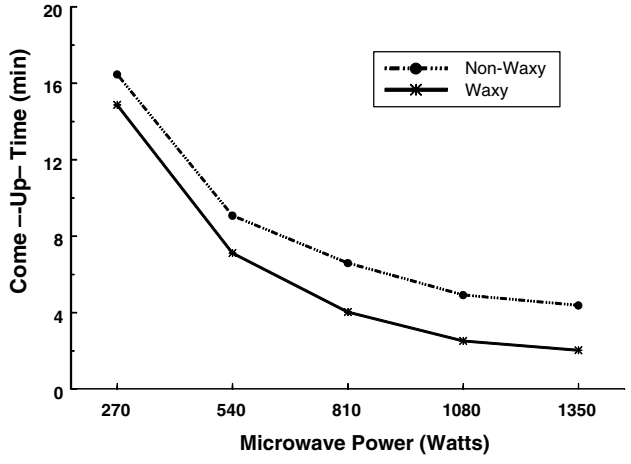

Fig. 1. Microwave power levels and come-up-time in waxy and non-waxy rice starches. (*Note*. Come-up-time = time to heat to T_m of starch.)

Apparently, the different structural features also enabled more rapid heat penetration in waxy than in non-waxy starch in this study, hence the lower CUT values for waxy starch.

3.2. Digestibility

The different CUT values observed in both starches did not appear to have significant impact on the in vitro digestibility of the starches, as shown in Fig. 2. However, the extent of digestibility by α-amylase increased in both waxy and non-waxy starches as digestion time increased. The action of α-amylase on starch granules depends on the penetration of the enzyme inside the granule (Hoover & Vasanthan, 1994). Changes in the degree of susceptibility of the starches to enzyme digestion would therefore be a function of the extent to which the microwave heating process induced any changes in the crystalline structure of the starches. It is known that structural, compositional, and fine chemical characteristics of a particular food influence the enzymatic availability of starch and the rate of digestion (Björck, Granfeldt, Liljeberg, Tovar, & Asp, 1994). On the other hand, the form of food, starch molecular arrangement and its degree of crystallinity and retrogradation are considered major determinants of the extent of starch digestion and absorption (Englyst, Kingman, & Cummings, 1992). The results obtained in this study indicate that the microwave heating did not cause any significant changes in the crystalline structure of the starches.

For both waxy and non-waxy starches, only slight digestibility increases were observed in the microwave heat-treated starches relative to native starches as microwave power levels were increased (Fig. 3). For non-waxy starch, the slight increase in digestibility did not occur until much higher microwave power levels were used. On the other hand, there was a uniform increase in digestibility of waxy starch as microwave power level increased, confirming the earlier observation that the granular structure of waxy starch permitted more rapid heat penetration of granules during microwave heating. In a previous study, Velasco, Rascón, and Tovar (1997) did not find any differences in digestibilities between conventionally and microwave reheated pulses. Xue et al. (1996) reported that while boiling of starches produced only minimal effects on digestibility, autoclaving produced significant differences in digestibility between starch types. However, the researchers also found that digestibility of waxy starches did not change in vitro. Similarly, our previous work (Anderson et al., 2002) showed that non-waxy rice starch heat-moisture treated in either conventional or microwave ovens did not show any clear digestibility differences. On the other hand, Tovar and Melito (1996) demonstrated a reduction in

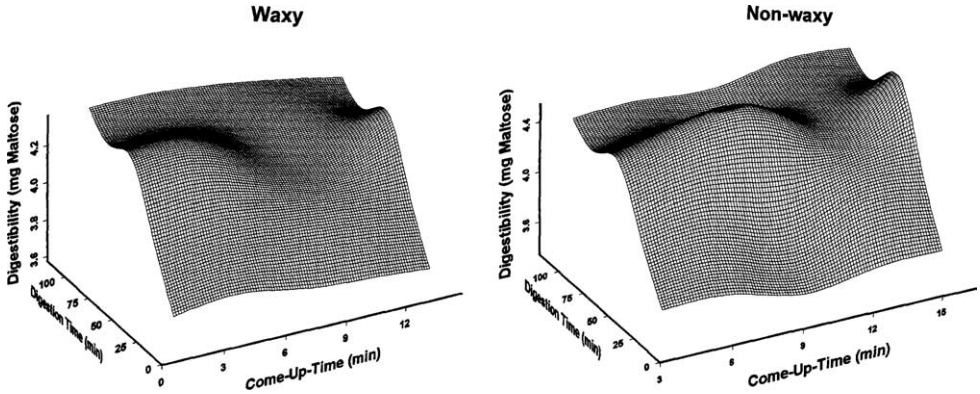

Fig. 2. Effect of come-up-time on digestibility of waxy and non-waxy rice starches. (*Note*. Come-up-time = time to heat to T_m of starch.)

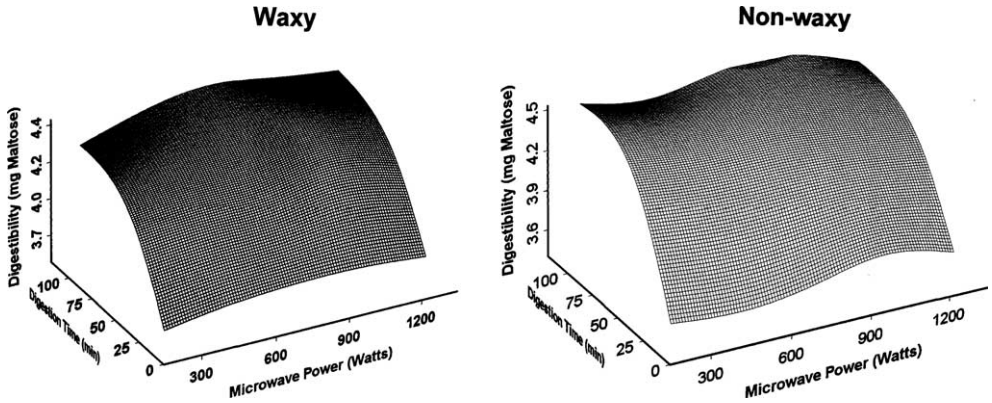

Fig. 3. Effect of microwave heating power levels and degree of hydrolysis on digestibility of waxy and non-waxy rice starches.

total starch content assessed enzymatically in beans submitted to drastic heating conditions. The researchers suggested that transglycosidation and other carbohydrate side-reactions may play a role in the process-induced limited digestibility of legume starches. The observations in the current study may suggest that the microwave induced changes in waxy and non-waxy rice starches were minimal with respect to changes in the granular structures to permit the formation of resistant starch or slowly-digestible starches, which is consistent with our previous findings (Anderson et al., 2002).

3.3. Pasting properties

Pasting properties of native and microwave heat-moisture treated starches are summarized in Table 1. Significant changes were observed in pasting parameters for both waxy and non-waxy starches heat-treated in the microwave oven, relative to native, non-treated samples. Pasting parameters for non-waxy starch increased significantly ($p \leqslant 0.05$) after microwave heat-treatment, whereas all parameters, except setback viscosity, decreased for waxy starch. Setback viscosity for microwave

Table 1
Rapid Visco Analyser pasting properties[A] of native and microwave heat-treated waxy and non-waxy rice starches

	Viscosity (RVU)					
	Heating Time (min)	PV	HPV	FV	Breakdown	Setback
Waxy	0	255.3^{a}	142.6^{a}	169.7^{a}	112.7^{a}	27.1^{c}
	60	81.8^{b}	41.9^{b}	84.1^{b}	39.9^{b}	42.2^{a}
Non-waxy	0	61.6^{d}	31.8^{c}	60.8^{d}	29.8^{c}	29.0^{b}
	60	78.7^{c}	42.9^{b}	80.4^{c}	35.8^{b}	37.5^{a}

[A] PV = peak viscosity, HPV = hot paste viscosity, FV = final viscosity, breakdown = (PV − HPV), setback = (FV − HPV). Data represent the average of at least three determinations from each of two replicates. Means in a column followed by different superscripts are significantly different ($p \leqslant 0.05$).

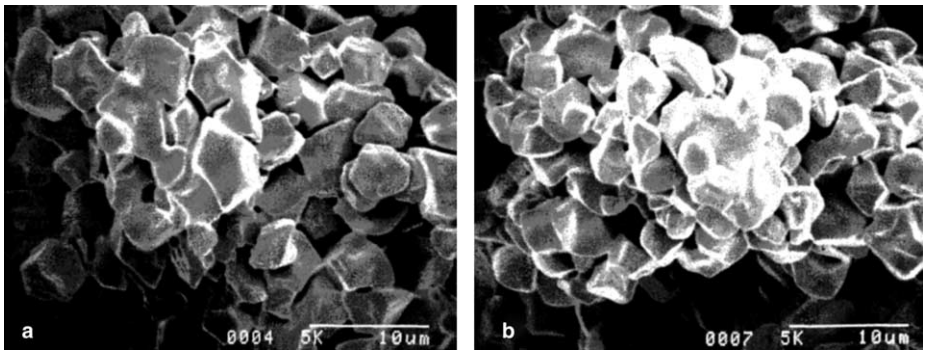

Fig. 4. Scanning electron micrographs of native (a) and microwave heat-treated (b) waxy rice starch.

heat treated waxy rice increased by 41%, from 27.1 to 38.2 RVU, over non-treated starch, and 29% in microwave heat-treated non-waxy starch. Setback is commonly used to describe the increase in viscosity that occurs on cooling a pasted starch (Fisher & Thompson, 1997). Thus, the data obtained in this study indicate that there was much higher re-aggregation of starch granules in waxy starch after microwave heat treatment than occurred in non-waxy starch, suggesting a re-association of amylopectin branch chains in the microwave heat-treated starch (Ward, Hoseney, & Seib, 1994). Abraham (1993) reported marginal improvement in the pasting characteristics of microwave heat-treated cassava starch.

Peak viscosity for waxy starch decreased from 255.3 to 81.8 RVU after microwave heat-treatment, indicating reduced swelling capacity of the starch granules which improves the shear stability of the granules leading to higher setback (Stute, 1992). On the other hand, the lowering of peak viscosity after microwave heat-treatment could be ascribed to shear thinning; the breakdown of the paste structure by the shearing action of the RVA paddle (Batey & Curtin, 1992). Thermal degradation of amylopectin and amylose granules during heating could also lead to lower peak viscosity (Anderson et al., 2002).

Non-waxy starch heated in a microwave oven showed an increase in breakdown viscosity from 29.8 RVU (non-treated starch) to 35.8 RVU after heating for 60 min. However, for waxy starch, breakdown viscosity decreased from 112.7 to 35.9 RVU after 60 min of microwave heat treatment, which reflects increased stability of microwave heat-treated starch under cooking (Anderson et al., 2002). The swelling of the starch granule is generally ascribed to the amylopectin fraction, while amylose is the fast retrograding molecule of the starch.

3.4. Microstructural characteristics of starches heat-treated in microwave

The structural characteristics of individual starch granules of native and microwave heat-treated waxy starches are shown in Fig. 4. Granule morphology did not appear to have been affected by microwave heating overall, except that heated starch granules showed slightly more aggregation than non-heated granules. Similar observation was made in the case of native and microwave heat-treated non-waxy starch (data not shown). This result suggests that changes in starch granular physical structure may not be necessary for internal recrystallization processes. Stute (1992) reported that gelatinization and damage to starch granules with respect to size, shape or birefringence do not occur during controlled application of heat/moisture to starches.

4. Conclusions

Microwave oven heating characteristics did not show significant effects on the extent of digestibility in waxy and non-waxy rice starches. Similarly, there was little variation in gross morphological structure between microwave heat-treated and non-treated waxy starch. On the other hand, microwave heating impacted significant changes in viscosity properties of both waxy and non-waxy rice starches. The heating parameters and other properties of microwave heating would require fine-tuning to enable the production of starches that are less susceptible to amylase digestion and thus produce slowly-digestible starches.

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