EXTRUDED RICE NOODLES: STARCH DIGESTIBILITY AND GLYCEMIC RESPONSE OF HEALTHY AND DIABETIC SUBJECTS WITH DIFFERENT HABITUAL DIETS

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ABSTRACT

High amylose rice variety was extruded to noodles and the starch digestibility and glycemic response of one healthy and two non-insulin dependent diabetic groups (Quezon City, Philippines and Toronto, Canada) with different habitual diets were determined. Rice extrusion significantly reduced the starch digestibility by 15% and the glycemic index in healthy volunteers by 36%. In both diabetic populations, the reduction in glycemic index was similar at 24%, suggesting that the effect was reproducible, and also that glycemic response was not affected by previous daily exposure of the subjects to rice. The effect of extrusion appears to be related to the starch gelatinization and retrogradation which occurred during processing as indicated by the lower amylograph viscosity and softer gel consistency of the rice noodles compared to the milled rice, as well as by the retrogradation test. The low glycemic response to high amylose rice and particularly the rice noodles suggests that these foods may have health benefits to both normal and diabetic individuals.

KEY WORDS: Blood glucose, high amylose rice, extruded rice, glycemic index, starch digestion, starch retrogradation

INTRODUCTION

Low glycemic index foods have been suggested to be more beneficial in the management of diabetes and hyperlipidemia (1-4). Processing, however, can modify the glycemic properties of starchy foods and, therefore, its effects have been the subject of many studies (5). Rice, a staple food in many countries of the world, is commonly extruded to noodles. Consequently, it is of interest to know how this process modifies the glycemic response.

Extrusion of wheat has been shown to raise the blood glucose response in rats and humans (6,7). While studies on diabetics have shown lower postprandial blood glucose response to extruded rice noodles when compared to milled rice (8,9), these studies used milled rice and...
extruded rice noodles which were not controlled for variety and physicochemical properties. The rice noodles were prepared from high amylase (28%) rice variety while the milled rice were either low (2.2%) or medium (15%) amylase rice varieties. Thus it is uncertain whether the difference in blood glucose response seen between the milled and extruded rice were an effect of extrusion or of varietal differences. Different rice varieties, even those with similar amylase contents, may differ in physicochemical properties which then may influence their glycemic response (10, 11). It is also uncertain whether the effect of rice extrusion is similar in normal and diabetic individuals or in diabetic subjects with different habitual diets. The effect of habitual diets on glycemic response has not been thoroughly addressed (5).

Therefore the objective of this study was to determine the effect of rice extrusion of noodles on the starch digestibility and glycemic response of one healthy and two diabetic groups, one group from the Philippines who eats rice and rice products daily and one group from Toronto, Canada who eats rice only occasionally. Physico-chemical characterization of the rice and rice noodles were also done to explain any differences seen between the milled rice and the extruded rice noodles.

**MATERIALS AND METHODS**

**Sample preparation**

A rough rice sample of IR42 (high amylase rice variety) was obtained from the International Rice Research Institute Farm. After aging for at least four months, they were dehusked with a Satake THU35A dehusker (Satake Engineering Co., Tokyo, Japan) to yield brown rice and then milled to white rice in an MC250 Satake one pass mill. Extruded noodles were prepared by a commonly used technique (12). Briefly, milled rice was ground to flour form, premoistened, uniformly fed into a single screw extruder at 160 g/min, and extruded at 15% moisture and 135°C. The noodles were dipped in boiling water for 15 sec and then in cold water. After straining, the noodles were air dried at ambient temperature.

For in-vitro and in-vivo testing, 50 g available carbohydrate portions of milled rice or rice noodles were cooked in 175 ml water for 22 min as previously described (10). Control bread was prepared using a standard method with 334 g all purpose white flour (Purity, Maple Leaf Mills, Toronto for Canadian study; Pillsbury Co., Phil. for the Philippine study), 312 ml water, 7 g sucrose, 4 g NaCl and 5.5 g active yeast; this recipe contained 250 g available carbohydrates.

**In-vitro digestibility test**

Two g available carbohydrate portions of freshly cooked rice or rice noodles were mixed with 10 ml pooled saliva, made up to 35 ml with distilled water, and incubated in a dialysis bag (12,000 MW cut off) suspended in a beaker containing 800 ml distilled water maintained at 37°C (13). Five ml aliquots of the dialysate were sampled every hour for 3 hrs and analyzed for individual sugars released (glucose, maltose, maltotriose) by high pressure liquid chromatography (Waters HPLC system with WISP automatic injector, model 6000 A pump, radial compression module, refractive index detector, Dextropac column and water as mobile phase at 0.5 ml/min). The experiment was done in duplicate.

**In-vivo tests**

Studies were conducted in Toronto, Canada and in Quezon City, Philippines. In Toronto, seven healthy individuals (2 males, 5 females; mean age 29 ± 2.7 yrs; all within 10% desirable weight) were used as subjects. Ten non-insulin dependent diabetic subjects (NIDDM; 3 males, 7 females; mean age 66 ± 2.6 yrs; 4 subjects greater than 10% desirable weight; 8 taking prescribed doses of oral hypoglycemic agents) were also tested. In the Philippines, 7 NIDDM subjects (5 males, 2 females; mean age 55 ± 2.9 yrs; 5 subjects greater than 10% desirable weight) were tested.
weight; 5 subjects taking prescribed oral hypoglycemic agents) participated in the study. All diabetic subjects were instructed not to take any medication the day before and during the test.

After a 10-12 hr fast, the subjects took in a random order breakfast test meals containing 50 g available carbohydrate portion of the freshly cooked rice or rice noodles. Each subject also tested white bread as a control and, in the case of the normal subjects in Toronto, also white bread plus 15 g lactulose (Merrill Pharmaceuticals, Concord, Ontario). All test meals were taken over a 10-15 min period with 250 or 500 ml water, tea or coffee without milk. The beverage was determined by individual preference and was constant for a given individual. For palatability, test meals for some subjects were served with 50 g raw tomato; this has been shown previously to have no significant effect on blood glucose response (13).

Finger prick blood samples were obtained with autolet lancets (Owen Mumford Ltd., Woodstock, Oxford, England) before and at 15, 30, 45 and 60 min after the start of the test meal in the case of normal subjects and before and at 30, 60, 90, 120, 150 and 180 min after the start of the test meal in the case of diabetics. Blood samples were analyzed for glucose by the glucose oxidase method (YSI 23 AM Glucose Analyzer, Yellow Springs Instrument, Box 279, Yellow Springs, OH) in the Toronto study, and by the Gilford spectrophotometric method (Gilford Spectrophotometer, Ohio, USA) in the Philippine study. Incremental blood glucose response area was calculated geometrically (14) and the glycemic index (GI) of the rice meals was expressed as a percentage of the mean area of the bread meal (5).

The healthy subjects also collected breath samples before and at hourly intervals up to 12 hours after the last meal using a modified Haldane-Priestley tube (13). As previously described (10), these were analyzed for hydrogen using a gas chromatograph (Gow Mac; with molecular sieve 5A 60-80 mesh column at 75 C with argon carrier gas at a flow rate of 29 ml/min). The total breath hydrogen was equal to the sum of all hourly breath hydrogen concentrations until 12 hrs. The total unabsorbed carbohydrate was estimated by comparing the breath hydrogen from the test meals to that from lactulose, a totally unabsorbed carbohydrate. Throughout the study, the subjects were asked to conform to the same daily activities. To reduce error in breath hydrogen measurements, they were required on the test days to consume a standard lunch of white rolls, skim milk cheese, instant vegetable soup and the same beverage they consumed with the test meal. An afternoon snack of three arrowroot biscuits were provided and the subjects were asked to delay supper until the final hydrogen sample was taken.

The protocol in this study was approved by the human subjects committee of the University of Toronto.

Chemical composition and physico-chemical tests

Samples were analyzed for proximate composition i.e. ash, protein, fat, moisture (15), and dietary fiber (16) for estimation of available carbohydrate content by difference from 100%. Amylose content (17), amylograph viscosity (18) and gel consistency (19) were also determined. The structural appearance of the freshly cooked samples was observed by light microscopy. The degree and rate of starch retrogradation was tested in-vitro (20). This involved three cycles of storage of the freshly cooked rice or noodles overnight at 1-2°C followed by reheating for 5 hrs at 42°C and 80% relative humidity. At the end of each cycle, samples were analyzed for reducing sugars after digestion with pullulanase and beta-amylase.

Statistical analysis

The in-vitro and in-vivo results were given as means ± standard error of the mean. The significant differences were calculated by Student's t-test for unpaired (in-vitro study) and for paired data (in vivo study). Statistical analysis was conducted with the SAS Statistical Package (SAS Institute, Inc., Cary, NC) for personal computer.
RESULTS

In-vitro digestibility test

The total amount of sugars released after 3 hrs was 15.3% significantly lower (p<0.05) in the rice noodles than in the milled rice (Table 1, Figure 1).

In-vivo tests

In the Toronto study, the blood glucose response of healthy subjects showed significantly lower values (p<0.05) for rice noodles than for milled rice at 30 and 60 min (Figure 2). The blood glucose area and GI in healthy individuals were also significantly lower (p<0.05) for rice noodles than for milled rice (Table 1), in agreement with the in-vitro results.

The same relationship was seen among diabetics both in Toronto and in the Philippines (Table 1, Figure 3) although the significantly lower (p<0.05) blood glucose response to rice noodles was seen only at 120 min in the Toronto and at 30 min in the Philippines diabetic. While the glycemic area for the rice noodles tends to be higher in the Toronto than in the Philippines.

TABLE 1

In-Vitro Starch Digestibility and Glycemic Response to Milled Rice and Rice Noodles

<table>
<thead>
<tr>
<th></th>
<th>Rice Noodles</th>
<th>Milled Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>In vitro study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total sugars released in 3 hr, mg/ml</td>
<td>0.55 ± 0.04 a</td>
<td>0.65 ± 0.02 b</td>
</tr>
<tr>
<td>In vivo study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal subjects-Toronto</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycemic area, mmol/L. min</td>
<td>52.87 ± 8.55 a</td>
<td>81.02 ± 7.62 b</td>
</tr>
<tr>
<td>Glycemic Index, % white bread</td>
<td>58.00 ± 12.22 a</td>
<td>91.00 ± 12.30 b</td>
</tr>
<tr>
<td>Total H2 production, ppm</td>
<td>17.81 ± 7.11</td>
<td>17.94 ± 6.01</td>
</tr>
<tr>
<td>Carbohydrate unabsorbed, g</td>
<td>1.20 ± 0.52</td>
<td>1.08 ± 0.36</td>
</tr>
<tr>
<td>Carbohydrate unabsorbed, %</td>
<td>1.49 ± 0.59</td>
<td>2.18 ± 1.72</td>
</tr>
<tr>
<td>Diabetic subjects-Toronto</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycemic area, mmol/L. min</td>
<td>679.30 ± 82.05 a</td>
<td>861.90 ± 69.87 b</td>
</tr>
<tr>
<td>Glycemic index, % white bread</td>
<td>64.00 ± 6.81 a</td>
<td>84.00 ± 6.97 b</td>
</tr>
<tr>
<td>Diabetic subjects- Philippines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycemic area, mmol/L. min</td>
<td>461.87 ± 105.66 a</td>
<td>610.60 ± 97.33 b</td>
</tr>
<tr>
<td>Glycemic index, % white bread</td>
<td>66.00 ± 7.17 a</td>
<td>87.00 ± 11.40 b</td>
</tr>
</tbody>
</table>

Means followed by different letters are significantly different (p< 0.05)
FIGURE 1
In-Vitro Starch Digestibility of Milled Rice and Rice Noodles

FIGURE 2
Blood Glucose Response of Healthy Individuals to Milled Rice and Rice Noodles
diabetics, the glycemic indices based on white bread were similar. Philippines and Toronto diabetics both showed a 24% lower glycemic response to rice noodles compared to milled rice.

In healthy volunteers, rice extrusion did not cause a significant increase in amount of unabsorbed carbohydrate (Table 1) despite the lowering in starch digestibility and blood glucose response.

**Composition and physico-chemical properties**

Rice noodles and milled rice from the same variety had very similar chemical composition but significantly different gel characteristics (Table 2). Rice noodles had a softer gel consistency and lower amylograph viscosity than milled rice. Microscopic examination showed that cooked rice noodles were less hydrated compared to milled rice (data not shown). Retrogradation tests showed the freshly cooked noodles to have significantly lower rate of sugar released compared to the cooked milled rice (Table 3). The difference became more prominent with storage cycles. These data suggest a greater degree of starch retrogradation in the noodles than in the milled rice.

**DISCUSSION**

This study showed that extrusion of rice to noodles can lower the in-vitro rate of starch digestion and blood glucose response in healthy and diabetic volunteers both in Toronto and in the Philippines where dietary habits are widely different. The similarity in trends between the two groups from the same population (healthy and diabetics in Toronto) and between the two
TABLE 2
Composition and Physico-chemical Properties of Milled rice and Rice Noodles

<table>
<thead>
<tr>
<th></th>
<th>Rice Noodles</th>
<th>Milled Rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available carbohydrate, % dry basis</td>
<td>86.3</td>
<td>86.0</td>
</tr>
<tr>
<td>Amylose, % dry basis</td>
<td>30.5</td>
<td>30.1</td>
</tr>
<tr>
<td>Gel consistency, mm</td>
<td>100</td>
<td>28 a</td>
</tr>
<tr>
<td>Amylograph viscosity, Brabender units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>peak</td>
<td>250</td>
<td>870 a</td>
</tr>
<tr>
<td>setback</td>
<td>145</td>
<td>425 a</td>
</tr>
<tr>
<td>consistency</td>
<td>155</td>
<td>630 a</td>
</tr>
</tbody>
</table>

a Significantly different from the rice noodles (p< 0.05)

TABLE 3
Total Sugars Released (ug/ml) during Starch Retrogradation Test

<table>
<thead>
<tr>
<th>Samples</th>
<th>Fresh</th>
<th>1 cycle</th>
<th>2 cycles</th>
<th>3 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milled rice</td>
<td>79.3 ± 23.0 a</td>
<td>77.7 ± 0.9 a</td>
<td>61.1 ± 1.9 b</td>
<td>41.7 ± 0.9 b</td>
</tr>
<tr>
<td>Rice noodles</td>
<td>68.2 ± 1.8 a*</td>
<td>61.6 ± 4.2 a*</td>
<td>40.0 ± 1.0 b**</td>
<td>31.4 ± 0.6 c*</td>
</tr>
</tbody>
</table>

Means in a row followed by different letters (a-c) are significantly different (p< 0.05).
* (p< 0.05), ** (p<0.01) significantly different from milled rice.

populations with different habitual diets (diabetics in Toronto and in the Philippines) indicate that this effect of rice extrusion on starch digestibility and glycemic response is reproducible and real. The low glycemic response to the rice noodles was not related to carbohydrate malabsorption, as indicated by the lack of change in total hydrogen production.

The results agreed with the previous report on the glycemic response of extruded rice noodles (8,9) but contradicted the results of others which showed higher digestion and glycemic response in humans and animals after extrusion of wheat products (6,7). Since the previous study (8,9) compared milled rice with low to medium amylose content to rice noodles with high amylose content while our study compared milled and extruded rice with the same high amylose content, our results suggest that the extrusion to noodles can result in the lowering of the blood glucose response to rice regardless of amylose content. The contradiction with results in wheat products is not clear but may be related to differences in the extrusion temperature and moisture content, and composition of the extruded food. Wheat contains greater protein, available carbohydrate and dietary fiber but lower amylose (12) than rice. The extrusion temperature used in the wheat products was higher (156-180 °C) compared to the ones used in the present study (135 °C) although the water used was almost identical (15-20%).
The differences in digestibility and glycemic response to noodles and milled rice could be due in part to differences in some of the physico-chemical properties of rice noodles relative to milled rice. The softer gel consistency and lower amyllograph viscosity of the rice noodles compared to milled rice seen in the present study are reflective of pregelatinization and some starch breakdown in the rice noodles during extrusion, and retrogradation upon cooling (21). Some starch gelatinization is required during extrusion as the gelatinized starch acts as a binder. The in-vitro test for retrogradation confirmed the greater retrogradation in rice noodles than the milled rice.

Retrograded starch is more resistant to hydration and hence to digestion because of the reformation of hydrogen bonds between amylase molecules and the return to a more crystalline structure (22). The degrees of gelatinization of retrograded starches have been shown to be 88% and 36% after 0 and 10 freeze-thaw cycles, respectively; freezing and thawing facilitates the retrogradation process (23). Similarly, Chinese noodles stored for 40 days had lower degree of gelatinization compared to noodles stored for 30 days (24). Resistance of retrograded starch to enzyme hydrolysis has also been demonstrated (25-28). For example, 9, 18 and 14% of total carbohydrates fed were recovered in ileostomy effluents from freshly cooked (low retrogradation), cooled (higher retrogradation), and reheated potato, respectively (25).

In conclusion, this study indicates that extrusion of rice to noodles can decrease the rate of in-vitro digestibility and glycemic response of normal and diabetic subjects regardless of their previous diet history. This may be related to the retrogradation of the high amylose rice starch which were gelatinized during extrusion as indicated by the higher amyllograph viscosity and harder consistency of milled rice compared to rice noodles. Upon storage, the greater reduction in digestibility in rice noodles vs milled rice further suggest that the starch in rice noodles are more prone to retrogradation.

ACKNOWLEDGEMENT

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REFERENCES


27. Matsunaga A, Kainuma K. Studies on the retrogradation of starch in commercially processed foods. J Home Econ. 1983; 34: 73-78


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