Starch Digestability and Glycemic Response to Extruded High Amylose and Rice Noodles

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ABSTRACT

A study was undertaken to determine the effect of extrusion on starch digestablity and glycemic response to rice. Extrusion of high amylose rice significantly reduced starch digestability and glycemic response (P, $\leq$ .05). This observation was related to gelatinization of starch during extrusion and starch retrogradation after processing as indicated by the high amylograph setback and consistency of milled rice compared to rice noodles. Retrograded starch is resistant to amylase digestion as indicated by the greater reduction in digestibility in rice noodles compared to *milled rice. Rice noodles may therefore be a beneficial food for diabetic and hyperlipidemic patients.*

Keyword: Extension, retrogradation, glycemic response, gelatinization, diabetes, hyperlipidemia

INTRODUCTION

Carbohydrate foods are disgested and absorbed at different rates (Jenkins *et al.* 1981, 1985a, 1988b). Those which are digested and absorbed at a slower rate have been suggested to be more beneficial to health and better control of chronic diseases such as diabetes, cardiovascular diseases and cancer.

It has been shown that processing of carbohydrate foods such as rice affects the rate of digestion and glycemic response. Extruded rice noodles produced lower glucose response compared to milled rice (Juliano 1985, Juliano 1989). However in these studies, the rice samples were not controlled for variety and physicochemical properties such as gelatinization temperature and gel consistency. Therefore it is uncertain whether the differences seen between samples were a true effect of processing or of varietal differences. Different varieties of rice may differ in amylose and physicochemical properties which then may influence, their glycemic and insulinemic responses.

Therefore more studies need to be done on the rate of starch digestibility and blood glucose responses of rice noodles making use of samples from the same variety. The physicochemical properties of the rice samples should also be studied and related to observed effects. This will help predict the glycemic response to rice varieties of known physicochemical characteristics. This study was done to determine the effect of extrusion on starch digestibility and glycemic response to rice. Two population groups of diabetics were used in this study, one group who regularly eats rice noodles (Philippines) and another group who does not (Toronto), to see whether the effect is independent of habitual diet.

SUBJECTS AND METHOD

In the Toronto study, seven healthy subjects (2 males, 5 females; ages 23 to 44 with mean age of 29 $\pm$ 2.74 years; within 10% desirable weight) were used as subjects. In addition ten NIDDM subjects (3 males, 7 females; age 52 to 72 with a mean age of 66 ± 2.59 yrs) participated in the study. Most of the subjects were taking oral hypoglycemic agents or insulin. The subjects were given standard medication as prescribed. In the Philippine study, nine NIDDM subjects (5 males, 2 females, age 45-64 with a mean age of 55 ± 2.9 yrs) participated in the study. More than half of them were taking oral hypoglycemics such as Diamicron, Diabinase, Eulocon and Glucophage and four of the subjects were more than 20% overweight.

Sample Preparation

Rough rice samples of IR42 was obtained from the 1985 wet season crop of the International Rice Research Institute (IRRI) farm. After aging for at least four months, it was dehulled with a Satake Thu35A dehusker, milled in an MC250 Satake one pass mill and aspirated. Extruded rice noodles were processed from the same variety of milled high amylose (IR42) rice. The rice was ground into an 80 mesh flour in a burr mill, premoistened, uniformly fed into a fabricated single-screw extruder at 85-90 °C die temperature. The noodles were dipped in boiling water for 15 min. and then cooled in cold water. After straining, the noodles were air dried at ambient temperature. Two rice noodles preparations were done: one for the Toronto study and the other, for the Philippine study.

Chemical, Physicochemical and Microscopic Analysis

Proximate composition and dietary fiber of the samples were determined (ADAC, 1980 and Prosky *et al* . 1985, respectively). Amylose content, amylograph viscosity and gel consistency of the samples were also determined (IRRI, 1974). Structural appearances of the freshly cooked samples were studied using light microscopy following iodine staining (Yiu, 1987).

In-vitro Digestibility Tests

Duplicate cooked rice samples containing 2 g available carbohydrate were mixed with 10 ml distilled water and 10 ml pooled human saliva. The samples were made up to 35 ml distilled water, mixed well, placed in a dialysis bag (50 mm, 12000 MW cutoff) and suspended in a beaker containing 800 ml distilled water maintained at 37°C. Five milliliters aliquots of the dialysate was sampled every hour for 3 hours and analyzed for sugars released by high pressure liquid chromatography ters, Ltd, HPLC system, WISP automatic injector, model 6000 A pump, radial compression module, Dextropac column with H20 as mobile phase at 0.5 ml/min). Sugars released were detected by the formation of peaks as they are separated by adhering or diffusing into the stationary phase of the column.

In-vitro Test for Starch Retrogradation

Two grams of freshly cooked rice and noodles were stored overnight in a cold room (1-2°C). The sample was then heated 4-6 hrs at 42°C and 80% relative humidity. This cycle was repeated 3 times (equivalent to 3 cycles). One gram of the sample was homogenized with 15.0 ml water using ultra-torax and then mixed well with 15.0 ml 0.2N NaOH. A 5 ml portion was then measured and macerated with a tissue grinder. An aliquot (1.5 ml) was measured, 1.5 ml of 0.1N HAC was added, made to 100 ml using 0.1N NaAC, ph 5.3. A 1 ml portion of enzyme solution containing 3.4 units of pullulanase and 2.0 units of B-amylase was added to 1 ml of homogenate and duplicate samples of this homogenate were incubated separately for 1, 2 and 2 hrs at 40°C and analyzed for reducing sugars according to Somogyi (1952).

In-vivo Tests

The in-vivo tests were conducted in two locations: Toronto and the Philippines. After a 10-12 hour fast, normal and diabetic subjects took in random order breakfast test meals containing 50 g available carbohydrate portion of the freshly cooked rice samples. Each subject also took at least one test of white bread as a control and in the Toronto study using normal volunteers, a test meal of white bread plus 15 g lactulose for the estimation of unabsorbed carbohydrate.

All test meals were taken with one or two cups of tea or coffee without milk. The beverage was determined by individual preference and was constant for a given individual. The subjects were asked to eat the test meals over a 15-minute period. For palatability, test meal for some subjects in one experiment were served with 50 g raw tomato.

White bread was prepared using a standard method with 334 g all-purpose white flour (Monarch, Maple Leaf Mills, Toronto, Canada), 62 ml warm water (40-43°C); 7 g sucrose, 4 g NaCl and 5.5 g active dry yeast. One recipe contains 250 g available carbohydrates. In the Philippine study, the same procedure was followed but a different brand of all-purpose flour was used (Pillsbury flour, PA).

Blood Glucose and Insulin

Finger prick blood samples were obtained with autolet lancets (Owen Mumford Ltd., Woodstock, Oxford England) at time periods of 0, 15, 30, 45 and 60 min for normal and at 0, 30, 90, 120, 150, 180 min for diabetic subjects after the start of the meal. Blood samples were collected into tubes containing 410 ug sodium flouride and 252 ug potassium oxalate and analyzed for glucose content. For the Toronto study, glucose was analyzed by glucose oxidase method (YS123 AM Glucose Analyzer, Yellow Spring Instruments, Box 279, Yellow springs 10#). For the Philippine study, glucose analysis made use of the Gilford spectrophotometry method (Gilford Systems, Ohio, U.S.A).

Blood glucose response area was calculated geometrically and the glycemic index (GI) of the rice meal was expressed as a percentage of the mean area of the bread meal:

$$GI = \frac{\text{Blood glucose area of the food}}{\text{Blood glucose area of the equivalent CHO as bread}} \times 100$$

The in-vitro and in-vivo results were given as means + standard error of the mean. The significance of the differences were calculated by one way analysis of variance followed by "Student's t test" for unpaired (in-vitro study) and for paired data (in-vivo study). The areas under the incremental postprandial blood glucose curves were calculated according to Wolever (1986). The in-vitro and in-vivo results were correlated with the physicochemical properties of the samples.

RESULTS

Chemical Composition

Total lipids were lower and total carbohydrates and fiber were slightly higher in both extruded rice noodles compared to milled rice of the same variety (Table 1). The extrusion process did not alter the amylose content of rice noodles used in the study.

In-vitro Digestibility Tests

The total amount of sugars released after 3 hrs was significantly lower ($p \leq 0.5$) in the rice noodles than in the milled rice in the Philippine study (Fig. 1, Table 2).

Table 1. Chemical composition of milled rice and extruded rice noodles (1% dry basis).

	NOODLE (T)[a]	NOODLES (P)[b]	MILLED RICE
Ash	0.41	0.84	0.97
Protein	7.89	8.84	9.35
Total lipids	0.09	0.23	1.70
Total CHO	91.60	90.25	87.98
Dietary fiber	2.25	3.51	1.95
Available CHO	89.36	86.28	86.03
Amylose	29.40	30.50	30.08

[a]Toronto study.
[b]Philippine study.

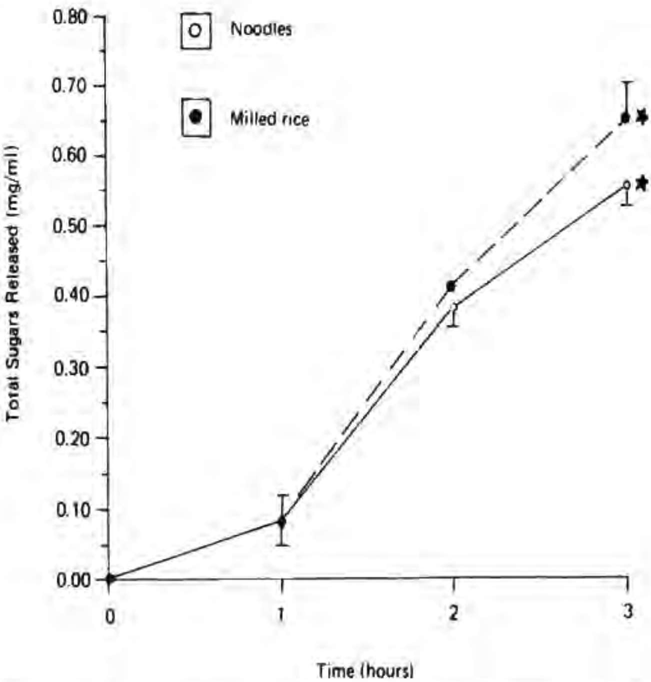


Fig. 1. In-vitro rate of starch digestion in rice noodles versus milled high amylose (IR42) rice. (Philippine study) Bars represent standard error of the mean; n = 2) (*$P \leq .05$).

In-vivo Study

In the Toronto study, blood glucose responses by normal subjects showed significantly lower values ($p < 0.05$) for rice noodles compared to milled rice at 30 and 60 min (Table 2, Fig. 2). The blood glucose response and GI were also significantly lower ($p \leq 0.05$) for rice noodles in agreement with the in vitro results.

Table 2. Rate of starch digestion in vitro and glycemic response and carbohydrate malabsorption in vivo by normal and diabetic subjects.[a]

IN-VITRO STUDY	RICE NOODLES	MILLED RICE
Total sugars released in 3 hr. mg/ml		
Toronto study	0.55 ± .06	0.59 ± 0.2
Philippine study	0.55 ± .04a	0.65 ± 02b
In vivo study		
Normal subjects		
Glycemic area,		
mmo1/L, min	52.87 ± 8.55a	81.02 ± 7.62b
Glycemic index, & white bread	58.00 ± 12.22a	91.00 ± 12.30b
Total H2 production, ppm	17.81 ± 7.11	17.94 ± 6.01
CHO unabsorbed, 9	1.20 ± 0.52	1.08 ± 0.36
CHO unabsorbed, %	1.49 ± 0.59	2.18 ± 1.72
Diabetic Subjects		
Toronto		
Glycemic area, mmo/L. min	679.30 ± 82.05a	861.90 ± 69.87b
Glycemic index, % white bread	64.00 ± 6.81a	84.00 ± 6.97b
Philippines		
Glycemic index, mmo1/L, min	461.87 ± 105.66a	610.60 ± 97.33b
Glycemic index, % white bread	66.00 ± 7.17a	87.00 ± 11.40b

[a]Means and standardization for rice varieties followed by different letters are significantly different ($p \leq 0.05$).

The same relationship was seen among diabetics both in Toronto and in the Philippines (Table 2, Figs. 3 and 4) however, the significantly lower ($p \leq 0.05$) blood glucose response to rice noodles was seen only at 120 min in Toronto and at 30 min in

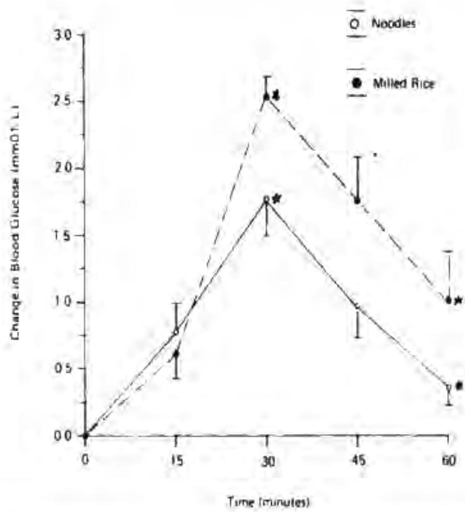


Fig. 2. Mean blood glucose response to rice noodles versus milled high amylose (IR42) rice in normal volunteers. (Bars represent standard error of the mean; n = 7) (*P ≤ .05).

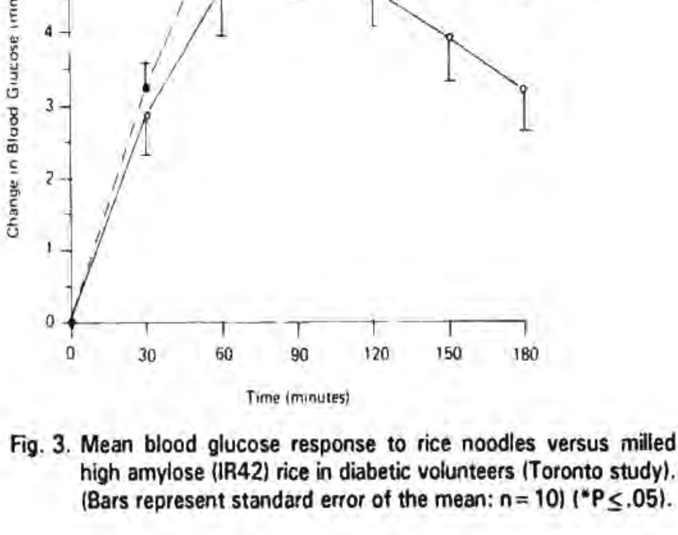


Fig. 3. Mean blood glucose response to rice noodles versus milled high amylose (IR42) rice in diabetic volunteers (Toronto study). (Bars represent standard error of the mean: n = 10) (*P ≤ .05).

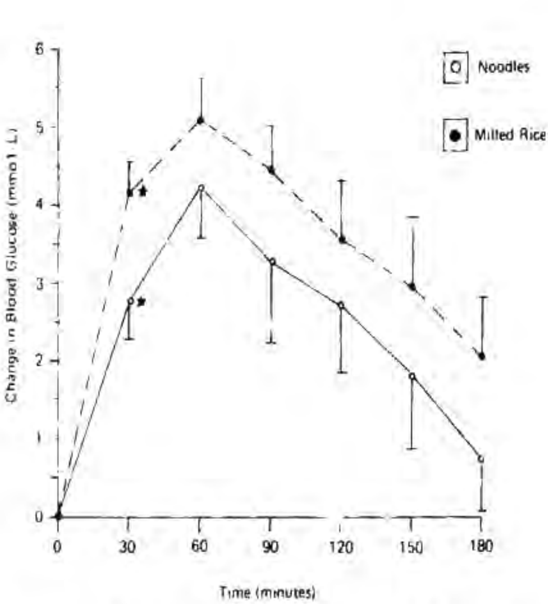


Fig. 4. Mean blood glucose response to rice noodles versus milled high amylose (IR42) rice in diabetic volunteers (Philippine study).
(Bars represent standard error of the mean: n = 9) (*p ≤ .05).

the Philippines. While the glycemic area for the noodles tend to be higher in the Toronto than Philippine diabetics, the glycemic based on white bread were similar.

Physicochemical and Microscopic Characteristics

Rice noodles and milled rice coming from the same variety have significantly different gel characteristics (Table 3). Rice noodles had a softer gel consistency and lower amylograph viscosity than milled rice. The GI was significantly correlated with amylograph viscosity ($r = 0.99$; $p \leq 0.05$). Microscopic studies showed that cooked rice noodles were less hydrated compared to milled rice (Fig. 5).

In-vitro Test for Starch Retrogradation

Freshly cooked noodles showed significantly lower rate of sugar released compared to the cooked milled rice of the same variety (Table 4). These differences were even more prominent as the samples were stored. The decrease in the rate of starch digestion of the two noodles after 1 cycle, were 6 and 35%,

Table 3. Physicochemical properties of extruded rice noodles and milled rice.

PROPERTY	NOODLES (T)a	NOODLES (P)b	MILLED
Gel consistency mm	250 + 12a	100 + 0b	28 + 0c
Amylograph viscosity BU			
peak	250 + 12a	250 + 10a	870 + 35b
setback	75 + 12a	145 + 8b	425 + 25c
consistency	75 + 9a	155 + 12b	630 + 42c

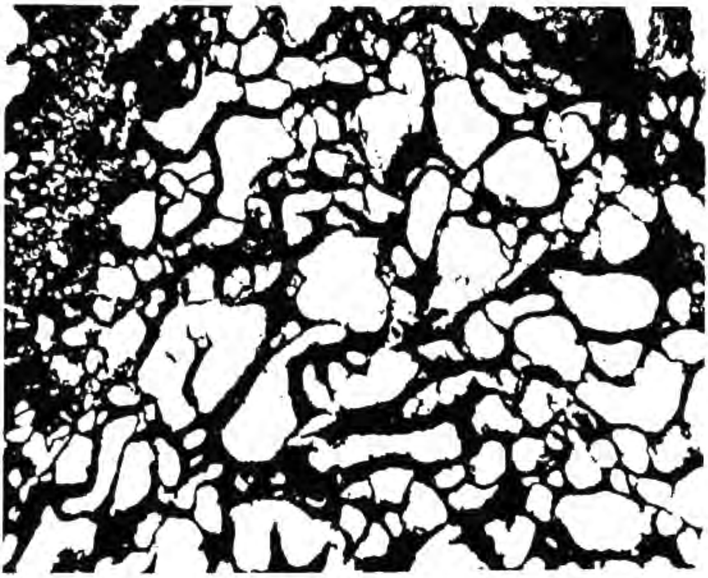
[a]Toronto.
[b]Philippines.
Note: Means for rice varieties followed by different letters are significantly different ($p<0.05$).

Table 4. Rate of starch digestion in vivo of fresh and stored rice samples.

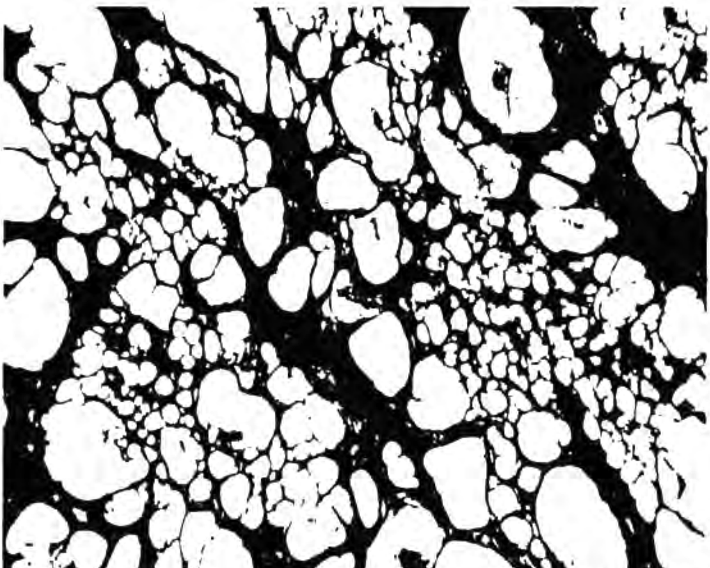
SAMPLES	Fresh	STORAGE PERIODS 1 cycle	2 cycles	3 cycles
		ug/ml c		
Milled rice	79.38 + 23a	77.70 + 0.90a	61.1 + 1.90b	41.70 + 0.90b
Noodles (T)a	67.70 + 1.10a	42.00 + 60b*	36.10 + 2.70c**	35.21 + 0.25*
Noodles (P)b	68.20 + 1.80a*	61.60 + 4.20a*	40.00 + 1.00b**	31.40 + 0.55c*

aToronto.
bPhilippines.
cTotal sugar released.
Note: Mean values of samples followed by different letters are significantly different (p 0.05).
Significantly different from milled rice.
* = $p < 0.05$
** = $p < .01$

and after the 2nd cycle, 18 and 23% compared to the milled rice (Table 4). However, the decrease in rate of starch digestion after the 3rd cycle was not as prominent as during the 1st and 2nd cycles. The data suggested a greater degree of retrogradation in the noodles than milled rice.



Milled Rice



Noodles

Fig. 5 Microscopic structure of rice noodles and milled high amylose (IR42) rice (White areas represent water spaces).

DISCUSSION

This study showed that extrusion of rice to noodles can lower the in-vitro rate of starch digestibility and blood glucose response in normal and diabetic volunteers.

The reduction of glycemic response to rice noodles compared to milled rice of the same variety was seen in diabetic volunteers both in Toronto and in the Philippines where dietary habits are widely different. This partly agreed with the results of Komindr *et al.* (1988) in their study of extruded rice noodles but contradicted the results of others which showed higher digestion and glycemic response in humans (NIDDM) and animals (rats) after extrusion of wheat products (23, 24). The contradiction may be due to differences in the extrusion temperature and moisture content, and composition of the extruded food. Wheat differs in chemical composition compared to rice with wheat containing higher protein, available carbohydrate and crude fiber (45).

The similarities of trends between two groups from the same population (normal and diabetics in Toronto) and two population groups (diabetics in Toronto and the Philippines) showed a real effect of extrusion of rice to noodles on starch digestability and glycemic response. Filipino diabetics who are regular rice eaters showed a 25% reduction in glycemic response in rice noodles compared to milled rice, while among Toronto diabetics, who are not regular rice eaters the reduction was 21%. This observation indicates a real lowering effect of extrusion digestability and glycemic response.

The differences in digestibility and glycemic response of noodles and milled rice could be due partly to differences in some of the physicochemical properties of rice noodles relative to milled rice (Table 3). The lower gel consistency and lower amylograph viscosity of rice noodles compared to milled rice seen in the present study are reflective of pregelatinization and some breakdown of starch in rice noodles during extrusion and retrogradation upon cooling (Khandher 1986). Retrograded starch has been shown to be resistant to hydration because of the reformation of hydrogen bonds between amylose molecules and the return of the crystallinity of the structure. Yatomi et al (1988) showed that upon heating, pregelatinized rice has a lower degree of gelatinization than untreated rice. However, starch gelatinization is required during extrusion as the gelatinized starch acts as a binder, and degree of gelatinization can range from 7 to 95% in commercial noodles. Matsunaga and Kainuma (1986) showed that degree of gelatinization (indexed by enzyme hydrolysis by BAP) of retrograded starches not stored (0 cycle) was 88% compared to 31.5% in retrograded samples stores (10 cycles). Another study by Matsukura et al (1983) showed that Chinese noodles stored 40 days had lower degree of gelatinization compared to noodles stored 30 days (40% vs 30% hydrolysis).

Retrogradation is a crystallization process that arises because of the strong tendency for hydrogen bond formation between hydroxy groups on adjacent starch molecules (13). Electron micrography of both raw and cooked noodles showed a honeycomb-like fibrillar network of retrograded starch, with protein material interwoven with the starch strand network (64). Resistance of retrograded starch to enzyme hydrolysis is well documented (17, 18, 48, 49, 50). Englyst and Cummings (1987) showed that 9, 18 and 14% of total carbohydrates fed were recovered in ileostomy effluents from freshly cooked, cooled and reheated potato, respectively. Differences in the rate of digestibility of rice noodles and milled rice can therefore be partly explained by starch retrogradation. This was reflected in the result obtained from the Slade test for starch retrogradation (Table 4). Freshly cooked noodles have more retrograded starch compared to milled rice and these differences were more prominent during storage. Other studies have shown reduction of digestibility of cooked rice stored at refrigerator conditions but the rice samples used in those studies were not characterized for amylose content and physicochemical properties (17, 18, 48, 49, 50, 56).

CONCLUSION

This study indicates that extrusion of rice to noodles can decrease the rate of in-vitro digestability and glycemic responses of normal and diabetic subjects. This may be related to retrogradation of the gelatinized high amylose rice starch during extrusion as indicated by the high amylograph setback and consistency of milled rice compared to rice noodles. Upon storage, the greater reduction in digestibility in rice noodles versus milled rice further suggest that the starch in rice noodles are more prone to retrogradation.

High amylose rice noodles may therefore be considered as lower GI food and can therefore add variety in planning diets not only for people with chronic diseases such as diabetes, hyperlipidemia and obesity but also normal individuals.

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