Chewing behavior and Bolus Properties as Affected by Different Rice Types

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***Abstract*—**The study aimed to investigate the effect of rice types on chewing behaviours (chewing time, number of chews, and portion size) and bolus properties (bolus moisture content, solid loss, and particle size distribution (PSD)) in human subjects. Five cooked rice types including brown rice (BR), white rice (WR), parboiled white rice (PR), high amylose white rice (HR) and waxy white rice (WXR) were chewed by six subjects. The chewing behaviours were recorded and the food boluses were collected during mastication. Rice types were found to significantly influence all chewing parameters evaluated. The WXR and BR showed the most pronounced differences compared with other rice types. The initial moisture content of un-chewed WXR was lowest (43.39%) whereas those of other rice types were ranged from 66.86 to 70.33%. The bolus obtained from chewing the WXR contained lowest moisture content (56.43%) whilst its solid loss (22.03%) was not significant different from those of all rice types. In PSD evaluation using Mastersizer S, the diameter of particles measured was ranged between 4 to 3500 μm. The particle size of food bolus from BR, HR, and WXR contained much finer particles than those of WR and PR.

***Keywords*—**Chewing behavior, Mastication, Rice, Rice types, Bolus properties

I. Introduction

CHEWING is the initial phase of food digestion and an important part of the activities linked to a good digestion in human body. The major purposes of chewing solid food are to reduce the particle size of ingested food, and to form a bolus suitable for swallowing. During chewing, the physical and physicochemical characteristics of solid food are subjected to alterations in several aspects, such as texture, particle size, moisture content, viscosity [1]. The food chewing can be highly variable depending on a number of factors including: the food itself (texture, hardness, and portion size); the processing of the food; and individual characteristics and preferences. It has been indicated that the physical aspects of food are important in influencing chewing behavior [2] and bolus properties. Furthermore, the physical form of food and the way that food is chewed has a significant effect on the rate and extent of starch digestion and thus on the metabolic responses of starchy food [3], [4].

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In the present study, rice was selected because it is an important staple food of population over the world and is consumed in several forms; however, the most commonly consumed is a whole kernel. There are varieties of rice types in the world, however, based on common pre-processing methods (de-hulling, milling, and -parboiling), it can be classified into three types, namely brown rice, white rice, and parboiled rice, each of which varies in texture, hardness, and chemical compositions.

White rice differs from brown rice in having a higher degree of milling. When cooked, white rice has been observed to exhibit higher water binding capacity, swelling ratio and peak viscosity; and to have a shorter cooking time [5], [6], [7], [8]. Rice with high water binding capacity yields soft textured cooked product (Park, Kim, & Kim, 2001). Rice types based on amylose content, which can vary from 0-35%, can be classified into 4 groups comprising waxy, low amylose, moderate amylose, and high amylose rice [9]. Rice texture is also highly correlated with amylose content: the higher amylose content, the harder the texture [10]. The waxy rice type has a hard and sticky texture, while low-amylose rice (10-20% amylose) has a soft texture when cooked. The intermediate amylose rice type (21–25%) produces a harder texture than that of the low amylose type whereas the high amylose type has the hardest texture [9]. In order to obtain an optimum cooked rice quality, high amylose milled rice requires more cooking water and longer cooking time than that having lower amylose content, depending on the gelatinization temperature of the starch.

In general, the texture of ingested food influences the chewing behaviour and bolus formation. A number of studies have been conducted on chewing aspects of several kinds of foods such as carrot [2] meat [11] and cheese [12], [13]. Only few studies have documented the effect of amylose content of rice on chewing behaviour. (Kohyama, Ohtsubo, Toyoshima, & Shiozawa, 1998) found that rice with higher amylose resulted in longer chewing time by using Electromyography (EMG). No investigation was done on chewing behaviour and bolus properties of rice as affected by rice pre-processing and amylose content in human with natural portion size and natural mastication.

This study was carried out to understand the effect of rice types on chewing behaviour and bolus properties. The correlation between variables (portion size, chewing time, chewing number, and moisture content) was evaluated to determine the interrelationships between variables. The finding of the study would provide more information on chewing which might be useful for mastication studies, and in addition could be linked to some nutritional studies and other related investigations.

II. Materials and Methods

A. Subjects

Six healthy human subjects with normal oral characteristics (5 female, 1 male) aged between 26 – 33 years were selected to participate in this study, on the basis of dental condition, age, and rice consumption which was assessed using a questionnaire. The project was reviewed and approved by the Massey University Human Ethics Committee (Southern A) prior to beginning the experiment. All subjects gave their informed consent to take part in the study. Each subject was scheduled to attend each session in the morning one by one and was able to attend only one session per day per person. Each session lasted approximately 60-90 min including training.

B. Cooked Rice Preparation

Rice samples comprised five rice types designated as: brown (BR); white (WR); parboiled (PR); high amylose (HR); and waxy rice (WXR). Raw brown, white, and parboiled rice samples were long grain Jasmine (low amylose) rice. All samples were purchased from local supermarket in Palmerston North, New Zealand. Whole kernels of rice samples were cooked until edible cooked rice was obtained, using an electronic rice cooker with water-to-rice ratio of 2.5:1 (v/v) for white, parboiled, and high amylose; and 3:1 (v/v) for brown rice, whilst a steaming procedure was applied to cook the waxy rice. After cooking, cooked rice samples (50-80g) were placed in plastic container, kept warm at 60±2ºC in food oven warmer, and served to participants after cooling down to approximately 40ºC, which is the temperature that cooked rice is normally consumed. Some characteristics of cooked rice were detailed and shown in table 1.

C. Textural Profile Analysis

Textural profile analysis (TPA) of the cooked rice was performed using a texture analyzer (TA-XT2 manufactured by Stable Microsystems, UK) with a 5kg load cell using a standard two-cycle compression force versus time program to compress the samples. The analyzer was linked to a computer that recorded the data via a software program. Cooked rice samples from each lot were kept warm during testing. A 35mm diameter cylindrical aluminium probe programming to move downwards to compress 30-35g of rice grains, with pre-test, test and post-test speeds of 2 mm/sec and test speed of 1 mm/min. TPA profile recorded the following parameters: hardness (N), stickiness (N),adhesiveness (Ns), cohesiveness, and chewiness (table 1). All textural analyses were replicated three times per sample.

D. Data Collection

The subjects were trained in order to familiarize them with every step of rice chewing prior to taking place the trials. They were instructed to take rice using a tablespoon with a normal portion size as they do at home. The subjects were also instructed to use a timer clock to signal that the chewing was beginning and finishing. Rice samples in containers were weighed before and after taking out by the subject in order to record the portion size. The subjects were asked to chew rice normally until the stage just before swallowing and then split the chewed sample (bolus) into small plastic container kept on ice, and wash their mouths before and after chewing rice. The chewing number and chewing time from the beginning to the end of chewing were recorded by researchers. Each rice type was served to the subject and chewed in random order. A total of 15 samples were performed for each session, comprising five (5) rice types and three (3) replicates. The bolus properties including bolus mass, moisture content, and solid loss were analyzed within the day of collection.

E. Determination of Particle Size Distribution

The particle size measurements was achieved by laser light diffraction using a Mastersizer S (Malvern Instruments Ltd, Malvern, UK) equipped with a 1000-mm lens, allowing for analysis of particles between 5 and 3500 µm. The whole food bolus of rice was dispersed in distilled water at ambient temperature (20 ± 2 °C) until an obscuration of 20-25% was obtained. The sample was placed in chamber dispersion for 2-3 min to ensure particles were independently dispersed and thereafter maintained by stirring during the measurement. This method expressed size distributions as a percentage of the total volume occupied in the laser chamber by the particles. The volume was converted to weight with the use of volumetric mass and expressed as cumulative values. PSD parameters obtained included largest particle size (D_{90}), mean particle volume (D_{50}), and smallest particle size (D_{10}).

F. Determination of Moisture Content and Total Solids

The un-chewed cooked rice, and the food bolus obtained, were subjected to measurement of bolus mass, and then used in determining the moisture and dry matter content (total solids) using oven-drying method to constant weight at 105ºC [14]. The total solid content was obtained from the amount of material remaining after all the water has been evaporated. The solid loss (%) was calculated from solid retained in the bolus compared with that in the portion size of un-chewed sample.

G. Data analysis

To study the effect of rice types on chewing behaviour and bolus properties, the data relating to the portion size (g), number of chews, chewing time (sec), moisture content (%) of the bolus, and solid loss (%) were analyzed via SPSS software as following, (1) Analysis of Variance (ANOVA) tests for differences between means were conducted, (2) Bonferroni confidence intervals were obtained as a post hoc test to determine which group means were different from which others, and (3) the correlations among the variables were investigated via correlation coefficients.

III. Results And Discussion

A. General Characteristics of Cooked Rice

Table I shows general characteristics of cooked rice used in this study. Rice types based on amylose content, varying from 0-35%, can be classified into 4 groups comprising waxy, low amylose, moderate amylose, and high amylose rice [9]. Table I also indicates texture profile of rice. The waxy type has a hard, adhesive, and sticky texture, while low-amylose rice (10-20% amylose) has a soft texture when cooked. The high amylose rice type produces a harder texture than that of the low amylose type. Different rice types require different cooking condition in order to obtain the desire eating quality; high amylose milled rice requires more cooking water and longer cooking time than that having lower amylose content, depending on the gelatinization temperature of the starch.

TABLE I
CHARACTERISTICS AND PREPARATION OF COOKED RICE SAMPLES

Rice type	Amylose Content (%)	Texture profile					Water: Rice ratio (v/v)	Cooking time (min)
		Hardness (N)	Stickiness (N)	Adhesiveness (Ns)	Cohesiveness	Chewiness		
BR	19.76	9.25±1.10	0.62±0.01	2.51±0.54	0.30±0.07	1.04±0.06	3:1	26
WR	19.44	8.79±0.41	0.46±0.04	1.38±0.23	0.34±0.05	0.75±0.05	2.5:1	16
PR	19.02	8.62±0.27	0.76±0.08	1.41±0.43	0.31±0.02	0.96±0.06	2.5:1	18
HR	26.72	9.46±1.36	0.80±0.02	2.92±0.18	0.32±0.005	1.28±0.21	2.5:1	22
WXR	2.04	41.69±3.82	1.71±0.12	5.28±1.12	0.38±0.02	7.55±0.08	Steaming	30

* = mean±SD of three replicates
BR, WR, PR, HR, and WXR stands for brow rice, white rice, parboiled rice, high amylose rice, and waxy rice, respectively.

B. Chewing Behaviour as Affected by Rice Types

Five major chewing behaviours and bolus properties as influenced by rice types were investigated, including: number of chews; chewing time; portion size; moisture content of bolus; and solid loss after the end of chewing. The summary statistics for each variable, grouped by subject across the 4 sessions are presented in Table II. Session-to-session variation is neglected for this analysis since an additional ANOVA (not reported) indicated no significant differences between sessions. The summary statistics for each variable, grouped by subject across the 4 sessions are presented in Table II. The results for each variable are summarized as follows:

Portion size: Group means range from 8.70 (BR) to 10.68g (PR). Rice types showed significant differences, with an overall F ratio value of 12.52. Post-hoc Bonferroni tests showed that WXR portions did not differ from those of PR, WR or HR; WR was not different from PR, and BR was not different from HR.

Number of chews: Group means range from 21.29 (PR) to 43.14 (WXR). Rice types showed significant differences, with an overall F ratio value of 156.24. Post-hoc Bonferroni tests showed that HR did not differ from BR or WR from PR. WXR was significantly different from all others.

Chew time: Group means range from 19.57 (PR) to 39.03 (WXR). Rice types showed significant differences, with an overall F ratio value of 101.29. The chewing time and number of chews were also affected by rice types. Waxy rice was chewed for longest time (37.31 secs) and highest number of chews (43.14 cycles) while chewing time of BR and HR was comparable, 28.59 and 28.81, respectively, and 31 and 31.44 cycles for number of chews. The biggest portion size was found in parboiled rice and white rice, whereas brown rice was found to be smallest. Post hoc Bonferroni tests revealed that there are no significant differences between BR and HR, or between WR and PR in relation to the chewing time. WXR stands alone and is higher than all others. Thus the rice types break down into three groupings: 1=BR/HR; 2=WR/PR and 3=WXR.

For the study on rice type effect, in the case of waxy rice, taking this rice type from the container by spoon was quite difficult compared to that of other rice types, due to cooked waxy grain being very sticky and compact in texture. However, the portion size of WXR (9.90g) was similar to those of PR (10.68g), WR (10.62g) and HR (9.55g) but was chewed for the longest time. The brown rice exhibited smallest portion size (8.70g), this may be because the BR is more bulky in density [15]. Even though the portion size of brown rice was smallest, it was chewed for a longer time than either white rice or parboiled rice. This may be caused by its course texture. BR consists of bran layer and germ which contains higher level of fiber and protein content [16], leading to the necessity to chew for a longer time in order to form a suitable bolus for swallowing. Similar chewing patterns were observed in high amylose rice, for which similar reasons may be applied in explanation. A number of studies found that there is high correlation between amylose content and hardness of rice [17], the high amylose rice was harder in texture as shown in table I.

C. Bolus properties

Solid loss: Group means range from 21.79 (PR) to 25.30 (WR). Rice types did not show significant differences, with an overall F ratio value of 2.24. Post-hoc Bonferroni tests were not performed as no groups differed (Table II).

Bolus moisture content: Group means range from 56.43 (WXR) to 74.55 (HR). Rice types showed significant differences, with an overall F ratio value of 158.87. Bonferroni tests showed, however, that BR, PR and WR were all not significantly different, with WXR alone being different from all others. The waxy type (un-chewed rice) contained lowest moisture content (43.39%) followed by BR (66.86%), while the initial moisture content of the remaining rice types indicated no significant difference, ranged between 69.74 to 70.33%. After chewing, more moistened boluses were obtained. The waxy type gained highest moisture content (23.04%, obtained by calculating the difference between initial and post moisture content, (Fig.1). The BR was the second highest gained of water content whereas that of the lowest moisture gained was found in WR and PR approximately 14%) (Table II).

When the bolus moisture content was considered, the amount of moisture up taken of bolus obtained from waxy rice was highest, followed by brown rice, this may be due the dryer food need more water and take longer chewing time in the mouth to lubricate the bolus suitable for swallowing [18]. The waxy rice indicated lowest moisture content this may be caused by the steaming method that applied to cook this rice type, which less water was taken up for this method. The differences in texture of rice depend on cooking methods as well but the present study did not aim to study the effect of rice cooking method, therefore, only the commonly used cooking method was adopted. The initial moisture content of brown rice was lower than that of white rice and parboiled rice. This may due to the fact that the brown rice took longer time for cooking which could cause more water evaporated. Moreover, brown rice contains higher level of lipids content existing in bran layer and germ, therefore, less water can penetrate inside the kernel.

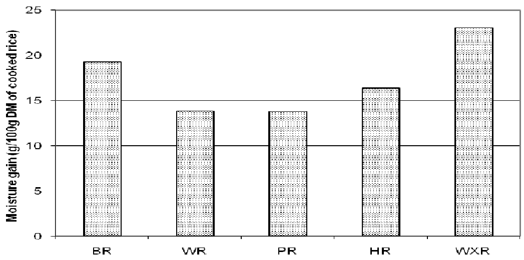

Fig. 1 Comparison of moisture content gain (%) between rice types

D. Particle Size Distribution

After mastication, rice lost it cohesive and was transformed into small particles. The average histogram of the rice particle size after chewing is present in Fig. 1. The diameter of chewed particle of rice measured was between 4 to 3500 µm. The large variations in PSD were observed for different rice types. BR, HR, and WXR contained higher number of finer particles than those of WR and PR was. When chewing time and number of chews of only high amylose white rice and white rice (low amylose) was compared, the high amylose rice was chewed for longer time and higher chew number, which this results were comparable to that studied by [19].

TABLE II
MIN-MAX VALUES AND F-RATIO OBTAINED FROM ANOVA WHEN TESTED THE EFFECT OF RICE TYPES (MIN AND MAX VALUES WERE OBTAINED BY AVERAGE FROM SIX SUBJECTS AND FOUR SESSIONS)

Variable	Rice type	BR	PR	WR	HR	WXR	Total	F
Chewing behaviour								
Portion size (g) (n=216 per cell)	Mean	8.70	10.68	10.62	9.55	9.90	9.89	12.52*
	Std. Deviation	3.06	3.79	3.75	3.22	3.12	3.48	
	Minimum	4.01	3.68	4.93	3.56	4.44	3.56	
	Maximum	18.5	16.76	18.04	16.36	17.16	18.5	
Number of chews (n=216 per cell)	Mean	31.50	21.29	23.77	31.47	43.14	30.23	156.24*
	Std. Deviation	7.59	8.78	8.39	9.98	14.11	12.60	
	Minimum	19	9	10	17	22	9	
	Maximum	49	46	47	53	81	81	
Chewing time (sec) (n=216 per cell)	Mean	28.68	19.57	21.96	28.83	39.03	27.62	101.29*
	Std. Deviation	7.33	9.31	9.63	10.77	16.21	12.96	
	Minimum	17.32	8.71	8.62	15.07	19.82	8.62	
	Maximum	45.34	44.12	46.1	52	84	84	
Bolus properties								
Moisture content (initial; %) (n=54 per cell)	Mean	66.86	70.33	70.24	69.74	43.39	64.11	1471.14*
	Std. Deviation	1.58	2.62	1.18	2.85	2.48	10.69	
	Minimum	65.52	66.6	68.68	64.41	41.66	41.66	
	Maximum	70.25	74.54	72.73	72.43	50.24	74.54	
Moisture content (bolus; %) (n=54 per cell)	Mean	73.17	74.35	74.27	74.55	56.43	70.55	158.87*
	Std. Deviation	3.06	3.83	3.30	4.52	7.15	8.44	
	Minimum	69.98	68.89	69.25	66.93	47.05	47.05	
	Maximum	79.02	81.08	80.47	80.96	70.42	81.08	
Solid Loss (%) (n=54 per cell)	Mean	25.29	21.79	25.30	22.66	22.03	23.41	2.24
	Std. Deviation	9.19	7.52	9.36	8.38	8.38	8.67	
	Minimum	5.71	5.35	8.07	7.3	11.54	5.35	
	Maximum	43.25	32.8	39.04	36.12	41.15	43.25	

* = significant at the 1% level or better

BR, WR, PR, HR, and WXR stands for brow rice, white rice, parboiled rice, high amylose rice, and waxy rice, respectively.

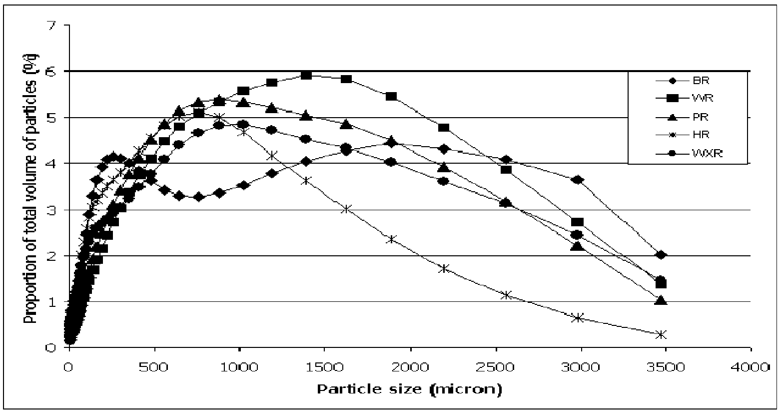

Fig. 2 Particle size distribution of different rice types after masticated by human subject
BR, WR, PR, HR, and WXR stands for brow rice, white rice, parboiled rice, high amylose rice, and waxy rice, respectively

E. Correlation between Variables

Number of chews and chewing time indicated the highest correlation whereas moisture content of cooked rice was significantly negatively correlated to chewing time (Table III). Significant correlations were observed between initial moisture content, number of chews, and chewing time. The significant correlation between portion size and chewing time, and number of chews was also found. The larger portion size the longer chewing time to reduce particle size of food, to incorporate moisture to bolus, and to form proper bolus for ingesting, which resulting in increasing the amount of moisture content in bolus. This can be seen in Table IV. There is significant variation exhibited between rice typesIn general, it was found that the higher the moisture content, the shorter the chewing time and smaller the number of chews. Cooked rice containing a lower amount of water needs more saliva (water) to moisten and form cohesive bolus suitable for swallowing [18], and hence needs longer time in the mouth. This result was similar to the study of [20] reported that the chewing time per weight of food was inversely related to the moisture content of food.

TABLE III
CORRELATION BETWEEN CHEWING BEHAVIOURS

		Portion size	Chew number	Chew time
MC initial	Pearson Correlation	0.127*	-0.505**	-0.383**
	N	270	270	270
Portion size	Pearson Correlation		0.148**	0.203**
	N		1080	1080
Chew number	Pearson Correlation			0.685**
	N			1080

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

IV. CONCLUSIONS

Overall, the results of this study revealed that chewing behaviours and bolus properties were affected by both subject and rice type. Chewing behaviour and bolus properties exhibited higher variation between individuals than were attributable to rice types. The waxy rice type indicated the greatest different from all other rice types in almost all aspects studied. The brown rice type was also revealed significant different in many aspects, especially when compared to those of white rice and parboiled rice which contain the same level of amylose content. The basic information that can be inferred from this study relate to how easily each type of rice can be broken down during mastication. The rice type that is chewed easier may have the higher rate and extent of starch digestion and thus on the metabolic responses of rice as a starchy food. However, it is too early to draw any conclusion from only the results obtained from this study. The effect of rice types on changes of starch during chewing as well as on particle size distribution was also conducted by this team of authors, for which results are forthcoming.

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