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Chewing cycle during mastication influences the *in vitro* starch digestibility of rice

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Abstract

The glycemic index of every individual differs depending on oral processing parameters including chewing cycle, chewing duration, food type, and processing. For this study, rice was used as sample (*white rice (Rv1)*, *brown rice (Rv2)* and *basmati rice (Rv3)* and its physicochemical properties were determined. The amylose content of the samples ranged between 22.35 – 32.42%. With different chewing cycles (15, 30 and 45 chews), the oral mastication parameters and GI of 10 human volunteers after rice mastication was determined. In order to understand the sensory preferences of consumers against rice varieties, the sensory analysis was performed using the new tool (i.e. temporal dominance of sensation). The size of particle was also calculated at 15, 30, and 45 chews, with all samples retaining a higher particle size (fifty percent particles greater than 4 mm) during 15 chews, while at 30 and 45 chews, there was a gradual decrease in the particle size with significant differences. The GI of the rice samples differed significantly between 15 (Rv1 – 57.59, Rv2 – 55.19, Rv3 – 54.98) and 30 chews (Rv1 – 72.44, Rv2 – 67.94, Rv3 – 68.17), but not between 30 and 45 chews (Rv1 – 72.83, Rv2 – 68.11, Rv3 – 68.45). Thus, this study highlights the need of oral mastication step for various *in vitro* digestion studies.

Keywords: Rice, oral mastication, particle size, glycemic index, temporal dominance of sensation

1. Introduction

Mastication is a process in which the food gets broken down to smaller pieces for further gastric and intestinal digestion. Depending upon the oral mastication features, the bolus (i.e. the food after chewing) may contain whole particles or particles of smaller sizes (Jiffry, 1981) [2]. When food grains are consumed as a whole, the differences in the chewing behavior of the individuals may result in the variations of the particle breakdown and thus it also influences the digestibility pattern of the food and its glycemic index (GI). It was reported by Read *et al*., (1986) [6] that swallowing food instead of chewing may reduce its GI, but it is impractical to implement. But, on the other hand, if the GI of any food need to be reduced, it can be chewed very less thus resulting in a larger particle size during further digestion process with reduced postprandial glycemic response (Ranawana, Leow, & Henry, 2014; Viren Ranawana, Monro, Mishra, & Henry, 2010) [4, 5]. For example, foods that are more elastic or cohesive in nature need more chews before swallowing because they are more difficult to fragment (Wee, Goh, Stieger, & Forde, 2018) [2], implying that consuming these foods gives the user more control over their eating habits. As a result, the scope of this research is to learn more about the effects of oral processing parameters (such as the chewing cycle) on the glycemic index (GI) of rice.

2. Materials and Methods

2.1. Selection of sample

The research used three distinct rice varieties with different physicochemical properties (Sivakamasundari. Moses., Anandharamakrishnan, 2020) [7, 8, 9, 10]. The rice was purchased from a local market in Tamil Nadu, India, and it included white rice *(ponni (Rv1) and basmati (Rv2)*, as well as brown rice *(ponni (Rv3))*. The amylose and starch content for the rice varieties were determined with reference to Sivakamasundari., Moses., Anandharamakrishnan, (2020) [7, 8, 9, 10].

2.2. Cooking of rice

Sivakamasundari., Moses., Anandharamakrishnan, (2020) [7, 8, 9, 10] provided preliminary data on the cooking properties of rice, based on which the cooking times were determined to be 30 minutes for Rv1, 25 minutes for Rv2, and 50 minutes for Rv3 with a rice: water ratio of 1:2 for Rv1, 1:1.5 for Rv2, and 3:1 for Rv3 respectively (Priyanka, Sivakamasundari, Moses, &

Anandharamakrishnan, 2020) [7, 8, 9, 10]. The cooked rice was then put in a container and allowed to cool before being analyzed.

2.3. *In vivo* oral mastication of rice

Ten human volunteers were chosen for this research with written consent prior to the experiment. During the tests, which began at 11:00 a.m., volunteers were given cooked rice samples (10 g) from which the portion size for each sample was determined (the difference in the weight of the sample in the cup before and after oral mastication). Following the collection of portion size data, each participant was given a predetermined sample portion size and an *in vivo* oral mastication analysis was conducted to determine bolus properties with reference to (van Eck *et al.*, 2019) [11]. Additionally the temporal dominance of sensation (TDS - a sensory analysis tool) for the rice varieties was determined. Apart from that, based on preliminary research conducted by Priyanka, Sivakamasundari, Moses, & Anandharamakrishnan, (2020) [7, 8, 9, 10], chew cycles for mastication were set to 15, 30, and 45 in this research and its influence on the particle size and *in vitro* starch digestibility of rice was determined.

2.4. Analysis of the oral masticated samples

The particle size distribution of the rice varieties after oral processing was measured using sieve analysis with reference to Peyron *et al.*, (2004) [3] with apertures of 4 mm, 2 mm, 1 mm, 0.71 mm and 0.56 mm.

2.5. *In vitro* digestion of the masticated sample

The impact of different chewing cycles on the digestion of rice was determined by analyzing the *in vitro* starch hydrolysis and glycemic index with reference to Sivakamasundari., Moses., Anandharamakrishnan, (2020) [11].

2.6. Statistical analysis

All of the tests were done in triplicate, and the mean and standard deviation were calculated. Furthermore, significant differences between the samples were analyzed using one-way ANOVA (SPPSS, ver. 20.0) with a p = 0.05 significance level.

3. Results and Discussion

3.1. *In vivo* oral mastication parameters of rice

The bolus properties of three different rice varieties were given in Table.1. The portion size for Rv1 was significantly higher than Rv2 and Rv3. On the other hand, the consumption time, chew cycles, chew cycle duration, solid loss were lesser for Rv1 whereas; the chewing, eating rate was higher for Rv1 than the other two varieties. This was because, the Rv3 (brown rice) had a tough bran layer which resulted in delayed mastication features. The observations of this study were consistent with the results reported by (Sethupathy *et al.*, 2020) [8].

Table 1: *In vivo* oral mastication parameters of rice

Parameters	Rv1	Rv2	Rv3
Potion consumed (g)	10.45 ± 0.48^a	9.17 ± 0.80^a	8.07 ± 1.09^b
Number of chewing cycle (No's)	26.5 ± 3.08^a	30.67 ± 4.76^b	32.00 ± 6.32^b
Time taken to consume the sample (s)	22.33 ± 2.34^a	27.00 ± 1.55^b	29.17 ± 3.97^b
Duration of chewing cycle (s)	0.85 ± 0.13^a	0.87 ± 0.19^a	0.98 ± 0.26^a
Rate of chewing (chews/s)	1.20 ± 0.20^a	1.19 ± 0.23^a	1.07 ± 0.25^a
Rate of eating (g/s)	0.40 ± 0.06^a	0.29 ± 0.05^b	0.27 ± 0.07^b
Solid loss during mastication (%)	40.52 ± 3.94^a	40.04 ± 3.01^a	32.48 ± 2.21^b

A statistically significant difference (at $p < 0.05$) between the varieties is indicated by different alphabets in the superscript of rows.

3.2. Sensory analysis of rice varieties

The sensory analysis (TDS) of rice in terms of flavor and texture was determined using senso-maker software and the parameters were scored by the volunteers based on the intensity of flavor and texture during mastication (Fig.1). In terms of Rv1 and Rv2 starchy flavor was highly dominant whereas; Rv3 has more branny flavor (Fig.1). In addition, the Rv2 has more aromatic flavor. In terms of texture, hardness was higher than the significant level for Rv3 whereas; more dryness was observed in the case of Rv1 and Rv2.

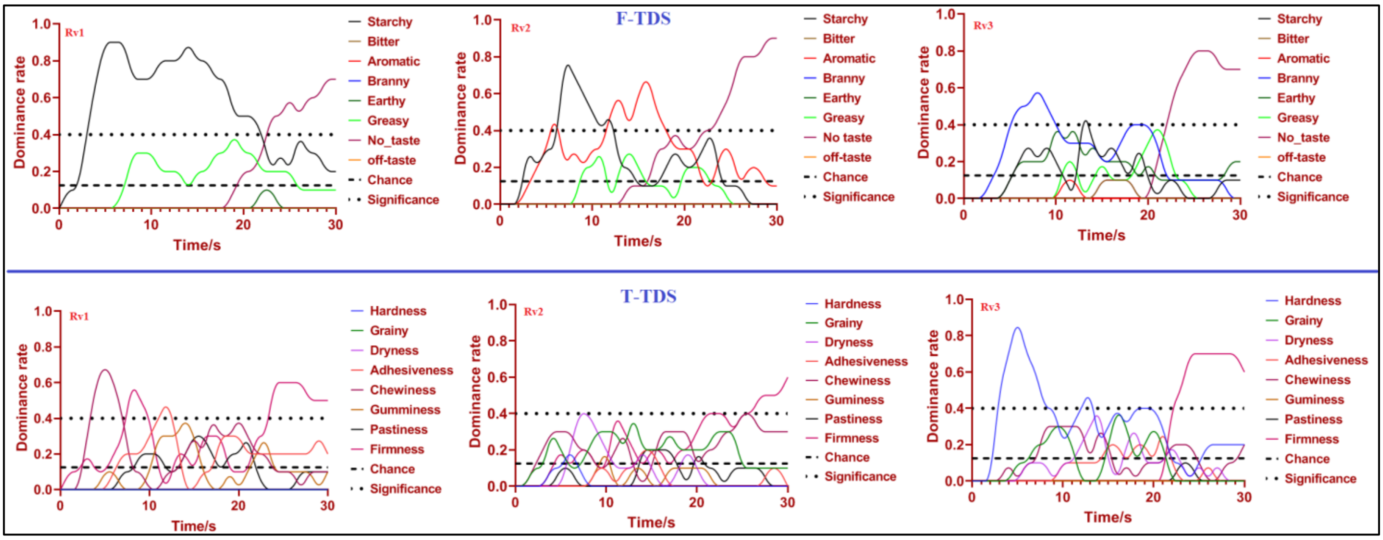

Fig 1: Temporal dominance of sensation of rice

3.3. Influence of chewing cycle on the particle size of rice

The particle size distribution of the rice varieties after *in vivo* oral processing was given in Fig.2 at three different chewing cycles. From the results, it can be observed clearly that, particle size was decreased gradually with the chewing cycle of 30 and 45 than 15 irrespective of the rice varieties. In case of Rv1 and 2, 46.11% and 54.08% of particles were greater than 4 mm during 15 chews whereas it was 78.55%, 67.66% and 71.65% for the Rv3. On the other hand, with 30 chews, 32.95% of Rv1, 34.36% of Rv2 and 38.69% for Rv3 were greater than 4 mm. This shows a clear significant particle breakdown at different chewing cycles. Finally, at 40 chew cycles, the particle breakdown was higher in the case of Rv1 and 2 whereas, no significant variations were observed for the Rv3 (30 vs. 45 chew cycles). Thus, particle breakdown during mastication may have an influence on the digestibility pattern and GI of rice as the particles of smaller size will have more surface area of contact with the digestive enzymes (Sivakamasundari, Priyanga, Moses, & Anandharamakrishnan, 2020) [7, 8, 9, 10].

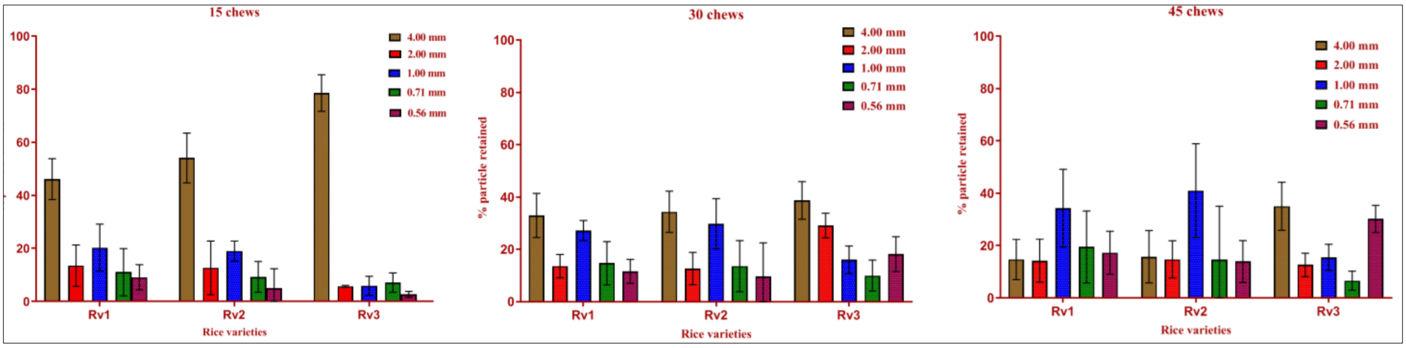

Fig 2: Particle size distribution of rice during *in vivo* mastication at different chewing cycles

3.4. *In vitro* digestion of the masticated sample

The starch digestibility parameters for rice varieties of different chewing cycles were determined and presented in Table.2 from which the correlation between particle size and GI was calculated. The relationship between particle size and GI was discovered, with the GI being negatively correlated (R^2– (-0.34)) with particles of 4 mm size after 15 chews. Then, at 30 chews, the correlation between GI and particle size (4 mm) was (R^2 – 0.26), while at 45 chews, it was (R^2 – (-0.43). Thus, rice has a lower GI as the particle size is greater.

Furthermore, by fitting the rate of starch hydrolysis (%) with a first order reaction (Goñi, Garcia-Alonso, & Saura-Calixto, 1997) [1], the starch hydrolysis parameters for the rice varieties at different chews were determined (Fig.3), and it was observed that the equilibrium percent hydrolyzed starch (C_∞) was higher for samples chewed 30 and 45 times than for samples chewed 15 times, and similarly with GI. However, since the subjects felt like swallowing the food after 30 chews, there was no substantial difference (p>0.05) in the GI for the samples chewed 30 and 45 times. Similar observations were reported by Ranawana *et al*., (2014) during *in vivo* oral mastication of rice with 15 and 30 chew numbers. Among the rice varieties, Rv2 and Rv3 displayed lesser GI due to the higher amylose content (Rv1 – 22.35%, Rv2 – 32.42%, Rv3 – 23.68%) and the presence of bran (Rv3) which restricted the access of the digestive enzymes (Sethupathy *et al*., 2020; Sivakamasundari, Moses, & Anandharamakrishnan, 2020) [8]. As a result, the findings confirmed that food glycemic response may be affected by oral mastication parameters.

Table 2: Starchy hydrolysis and glycemic index of the oral masticated sample (15, 30 and 45 chews)

Rice varieties	C_∞ (%)	k (min^{-1})	HI	GI	R^2
Rv1 (15)	43.61 ± 2.79^{a}	0.04 ± 0.01^{a}	32.57 ± 0.34^{a}	57.59 ± 0.19^{a}	0.97
Rv1 (30)	70.34 ± 2.17^{b}	0.06 ± 0.01^{b}	59.63 ± 0.43^{b}	72.44 ± 0.24^{b}	0.98
Rv1 (45)	71.07 ± 2.32^{b}	0.06 ± 0.01^{b}	60.33 ± 0.52^{b}	72.83 ± 0.29^{b}	0.97
Rv2 (15)	36.40 ± 1.40^{a}	0.04 ± 0.0007^{a}	28.20 ± 1.11^{a}	55.19 ± 0.61^{a}	0.99
Rv2 (30)	61.10 ± 1.68^{b}	0.06 ± 0.01^{a}	51.42 ± 2.08^{b}	67.94 ± 1.14^{b}	0.96
Rv2 (45)	61.60 ± 1.84^{b}	0.06 ± 0.01^{a}	51.73 ± 1.83^{b}	68.11 ± 1.01^{b}	0.96
Rv3 (15)	34.93 ± 2.42^{a}	0.05 ± 0.01^{a}	27.82 ± 1.03^{a}	54.98 ± 0.57^{a}	0.98
Rv3 (30)	61.65 ± 1.11^{b}	0.06 ± 0.01^{b}	51.85 ± 1.27^{b}	68.17 ± 0.70^{b}	0.97
Rv3 (45)	62.13 ± 1.02^{b}	0.06 ± 0.01^{b}	52.35 ± 1.27^{b}	68.45 ± 0.70^{b}	0.98

C_∞ - Equilibrium (%) of hydrolyzed starch; k – starchy hydrolysis rate (min^{-1}); HI – Hydrolysis index; GI – Glycemic index
A statistically significant difference (at p< 0.05) between the varieties is indicated by different alphabets in the superscript of rows.

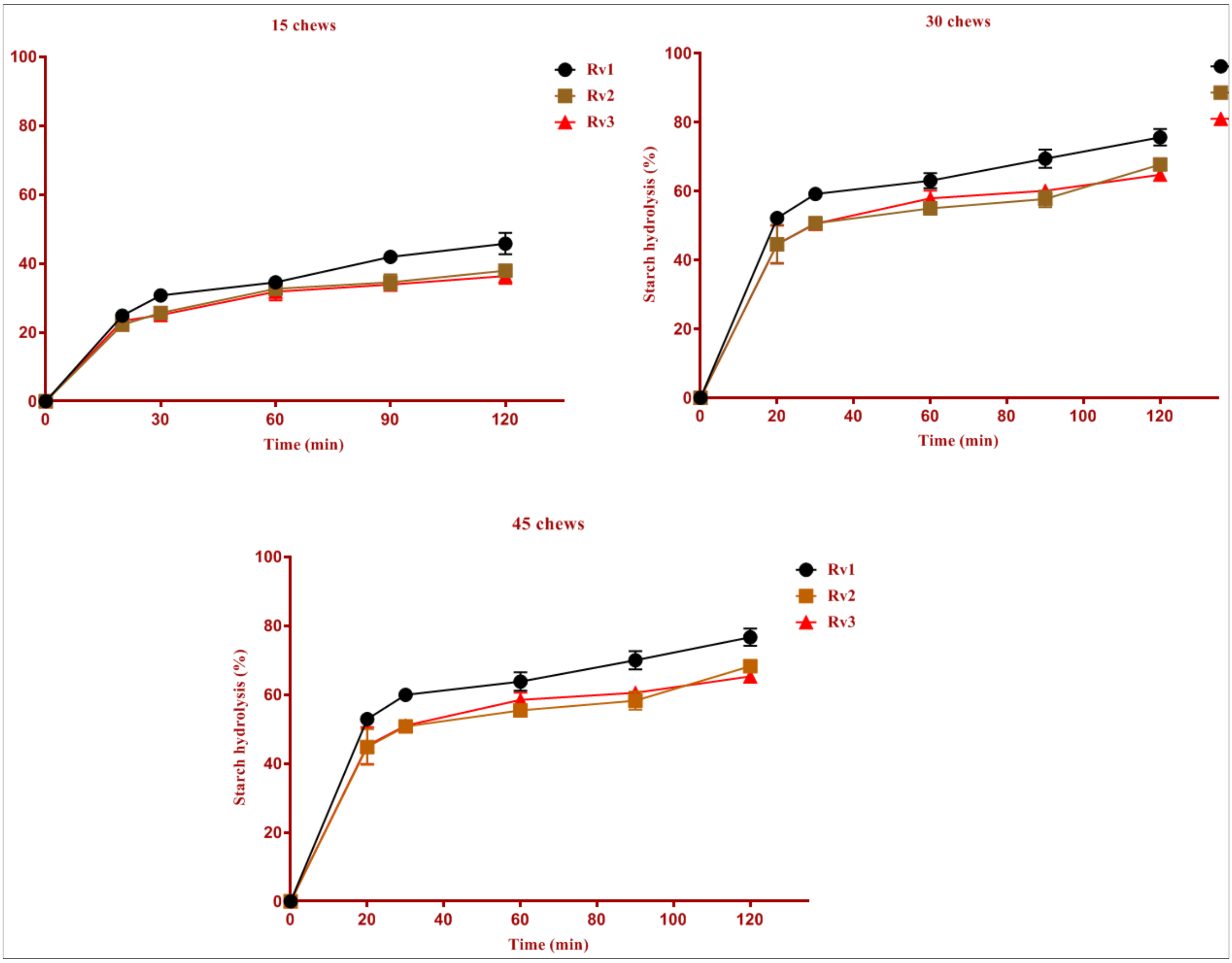

Fig 3: Starch hydrolysis of rice at different chew cycles

4. Conclusion

Mastication's effect on the GI of rice varieties was investigated. The oral mastication parameters for rice varieties differed greatly depending on their physiochemical property. Furthermore, the sensory perception of the rice varieties during mastication was presented by temporal dominance of sensation, and thus this technique can be used to analyze consumer acceptance of foods. Further, the particle size of rice varieties differed significantly across three separate chewing periods, which had an effect on their digestibility pattern. When compared to 30 and 45 chew periods, rice chewed 15 times elicited lower GI. As a result, the study's *in vitro* findings suggest that habitual mastication of foods can affect digestion rate. But, until conclusive proof can be obtained, further research is required, and the current study provides a strong foundation on which future research can be established.

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