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# Studies on Rheology of Rice Cake Batter Along with Texture and Microstructure Properties of Steamed Rice Cakes

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## Abstract

Incorporating gas bubbles into food structures results in a remarkable alteration in their rheological properties and physical appearance. A complete description for the cellular structure in solid food foams includes information related to pore size and distribution and also that relating to the mechanical behavior, defining final product texture. Texture profile analysis were used to study the texture of the steamed rice cakes. Mean pore size and distribution was obtained using flatbed scanner, followed by image analysis. Fundamental rheological measurements were made to study the rheological properties of the rice cake batter. The effect of addition of xanthan gum and steaming time on the mean pore size, texture and distribution was studied. Addition of hydrocolloid (xanthan gum, XG) at 0.1% concentration resulted in lower hardness of rice cakes with a narrower pore size distribution and larger mean pore cross section diameter. Rheology studies showed that XG-added rice cake batter had lower moduli values compared to batter without XG. The effect of steaming time (300 s, 600 s, 900 s) on the texture and pore size distribution of rice cakes showed that hardness (g) was in the order of 300 s <600 s < 900 s with smaller mean pore cross section diameter, respectively. Thus, steamed rice cakes (900 s) with lowest mean pore cross section diameter were harder compared to those with highest mean pore cross section diameter, which were softer (300 s).

***Keywords:*** *Steamed Rice Cake; Rheology; Texture Profile Analysis; Image Analysis*

## Introduction

Steamed rice cakes are very popular and are prevalent in many different cuisines. The names by which the rice cake is known include *Rijsttaart* and *Rijstevlaai* in Dutch and Belgian cuisines, *Puto* in Filipino, and *Tteok*, in Korean [1]. While the basic recipe remains the same, there are slight variations. Puffed rice cakes are eaten in North America, while in Vietnam a chewy sponge cake, *Banh Bo*, is made from rice flour. In Italian cuisine, specifically in Tuscany, *torte di riso* is a rice cake eaten as a substantial dessert. *Chwee Kuch*, also called as the 'water cake', remains a firm favorite amongst many a Singaporean and is a typical breakfast dish. We investigate here an Indian variant of steamed cakes (*steamed rice cake*) made with blend of parboiled rice and dehulled black lentil (*Phaseolus mungo*) made by the bacterial fermentation (12 - 18h), commonly in the ratio of 3:1. Indian rice cake is no longer regional and has gained visibility internationally too with experimental twists. The reason for the popularity being, its nutritional value and look out for convenient snacking solutions. A set of mini rice-cakes is now a regular feature on the air-craft menus. Canadian food giant, McCain Foods Limited in 2012, introduced frozen steamed rice cakes targeting home makers, working women and consumers, who are constantly in search of convenience foods.

These rice cakes are soft, moist and spongy with a desirable sour flavor. The spongy texture observed is due to the presence of surface active protein (globulin) and arabinogalactan (polysaccharide) in black lentil. The surface-active globulin from black lentil has high foam forming activity resulting in enhanced viscosity, thus responsible for the gas holding and dough raising capabilities [2,3]. Unlike black lentil, other legumes lack this characteristic and are considered unsuitable for such food foam preparations. The mucilaginous nature of black gram is due to arabinogalactan. Arabinogalactan from black lentil has a high molecular weight and is also highly viscogenic and may have a branched chain structure somewhat similar to that of guar gum [4]. It is believed that the mucilaginous characteristics help in the retention of $CO_2$ during the natural fermentation of thick batter and is responsible for the soft, spongy texture of steamed rice cake. With the progress of fermentation there is change in batter volume, acidity and non-protein nitrogen [5,6].

Iyer and Ananthanarayan [7] explored the possibility of expediting the rice batter fermentation process by addition of $\alpha$-amylase. The fermentation time reduced from a conventional 14h to 8h while maintaining the sensory attributes of the final product successfully. The sensory profile of the steamed rice cake was assessed by Durgadevi and Shetty [8] using principal component analysis. The sensory attributes measured were color, fluffiness, sponginess, compactness, firmness, stickiness and sourness. Instant idli mix, commercially available in the Indian market, has been found to lack the characteristic spongy and fluffy texture as compared to the product prepared traditionally. Hydrocolloids are found to have considerable effect on the texture of the food product [9]. Thakur., *et al*. [10] studied the effect of different methods of incorporation of xanthan gum in instant idli mix. The desired textural properties (lower hardness, lower cohesiveness and more elastic modulus) of steamed rice cake were obtained when pre-swelled xanthan was added at 0.1% concentration. The texture profile parameters of steamed rice cake were obtained from the force deformation curves as follows: hardness, the highest peak force for the first compression; springiness, the elastic recovery that occurs when the compressive force is removed; cohesiveness, ratio of positive areas of second and first compression cycle; gumminess, product of hardness and cohesiveness; chewiness, product of gumminess and springiness (Bourne 2002).

The rheological behavior of rice batter suspensions, and black gram suspensions has been reported earlier [11]. Bhattacharya and Bhat [12] studied the steady shear rheology of batter suspensions and suitability of applicable rheological models. Common rheological models fitted to the shear stress and shear rate data are Hershel-Bulkley model, ($r^2$=0.985-0.994) and the Casson model ($r^2$=0.983-0.993). Scanty literature is seen relating to the viscoelastic properties of rice cake batter and no literature is available on the pore size distribution data in steamed rice cakes. Bubble size is most important parameter defining food foams. A complete description of the cellular structure in solid food foams includes information related to pore size and distribution and also that relating to the mechanical behavior that defines final product texture. Hence, the study was undertaken to understand the mechanical and textural properties of steamed rice cakes with reference to its structural characteristics. In solid food foams like steamed rice cakes, bubbles contribute significantly to the texture of the product and are responsible for the elastic and viscous natures of the food. Therefore, an attempt was made to measure the mean pore size and the pore size distribution.

## Materials and Methods

### Raw materials and steamed rice cake preparation

Parboiled rice and dehulled black lentil were obtained from the local market. Rice and dehulled black gram were washed thoroughly and soaked in water separately for 5h. The ratio of water to grain was 3:1 (v/v). They were separately ground in a wet grinder (Kenstar food processor, Videocon Industries Ltd., Aurangabad, India) at a speed of 1250 rpm for 180 s. The two separate slurries were combined and mixed with a hand blender. The humidity in the room during sample preparation was measured using a digital hygrometer (TEMPT-EC, Mumbai, India) and found to be in the range of 50 - 55% RH. The batter was then fermented naturally at a temperature of 30°C for 16 hr. The fermented batter was poured into the cake cups in the mold. These cups were 3 inches in diameter and 1 inch in depth. Weight of batter in each cup was approximately 20 - 25g. Four batches were prepared. These molds were loaded in an autoclave and steamed for 300 s. The cakes were was cooled on the pan at room temperature and removed individually. They were then packed in separate zip pouches and labeled.

Xanthan gum was procured from Omni, India. The stabilizers were incorporated in the batter before fermentation. Weighed amount of the stabilizer was mixed in a small amount of water and solubilized. The stabilizer solution was mixed well with the freshly ground batter and homogenized with a hand blender to distribute the stabilizer uniformly in the batter.

### Physical properties of batter and steamed rice cakes

Density and pH measurements of the batter having a blend ratio of 3:1 (parboiled rice:black gram), were carried out at different fermentation times. The pH of the batter at different fermentation was recorded using a digital pH meter (Model ARX 17E, Serial No. 7146, CD Instrumental Pvt. Ltd.). Bulk density (kg.m$^{-3}$) was measured by seed displacement method using mustard seeds.

### Fundamental rheological measurements

Rheological measurements were made on fermented batter. A controlled shear/stress rheometer (Anton Paar, MCR 301, GmbH, Germany) equipped with parallel plate (25 mm diameter, 1 mm gap) measuring system (PP25-SN14205) was used in the study. Rheological characterization was carried out using both shear flow and oscillatory tests. The sample was prevented from drying during the test by applying silicone oil at its edges.

### Flow curves

Shear measurements (flow curves) were performed to evaluate the flow behavior of batter. Shear stress ( $\tau$ ) was measured as a function of shear rate over the range 1-100 s$^{-1}$ at 25°C. Apparent viscosity was measured as a function of shear rate over the range 0.01 - 1000 s$^{-1}$ at 25°C. Apparent viscosity was reported as the mean of three replicates on each sample.

### Small amplitude oscillatory sweep (SAOS) experiments

The viscoelastic behavior of batter was characterized using an oscillatory rheological experiment where both stress and strain commonly present a sinusoidal variation. At first, a strain sweep test (0.001 - 100%), also called as the small amplitude oscillatory shear (SAOS) test, was done keeping the frequency constant (5 rad s$^{-1}$) in order to know the linear viscoelastic region. A small amount of batter was deposited on the plate and allowed to rest for 120 s, allowing any normal stresses to relax. Linear viscoelastic region (LVR) is known as the region where the stress is proportional to strain. It was found that below 0.1% strain, the batter showed linear behavior i.e. the test is non-destructive in nature. The test also allows measurement of the relative contributions of elastic (G′, storage modulus) and viscous (G″, loss modulus) response of materials. The frequency was varied between 1-100 rad s$^{-1}$. The storage modulus is a measure of the energy stored in the material and recovered from it per cycle while the loss modulus is the measure of the energy dissipated or lost per cycle of sinusoidal deformation [13]. Frequency sweep experiments were also performed. All samples possessed higher G′ values than G″ .

### Thermo-rheological properties of rice cake batter

Dynamic rheological tests were performed for the continuous measurement of dynamic moduli (G′, G″) during temperature sweep testing of the batter. The temperature was elevated and precisely controlled by a Peltier system that was part of the rheometer. Silicone oil was used to minimize water evaporation from the sample. For temperature sweep experiments, the temperature was raised at a ramp rate of 2°C min$^{-1}$, and viscoelastic parameters were measured as a function of temperature. For both experiments, the strain was set below 0.1%, and the frequency was fixed at 5 rad s$^{-1}$, where $\omega$ is the angular frequency. The test was performed to determine sample behavior at constant frequency and strain in the temperature range 20 - 100°C. The development and demise of moduli values and the change in viscosity was monitored.

### Pore size distribution in steamed rice cakes using image analysis

Thin slices were cut horizontally and were placed over the glass of the scanner (HP scan-jet) having a resolution of 600 dpi (dots per inch). The scanned image was analyzed using the ImageJ software. The brightness and contrast was adjusted. A grey level threshold of 180 - 190 was usually chosen to extract data from background. Using bars of known lengths, pixel values were converted into distance units. In order to generate the pore size distribution, the frequency of discrete bubble sizes was tabulated in ascending order. The results were analyzed to obtain the size distribution plots.

### Texture profile analysis (TPA) of steamed rice cake

Texture profile analysis is also known as the two-bite test. It provides textural parameters which correlate well with sensory evaluation parameters (Bourne 2002). Idli has a circular shape of approximately 7 - 10 cm diameter, with lower and upper surface bulging, so that the product is thick at the center (2 - 3 cm) and tapering towards periphery. The texture of rice cakes was analyzed using TA-XTplus, Texture analyzer from Stable Microsystems (Surrey, UK). The software used was Texture expert 32. The cut test was conducted in the center where the average thickness is, 2 - 3 cm using knife probe (TA-8) in the normal mode at 2 mm/s up to a depth of 10 mm. Texture was expressed as the load in grams required to cut the product. The instrument was calibrated with a 50 kg load cell. Several parameters such as hardness, chewiness, springiness were calculated based on the deformation curves. Among the several textural parameters, hardness and chewiness and springiness were selected to represent the results because of their repeatability and reasonable variations.

### Microscopy: Confocal laser scanning microscopy (CLSM) and environmental scanning electron microscopy (ESEM)

Confocal laser scanning microscope (Olympus IX-81, Japan) and environmental scanning electron microscope (ESEM, Quanta 200) were used to observe the microstructure of batter and steamed rice cakes. For CLSM, 2-3 ml of the rice cake batter was taken immediately after mixing (before fermentation) and thin sections, approximately 1 - 2 mm in thickness were excised from the center of the steamed rice cake using a pathology blade lightly greased with mineral oil. The samples were dyed with fluorescein isocyanate, specific for protein. The thin section of steamed cakes were fixed in a 1% glutaraldehyde, 4% paraformaldehyde in 0.05M potassium phosphate buffer, pH 6.8 for 1 h at room temperature. The fixing solution was removed by rinsing with the 0.05 M potassium phosphate buffer, and the samples were dehydrated in a graded ethanol series 15 min each in 10, 30, 50, 70, 90, 95, and 100% ethanol [14]. Each of the prepared samples were examined under the microscope.

For ESEM, the steamed rice cake samples were mounted on circular aluminum stubs with double-sided sticky tape. ESEM allowed cake batter and steamed cake to be studied in its natural hydrated state, without undergoing any drying or coating. The microstructure of rice-cakes was also observed at smaller length scales (10 μ m) using ESEM. The mucilaginous nature of black gram is identified as arabinogalactan and was seen in the ESEM image. The starch granule size varied between 3 - 5.3 μ m.

### Statistical Analysis

All batter systems and samples of steamed rice cakes were prepared and tested at least three times in a completely randomized design. The data was analyzed using statistical software (Jandel Sigmastat, for windows version 2.03). The means reported are statistically significant at the 95% confidence level ($p < 0.05$, by one-way analysis of variance).

## Results and Discussion

### Rice batter properties

The density varied between 1050 (0 hr) and 590 kg $m^{-3}$ (16 hr), because of the entrapment of gases in the batter density. It was found that the pH drops drastically from 6 to 4.2, as the fermentation time increases. Ghosh and Chattopadhyay [15] found similar trend in the pH (5.9 - 4.2). The bulk density of fresh steamed cakes was 610 ± 0.02, whereas the density of XG added cakes was 555 ± 0.02 $kg^{-3}$.

### CLSM and ESEM

The micrographs of CLSM show increased mean pore cross section diameter (Figure 1 B, rice cake batter) than that shown in Figure 1 A (steamed rice cakes). The mucilaginous nature of black gram was seen in the ESEM image (Figure 1D) identified as arabinogalactan polysaccharide. ESEM micrograph (Figure 1C) shows hydrated cake batter, while Figure 1 D shows swollen starch granules with size varying between 3 - 5.3 μ m.

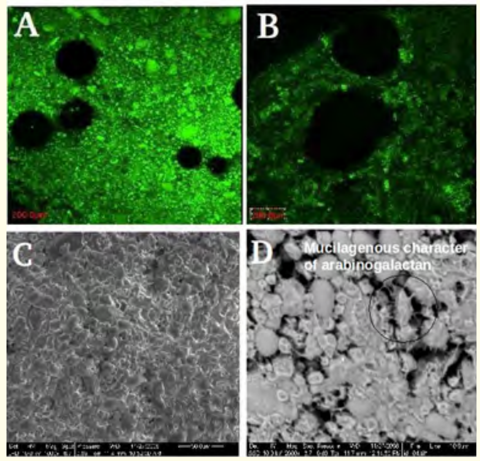


***Figure 1:*** *CLSM image of rice cake batter (A) and steamed rice cakes (B) at a scale of 200 µm. ESEM image of cake batter at a scale of 50 µm (C) and steamed rice cake at a scale of) (D).*

**Flow curve of rice cake batter**

The data for shear stress ( $\tau$ ) and shear rate ( $\gamma$ ) was plotted (Figure 2) and the flow behavior index (n) and consistency index (k) and of batter for a blend ratio of 3:1, were calculated from the power law equation (Oswald-de Waele model).

$\tau = k\,\gamma^{n}$ (1)

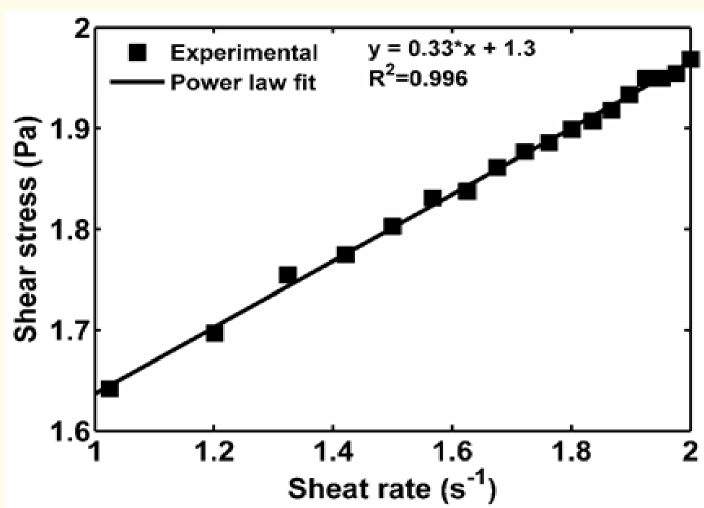


***Figure 2:*** *Flow curve of rice cake batter showing the shear thinning behavior fitted to the power law model. The measurements were made in triplicates.*

The power law model fitted the data well ($r^2$=0.996) and the flow behavior index was found to be 0.33 ± 0.04, which indicated non-Newtonian behavior of the batter. The measurements were made in triplicates. The batter was therefore found to be pseudoplastic (shear thinning) in nature. Shearing causes entangled long chain molecules to straighten out and become aligned with the flow, reducing viscosity.

Batter viscosity decreased with increasing shear rate, revealing the shear thinning characteristics of the batter (Figure 3). At $\gamma < 1\ s^{-1}$, the batter showed plateau of zero-shear viscosity (linear regression analysis). The zero-shear viscosity is the value of the apparent viscosity in the limit of zero shear rates (i.e. when the fluid is at rest). Viscosity curves of polymers with linear chain without interaction forces often show a zero shear viscosity plateau. In the physical terms, it represents the ability of the material to avoid sedimentation during storage. A high zero shear viscosity means that the fluid is homogeneous during longer storage.

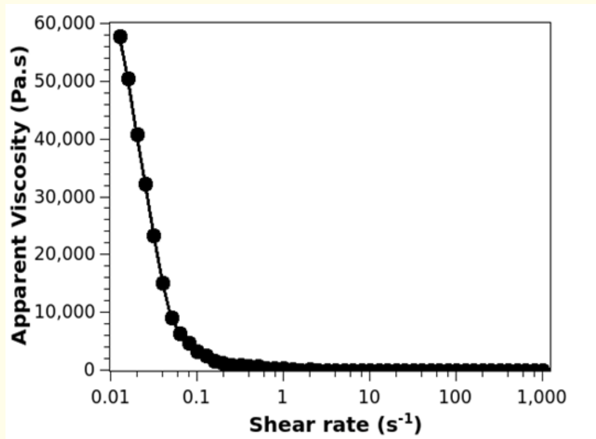


***Figure 3:*** *Apparent viscosity of rice cake batter with a blend ratio 3:1 (parboiled rice:black gram) subjected to 16 h. fermentation at 30°C. The measurements were made in three replicates.*

## Small amplitude oscillatory sweep (SAOS) experiments

### Frequency sweep

The LVR determined from the strain sweep experiments is used to locate the plateau in which the values of G′ and G″ are nearly constant (Figure 4A). A percent strain below 0.1% in that region and the corresponding frequency of 5 rad s-1 is used for the subsequent analyses. At a strain of 15.45%, G′=G″, and this is called the 'gel point'. This indicates viscoelastic nature of the batter. Microscopically, at the gel point you have creation of a 3D network throughout the sample that can support itself. Dynamic mechanical behavior of batter was investigated by varying the frequency between 1 and 100 $s^{-1}$ (Figure 4B). It is seen that over the frequency range investigated, G′ is higher than G″ indicating that the batter exhibits a viscoelastic behavior, with solid-like characteristics [16,17]. This suggests the systems behaves more like a solid [18]. Also, G′ and G″ are parallel to each other which indicates strong gel-like character [19].

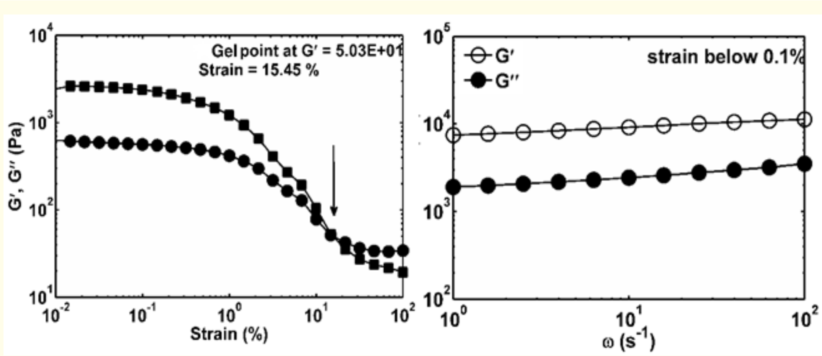


***Figure 4:*** *(A) Dynamic strain sweep test and (B) Dynamic frequency sweep test of rice cake batter with a blend ratio 3:1 (parboiled rice:black gram) subjected to 16 h. fermentation at 30°C.*

### Thermo-rheological properties

The onset temperature of gelatinization and the subsequent change in the moduli values (G′, G″) with temperature was monitored for the batter using a temperature ramp (Figure 5). The storage modulus and the loss modulus exhibited similar trend. There was no significant elastic response (G′) below 50 °C. This phase is supposed to be amylose-rich since amylose leaches out of the starch granules due to the combined effect of heat and water absorption. The softening point, point where granule aggregate formation results in a measurable increase in viscosity, as evidenced by the increase of G′, is found to be 49 - 50 °C. This is where the internal structure of the sample begins to soften. High G′ value indicates a well cross-linked network structure [20] and increases elastic properties. Starch gelatinization results in the network formation during which batter transforms from liquid to solid-like structure. As indicated by Ring [21], the gelatinized starch granules could strengthen the gel network built by amylose. Further heating causes the G′ to decrease indicating destruction of the network, possibly due to melting of the crystalline regions remaining in the swollen starch granules or results from disentanglement of the amylopectin molecules that softens them [22,23]. The peak height in Figure 5 corresponds to the maximum concentration of the swollen starch granules and the maximum viscosity just before their physical breakdown on cooking [24].

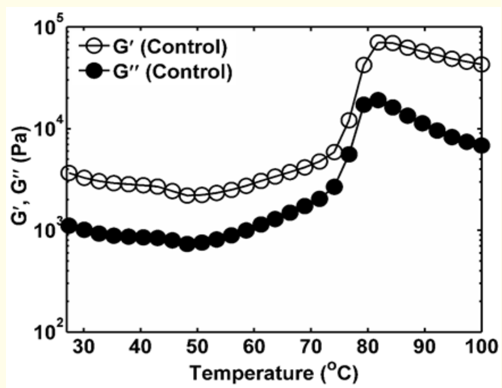


***Figure 5:*** *Temperature ramp test for rice cake batter with a blend ratio 3:1 (parboiled rice:black gram) subjected to 16 h. fermentation at 30°C.*

### Effect of xanthan gum on rheology, microstructure and texture of steamed rice cakes

Dynamic frequency sweep experiments were done with xanthan gum (XG) at 0.1% concentration. G′ values greater than G″ is typical of a biopolymer gel behavior [25]. It was found that on addition of XG the moduli values decreased. All samples exhibited a dominant elastic behavior since G′ was larger than G″ over the studied frequency range. Hydrocolloids modify the dynamic spectra although different trends may be induced in different systems.

The dynamic rheological properties of batter with and without addition of xanthan gum is shown in Figure 6. Decreased moduli values (G′, G″) for XG mean that there is reduction in firmness and elasticity of the batter leading to soft and spongy rice cakes (Table 1). The apparent viscosity of batter with and without addition of xanthan gum was 4.4 Pa.s and 3.8 Pa.s, respectively at a shear rate of 100 $s^{-1}$. Nisha and others (2005) also observed a similar trend of increase in batter viscosity. Xanthan gum, as a hydrocolloid is known to stabilize foam by increasing the viscosity of the rice-cake batter which in turn results in more air holding capacity leading to decrease in hardness [10]. The bulk density of fresh steamed cakes was 610 ± 0.02, whereas the density of XG added cakes was 555 ± 0.02 kg $m^{-3}$.

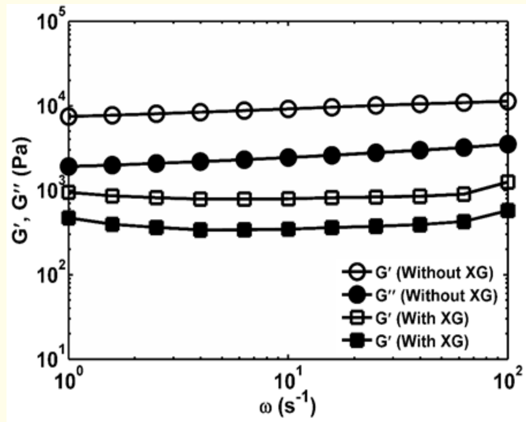


***Figure 6:*** *Dynamic frequency sweep test of rice cake batter showing variation of G' and G'' with and without xanthan gum.*

Comparison of the pore size distribution (Figure 7) in rice containing XG to the one without XG showed that the distribution of the former was narrower compared to the control (without XG). This effect may be because of the greater resistance of the product to drainage as a result of addition of xanthan gum. The mean pore size showed an increasing trend from 406 ± 18.6 – 466 ± 7.8 μ m with the addition of XG. The values reported are based on all the experiments. Thus, decreased moduli values and larger mean pore size resulted in softer rice-cakes. Rice cakes made without XG had higher G' values and lower mean pore size. Also, the texture profile analysis showed that the rice-cakes containing XG have less hardness, gumminess and chewiness than the control (Table 1). The effect could be presumably attributed to the higher water binding capacity and higher viscosity leading to higher air incorporation [10].

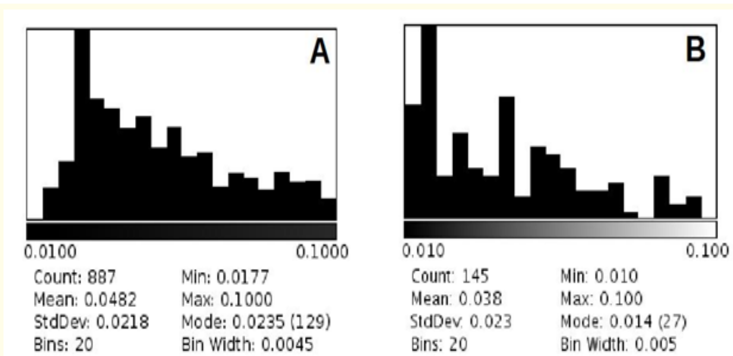


***Figure 7:*** *Pore size distribution in steamed rice cake with (A) and without (B) xanthan gum (XG). The mean values reported are in cm (Multiply by 104 to convert to mm). The distribution reported is mean of five replicates. Count: No. of cells /image; Min & Max: Width of distribution; Mode: peak of distribution.*

| TPA parameters | Without Xanthan gum | With Xanthan gum |
|---|---|---|
| Hardness (g) | 2258.7 ± 0.05 | 880.8 ± 0.03 |
| Chewiness | 1641.5 ± 0.04 | 450.7 ± 0.03 |
| Springiness | 0.9 ± 0.02 | 0.5 ± 0.01 |
| Cohesiveness | 0.7 ± 0.02 | 0.9 ± 0.01 |
| Resilience | 0.4 ± 0.03 | 0.6 ± 0.03 |

***Table 1:*** *Comparison of the texture profile analysis of steamed rice cake with and without xanthan gum. Values reported are mean of five determinations and significantly different from each other ($p < 0.05$).*

**Effect of different steaming times on texture and microstructure of steamed rice-cakes**

The TPA of rice-cake was performed for steaming times of 300, 600 and 900 s. As the steaming time increased, the hardness, gumminess and chewiness of the rice-cakes increased. Thus, 300 s steamed rice-cakes were softer than those steamed for 600 s and 900 s (Table 2). The pore size distribution data at different cooking times is shown in figure 8. Mean pore size decreased from 406 ± 18.6 – 335 ± 7.8 μ m. The differences between the mean pore size at steaming times of 300, 600 s and 900 are significant ($p < 0.05$). The values reported are based on all the experiments carried out. The moisture content in rice-cakes decreased from 66% to 63% with increase in steaming time. This means that the free water present in the batter is absorbed by the starch in the rice and the black gram lentil.

| TPA parameters | 300 s | 600 s | 900 s |
|---|---|---|---|
| Hardness (g) | 2258.7 ± 0.05 | 2628.2 ± 0.02 | 4000.1 ± 0.04 |
| Springiness | 0.9 ± 0.02 | 0.9 ± 0.01 | 0.9 ± 0.01 |
| Cohesiveness | 0.7 ± 0.02 | 0.8 ± 0.01 | 0.8 ± 0.03 |
| Resilience | 0.4 ± 0.03 | 0.5 ± 0.02 | 0.6 ± 0.01 |

***Table 2:*** *Comparison of the texture profile analysis of steamed rice cake at different steaming times. Values reported are mean of five determinations and significantly different from each other (p < 0.05).*

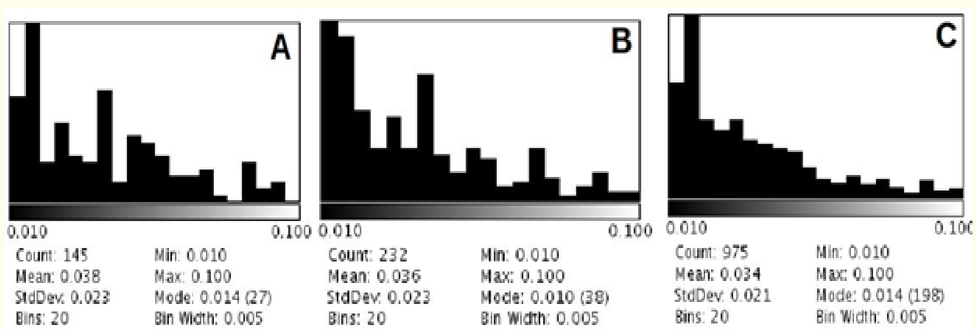


***Figure 8:*** *Pore size distribution in steamed rice cake at different steaming times. (A) 300, (B) 600 , (C) 900 s. The mean values reported are in cm. The mean values reported are in cm (Multiply by 104 to convert to mm). The distribution reported is mean of five replicates. Count: No. of cells /image; Min & Max: Width of distribution; Mode: peak of distribution.*

## Conclusions

Steamed rice cakes are disperse systems consisting of (semi-) solid phase with starch granules and sometimes other solid grain constituents being integrated and a gaseous phase. These phases form a cross-linked network which decisively determine the rheological behavior of the system. Foam structure has been quantified by measuring the pore size and size distribution data along with rheological characterization using small amplitude oscillatory rheometry to provide a more comprehensive description of these type of systems. Flow behavior studies exhibited the shear thinning and viscoelastic behavior of batter. Dynamic rheological tests allow continuous measurement of dynamic moduli during the physical transformations taking place as a result of temperature. The temperature ramp test showed that the onset temperature of gelatinization is 49°C and the G′max occurs at 81.8°C (gelatinization temperature). Addition of 0.1% preswelled xanthan gum gave softer rice-cakes with decreased moduli values (G', G'') and larger mean pore size. Xanthan gum addition aids in a more uniform size distribution. Thus, the shear modulus is found to be inversely proportional to the pore size. Texture profile analysis showed that as the steaming time increased, rice cakes became harder with smaller mean pore size and decreased moisture content. Rice cakes steamed at 300 s were softer with the highest mean pore size and those steamed at 900 s were harder with lowest mean pore size.

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**Volume 8 Issue 2 April 2017**