Studies in rheological behavior of rice flour dough prepared with varied amount of water – Used to prepare extruded products and rice cakes

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Abstract
Rice is largely grown in Southeast Asia region to prepare various food products. Rice flour dough containing about 24-32% water is largely used to prepare rice cakes and extruded products. In this research work an investigation is made into the rheological behavior and rheological model fitting of the rice flour dough samples prepared using 24, 28 and 32% water. Flour was analyzed for water solubility index and water absorption index, whereas, the dough samples were analyzed for degree of gelatinization and thermal properties. It was determined that the dough samples exhibited shear-thinning behavior. Of the general models tried – Power Law, Bingham Plastic and Herschel-Bulkley, Herschel-Bulkley model best fitted the flow behavior of the dough samples. Yield stress and liquid consistency index decreased, whereas, flow behavior index increased with increase in the quantity of water in the dough. It was also determined that the values of degree of gelatinization, endothermic heat and peak temperature decreased with increase in the water content in the dough. The reason for the decrease is attributed to the plasticization effect caused by the water molecules in the dough samples.

Key words: rice flour, dough, Herschel-Bulkley Model, yield stress, rheology

1. Introduction
Rice (Oryza sativa) is a largely produced food crop in South East Asia. It is used for preparing food products like pasta [1], phirni [2], idli [3], soups [4], dosa [5], spaghetti [6], porridges [7], etc. It is also used for brewing [8]. Rice is favorable due to its features like: containing no gluten, low in sodium and low in protein constituents. [9] low levels of fat and fibre, high amount of easily digestible carbohydrates.

Studies in the rheological behavior of doughs prepared from flours of rice [10], maize [11], wheat [12], bajra [13], bengal gram [14], black gram [15] etc. is important for: product development, sensory assessment, quality control, process design, product standardization process scale up, [16] design of food processes, processing equipment and, understanding the structure of the food materials. [17] Sivaramakrishnan et al. [18] studied the effect of addition of hydrocolloid like hydroxyl propyl methyl cellulose (HPMC) on the rheological properties of dough used for making bread. Lazaridou et al. [19] analyzed the rheological behavior of the rice flour dough prepared by the addition of hydrocolloids like pectin, carboxymethylcellulose (CMC), agarose, xanthan and oat β-glucan. Sozer [20] investigated the creep-recovery and dynamic oscillation measurements of the guar gum, casein and egg white stabilized rice pasta dough. Torbica et al. [21] produced gluten-free bread formulations using rice flour dough by adding with husked and unhusked buckwheat flour showing improved storage modulus and yield stress values.

However, there is no study reported regarding the effect of water content on the rheological behaviour of rice flour dough used for making rice cake and extruded products. Rice cakes and rice extruded products are generally prepared by adding about 24-32% water. [22] The objective of the present research is to investigate the rheological behavior of rice flour dough prepared with varying quantity of water used for preparing the above mentioned products.
Rice flour was characterized for proximate analysis, water solubility index and water absorption index, whereas the dough prepared with varied quantity of water (24, 28 and 32%) was characterized for degree of gelatinization by differential scanning calorimetry and chemical method, and rheological analysis consisting of plots of viscosity vs shear rate and model fitting.

2. Materials and Methods
2.1 Materials
Commercial rice (variety: Ratna) was procured from Dahivali Rice and Pulse Mills, Karjat, Maharashtra, India; and was milled in a laboratory mill. Proximate composition of rice flour, determined as per AOAC [23], is listed in Table 1. The particle size of the rice flour was maintained between 422 and 354 μm. Distilled water was obtained from Bio Lab Diagnostics India Pvt. Ltd., Mumbai, India.

2.2 Methods
2.2.1 Preparation of rice flour dough
100 g rice flour was added with varied quantity of distilled water (24, 28 and 32 w/v of the total weight of rice flour) and mixed using a glass rod in a 500 ml beaker. Room temperature and relative humidity were maintained constant at 37 ± 2°C and 70 ± 5%, respectively. Mixing was carried out for about 5 min. Prepared dough was characterized for rheological properties.

2.3 Characterization and Testing
2.3.1 Water solubility index and Water absorption index
Water solubility index (WSI) of the flour was determined following the method of Anderson et al. [24]. 30 mL of distilled water was mixed with 2.5 g of flour for 30 min using a magnetic agitator at 500 rpm (Remi, India). This suspension was centrifuged at 3000 rpm for 10 min (Remi Centrifuge, India). The liquid phase was placed in a petri dish and dried at 105°C until constant mass was obtained. WSI was determined from the dry sample using the following formula:

\[
\text{WSI} = \left(\frac{\text{Mass of the dry sample}}{\text{Initial weight of the sample}}\right) \times 100
\]

The remaining gel was weighed and the water absorption index (WAI) was calculated as follows:

\[
\text{WAI} = \left(\frac{\text{Mass of liquid}}{\text{Dry sample mass}}\right) \times 100
\]

2.3.2 Analysis of Degree of gelatinization by Chemical Method
The degree of gelatinization of the rice flour dough, prepared using 24, 28 and 32% water, was measured according to the method reported by Birch and Priestly [25]. The dough samples were dried in oven at 58°C. 0.2 g of dough sample was taken in a 125 ml Erlenmeyer flasks and was added with 98 ml distilled water and 2 ml of KOH (10 M); and then mixed for 5 minutes prior to centrifugation at 3000 rpm for 15 min. 1 ml of the supernatant was pipetted and was added with 0.4 ml hydrochloric acid (0.5M) followed by the addition of 10 ml distilled water and 0.1 ml iodine solution. The mixture was homogenized and then measured for absorbance at 600 nm. The degree of gelatinization of standard starch was determined in the same manner to obtain the standard curve of rice and applied to calculate degree of gelatinization of sample.

2.3.3 Differential Scanning Calorimetry (DSC)
A TA-60WS DSC (Shimadzu Analytical Pvt. Ltd., Singapore) was utilized to measure the degree of gelatinization properties for the sample. 20 mg wheat batter sample was transferred into a DSC pan. The pan was hermetically sealed and inserted in the calorimeter. Thermal curves included onset temperature (T<sub>o</sub>), peak temperature (T<sub>p</sub>), endothermic peak area (H<sub>e</sub>) and endset temperature (T<sub>e</sub>). Heating rate was maintained at 10°C/min from 30 to 250°C. DSC-60 software, supplied by the instrument manufacturer, was used to determine the mentioned temperatures and peak area. The software drew a tangent line at the steepest point of the DSC curve and a baseline connecting the starting and the ending points of the peak. The intersections of the baseline with the DSC curve determined the onset and ending temperatures. Gelatinization energy (endothermic peak area, H<sub>e</sub>) was calculated by drawing a straight line between onset temperature and ending temperature and was recorded as J/g.

2.3.4 Rheological analysis
A rheometer (MCR 101, Anton Paar, Austria) with a parallel plate assembly was used to analyze the rheological behavior of the prepared rice dough samples. Parallel plates (diameter: 35 mm, PP35-SN20785) were separated by a distance of 1 mm during the rheological analysis. The rheological data analysis was performed using Rheoplus/32V3.40 software supplied by the manufacturer. A temperature of 37±0.5°C was maintained constant during the rheological measurement. Dough samples were set on the rheological peltier for 3 min of relaxation time before every measurement. Grease was applied on the exposed surface of samples to prevent sample dehydration. Twenty five shear-stress/shear-rate data points were obtained, at 6 points/decade, during the shearing of the samples from 0.01 s<sup>−1</sup> up to 100 s<sup>−1</sup> shear rate within the experimental time of 200 s. [26] The whole process of sample preparation was repeated twice, while all rheological investigations were performed on triplicate samples. Shear-stress and shear-rate data were fitted to the rheological models like Power law (Equation 1), Herschel-Bulkley (Equation 2), Bingham plastic (Equation 3). The flow behavior index and fluid consistency index for the

### Table 1: Proximate composition of rice flour (variety: Ratna)

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Constituent</th>
<th>Mean ± S.D. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Moisture</td>
<td>8.0 ± 0.5</td>
</tr>
<tr>
<td>2.</td>
<td>Fat</td>
<td>1.6 ± 0.4</td>
</tr>
<tr>
<td>3.</td>
<td>Protein</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>4.</td>
<td>Ash Content</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>5.</td>
<td>Crude Fibre Content</td>
<td>1.6 ± 0.4</td>
</tr>
<tr>
<td>6.</td>
<td>Carbohydrate by difference</td>
<td>86.6 ± 1.8</td>
</tr>
</tbody>
</table>

S.D. = Standard Deviation (n=3)
best-fitted equation was estimated by employing a non-linear regression analysis of viscosity/shear-rate data using the software (Rheoplus/32V3.40) supplied by the equipment manufacturer.

\[ \sigma = k \gamma^n \]  
\[ \sigma = \sigma_0 + k \gamma^n \]  
\[ \sigma = \sigma_B + n \gamma \]  

(Equation 1) \hspace{1cm} (Equation 2) \hspace{1cm} (Equation 3)

Where, \( \sigma \) is shear-stress (Pa), \( \gamma \) is shear-rate (s\(^{-1}\)), \( k \) is fluid consistency index (Pa.s\(^n\)), \( n \) is flow behavior index (dimensionless), and \( \sigma_0 \) is the yield stress (Pa); the subscripts P, HB and B indicate for Power law, Herschel-Bulkley and Bingham plastic models respectively.

Suitability of the rheological models was judged by determining the regression coefficient (R\(^2\)).

3. Results and discussion

3.1 Water solubility index and Water absorption index for rice flour

WAI and WSI values obtained for the rice flour are tabulated in Table 2.

<table>
<thead>
<tr>
<th>WAI (%)</th>
<th>WSI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.40 ± 1.3</td>
<td>1.62 ± 0.11</td>
</tr>
</tbody>
</table>

Table 2: WAI and WSI values obtained for the prepared rice flour

3.2 Analysis of Degree of gelatinization by Chemical Method

The effect of water content on the degree of gelatinization of rice flour dough by chemical method is shown in Fig. 1. The degree of gelatinization of rice flour dough prepared with varying quantity of water ranged as 113, 106 and 96%. The gelatinization of rice flour dough depends on time, amount of water and process [27]. Degree of gelatinization decreased with increase in water content in the rice flour dough. Water becomes easily available to the starch molecules in rice with increase in the water. Thus, the starch molecules get more water to absorb. Thus, gelatinization will be faster, decreasing the degree of gelatinization.

3.3 Rheological analysis

Fig. 2 depicts the plot of shear stress (Pa) vs shear rate (s\(^{-1}\)) obtained for the prepared rice flour dough samples. It was determined that the shear stress of the samples decreased with increase in shear rate. Thus, all the prepared dough samples depicted shear thinning behavior. The yield stress of the samples decreased with increase in water content in the doughs prepared. This was attributed to the plasticization effect induced by the water molecules in the dough, making it able to flow easily. Yield stress of the dough samples decreased from 9,500 Pa for dough prepared with 24% water to 8,000 and 6,000 Pa for the dough samples prepared using 28 and 32% water. Increased quantity of water, made the dough carbohydrate molecules (major component of rice) get more separated from each other, decreasing the yield stress values. It was also determined that the decrease in shear stress was drastic after a certain shear rate. This point of drastic decrease shifted towards left (i.e. lower shear rate) with increase in the quantity of the water in the dough. This was again attributed to the plasticization effect induced by the water molecules in the dough. Increased water content, made the dough get more plasticized, decreasing its ability to resist the rotation of the spindle. More the water content, easier it is to destruct the molecular arrangement of the dough. The point of drastic decrease in shear stress shifted from 20 s\(^{-1}\) shear rate for dough containing 24% water to 8 s\(^{-1}\) shear rate for dough prepared with 28% water and to 5 s\(^{-1}\) shear rate for the dough prepared using 32% water.

Fig. 3 is a plot of viscosity vs shear rate obtained for the prepared rice flour dough samples. Similar to the shear stress vs shear rate plot (Fig. 1), viscosity of the dough decreased with increase in shear rate, depicting shear-thinning behavior. Shape of the curve is very similar to the shear stress vs shear rate plot. Zero shear viscosity of the dough samples decreased with increase in the water content in the dough, which was attributed to the plasticization effect induced by the water molecules. Zero shear viscosity decreased from 1,00,000 Pa.s for dough prepared using 24% water to 70,000 Pa.s and 50,000 Pa.s for dough samples prepared using 28 and 32% water. The point of drastic decrease for the samples shifted towards left (lower
Table 3: Yield stress, k and n values obtained for the dough samples prepared with varying quantity of water fitted with Herschel-Bulkley model.

<table>
<thead>
<tr>
<th>Water content</th>
<th>Flow behavior index (n)</th>
<th>Fluid consistency index (k)</th>
<th>Yield stress (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24%</td>
<td>0.62</td>
<td>1822.5</td>
<td>9606.9</td>
</tr>
<tr>
<td>28%</td>
<td>0.73</td>
<td>729.2</td>
<td>77982.1</td>
</tr>
<tr>
<td>32%</td>
<td>0.79</td>
<td>547.5</td>
<td>4981.9</td>
</tr>
</tbody>
</table>

Table 4: Thermal characterization of prepared dough samples

<table>
<thead>
<tr>
<th>Water content</th>
<th>Endothermic Heat (J/g)</th>
<th>Peak Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24%</td>
<td>84.87 J/g</td>
<td>111.02</td>
</tr>
<tr>
<td>28%</td>
<td>56.82 J/g</td>
<td>105.32</td>
</tr>
<tr>
<td>32%</td>
<td>23.48 J/g</td>
<td>93.75</td>
</tr>
</tbody>
</table>

Fig. 3 Plot of viscosity (Pa.s) vs shear rate (s⁻¹) obtained for the prepared rice flour dough samples

Fig. 4 Model fitting of Bingham plastic and Power Law model to the experimental data obtained for 24% water containing rice flour dough

Fig. 5 Model fitting of Herschel-Bulkley model to the experimental data obtained for 24% water containing rice flour dough

shear rate) with increase in the shear rate. The point of drastic decrease was same as that obtained for the plot of shear stress vs shear rate.

Among the common rheological models attempted, the suitability of Herschel-Bulkley (with experimental stress values) was superior to power law and bingham plastic models. (Fig. 4 and 5). The values of regression coefficient obtained for power law, bingham plastic and Herschel-Bulkley model were 0.9654, 0.9438 and 0.9698 respectively. Values of yield stress, fluid consistency index (k) and flow behavior index (n) obtained for the dough samples prepared with varying quantity of water fitted with Herschel-Bulkley model are listed in Table 3. It was determined that flow behavior index (n) increased, whereas, fluid consistency index and yield stress values decreased with increase in concentration of water in making the dough using rice flour.

3.4 Differential Scanning Calorimetry (DSC)

Endothermic heat (J/g) and peak temperature (°C) values obtained for the prepared rice flour dough samples are reported in Table 4. It was determined that the endothermic heat and peak temperature values decreased with increase in water content in the dough. Endothermic heat value decreased from 84.87 to 23.48 J/g, which is a decrease of about 72%; whereas, peak temperature decreased from 111.02 to 93.75 °C, which is a decrease of about 15%, for an water increase from 24 to 32% in the preparation of the rice flour dough. This decrease is quite appreciable compared to the extra amount of water added. This was attributed to the plasticization effect induced by the water molecules in the dough, making the dough get loosened up, decreasing the endothermic heat and peak temperature. [27]

4. Conclusion

Dough was prepared using rice flour and varied quantity of water – 24, 28 and 32% water. Rice flour was characterized for water absorption index and water solubility index; whereas, dough samples were characterized for degree of gelatinization, thermal properties, viscosity vs shear rate, shear stress vs shear rate and rheological model fitting. It was determined that the dough samples exhibited shear-thinning behavior. Also, the degree of gelatinization, endothermic heat and peak temperature values decreased with increase in the water content in the dough. Herschel-Bulkley model best fitted the flow behavior of the dough samples. Fluid consistency index and yield stress values decreased, whereas, flow behavior index increased with
increase in water content in the dough.

5. References

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