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A comparative study of flow properties of basmati and non-basmati rice flour from two different mills

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A B S T R A C T

The flowability of basmati and non-basmati rice flour from stone and super mill was compared. On comparing, both basmati and non-basmati rice flour from stone mill was found poor flowable. However, non-basmati flour was less flowable than basmati flour. Particle size (stone mill (StM) 114.1–129.6 μm, super mill (SM) 196.4–239.5 μm) of both the flours was significantly different. The flowability of basmati and non-basmati rice flour was significantly affected by properties *viz.*, for non-basmati flour: the particle shape circularity (StM 0.562, SM 0.642), surface roughness (StM 146.36 nm, SM 111.28 nm) and compressibility (StM 26.08%, SM 24.22%), making it less flowable than basmati flour: particle shape circularity (StM 0.661, SM 0.768), surface roughness (StM 122.21 nm, SM 90.67 nm) and compressibility (StM 21.02%, SM 17.18%). Basic flow energy, stability index and specific energy was significantly higher in non-basmati flour, thus required more energy (StM 184.37 mJ, SM 113.15 mJ) to flow than basmati rice flour (StM 151.25 mJ, SM 96.74 mJ). Overall, the flowability was analyzed at three different pressures (3,6 and 9 kPa) and the non-basmati rice flour from stone mill was found less flowable as indicated by the flow function coefficient (1.90 at 3 kPa) in comparison to basmati (2.61 at 3 kPa) creating difficulty in bulk handling.

1. Introduction

All around the world, food powders (e.g. wheat, rice and corn flours) are widely used materials, both in industry and households and are considered as the most difficult materials to characterize. Rice flour is a product obtained from rice milling. Rice milling is the biggest agro-based industry of India with about 1,74,296 rice milling units throughout the country (Goyal et al., 2014). It is being utilized in various productions such as rice noodles, sweets, baby foods and rice cakes (Kim, 2013). Besides its utilization, it is one of the most suitable cereal grain flours for preparing foods for patients with celiac disease (CD) (Arendt and Dal Bello, 2008). The suitability of the rice flour is attributed to its low level of prolamins compared with that of wheat flour (Kim, 2013). Powders and bulk materials cannot be viewed as invariant entities. Their physical properties can differ significantly from supplier to supplier; they may have natural variation through change in compositional proportionality; environmental variation such as humidity could alter their cohesion/adhesion; and of course actually processing/transferring the material from one place to another may change its particle size distribution, morphology or surface texture. All of these factors may significantly impact their process behaviour/response.

With the increasing quantity and variety of powders being produced in industry, there is a need for information about their handling and processing characteristics, especially for food powders, because of their complexity. The flowability of powders and their flow behaviour are important in handling and processing operations, such as transportation, formulation and mixing, compression and packaging. Thus, the characterization of powders and bulk solids regarding their flow properties plays an important role, e.g., for product development and optimization, customer support and the response to customer complaints. Because flowability is multidimensional for its dependency on physical and chemical characteristics, type of equipment, process flow, etc., its quantification is also a complex task. There are various factors which affects the flowability of the powders. Moisture may be considered as one among them as it tends to make powders more cohesive, however, above a certain levels; the moisture may act as a lubricant and improve flow. Likewise, reducing particle size tends

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to reduce flowability, because the particle surface area per unit mass increases as particle size decreases, providing a greater surface area for surface cohesive forces to interact and resulting in more cohesive flow. Moreover, increased temperature in the range of 10–30 °C, where most fat melting occurs, can also increase powder cohesiveness in powders with significant fat content due to the formation of liquid fat bridges between particles. Increasing temperature will tend to make components more plastic and thus more cohesive, however, increased temperature may vaporize moisture which will make the powder less cohesive (Fitzpatrick et al., 2007). Particle shape and particle roughness can also influence the flow properties of the powder. The surface roughness of the particle is an important factor which controls the interparticle interaction by Van der Waals forces and mechanical linkages. For example, smoother the surface, greater is the contact among the particles and thus increase in inter-particle forces (Ferrari et al., 2004).

The characterization of powder flow properties is often required for reliable design and proper operation of industrial processes. The effect of the state of compaction on bulk solids flowability is probably the most critical area of understanding. Flowability, being an inherent property, cannot be described by any one value or any single index (Prescott and Barnum, 2000). During various stages of processing, flowability of bulk properties might change significantly, affecting the quality of the final product, but the mechanisms of these changes are hardly understood (Muzzio et al., 2002). Compression, impact, attrition, and cutting are some of the grinding actions applied in the size reduction of particulate material. The type and method of grinding has a profound impact on the physico-chemical characteristics of the rice flours produced (Chen et al., 1999). Very few scientific work has been conducted to investigate the effect of different types of grinding on rice flour (Kim, 2013; Nishita and Bean, 1982) and the present authors have reported the effect of grinding (in stone and super mill) on rice flour flowability in terms of physical, compendial and non-compendial methods (Jan et al., 2016). However, no information is available on the shear and dynamic properties of rice flour ground from stone mill and super mill. Hence, the present research objective was undertaken to characterize and compare the flowability parameters of basmati and non-basmati rice flour milled in stone and super mill with respect to shear and dynamic properties along with particle shape and size as well as surface roughness.

2. Materials and methods

2.1. Sample preparation

The broken rice samples of varieties PR-1509 and PUSA-666 were obtained from Krishi Vigyan Kendra, Sangrur, Punjab, India and were ground in stone mill (S.V. Industries Pvt. Ltd., Ajmer, India) and super mill (Perten Instruments, Huddinge, Sweden). Applied operating conditions of these mills are mentioned as below:

Stone mill- It was a disc type mill with both the discs rotating in opposite direction. The capacity of this mill was 45 kg. The discs rotate at a speed of 4200 rpm. 200 g sample was used with feed rate 70 g/min. The sample was rapidly crushed between the two discs by abrasive forces and the milled rice collected in a sample container. Sample was crushed and passed through a 100 mesh size screen, as the commercial size of the rice flour is in the range of 125–177 μm (Kim, 2013).

Super mill- It was also a disc type mill with one stationary and one rotating disc. The rotating disc rotates at high speed of approximately at 2800 rpm. 200 g sample was used having feed rate 30 g/min. The sample was crushed between the two discs and collected in a container. The grinding coarseness of the milled flour can be varied by changing the gap between the discs (1.7 mm) in the mill.

2.2. Proximate composition

According to AOAC Standards (1995), the milled rice flour samples were analyzed for protein, fat, fiber, and ash content. The moisture content of all the flour samples were kept constant at 11% (wet basis) either by adding requisite percentage of water to the sample or by oven drying.

2.3. Particle size and shape

Particle size of flour samples (both from super and stone mill) were analyzed by Laser diffraction particle size analyzer (Cilas, Model 1190, Madison, WI). Wet mode method was used for the analysis of particle size determination of rice flours 1 g of sample was dispersed in deionised water. Sonic measurements were performed to avoid the aggregation of flours. Based on the particle size distribution (PSD), the particle diameters at cumulative volume percentage of 10% (D_{10}), 50% (D_{50}) and 90% (D_{90}) were used to study the particle characteristics of the samples.

Shape analysis of the basmati and non-basmati flour samples were done by Field emission scanning electron microscope (FESEM) (JEOL JSM 7600 F, Peabody, USA) with working distance (WD) of 4.5–6.0 mm and a voltage of 1.5–2.0 kV. At least 25 images with more than 50 particles were analyzed per sample by using image analysis software ImageJ for shape descriptors like circularity and aspect ratio (Schneider et al., 2012). Circularity is a function of the area divided by the square of the perimeter.

$$Circularity = 4\pi\,X\,\frac{(Area)}{(Perimeter^2)}$$

$$\text{Aspect Ratio} = \frac{Mininimum\ diameter}{Maximum\ diameter}$$

2.4. Surface roughness

The surface topography and roughness of basmati and non-basmati rice flour from both mills (super and stone mill) were measured using an atomic force microscope (NanoScope Digital Instruments, Santa Barbara, USA). Altogether 100 images were analyzed for basmati and non-basmati rice flour particles. Different regions of 5 different particles were scanned for the roughness measurement and the average values were reported. The entire single particle AFM imaging was carried out at ambient conditions (30 °C; 60–75% relative humidity). The images were captured at a scan size of 2 μm and were then analyzed using the accompanying software NanoScope Software 8.10. In the present study, Root mean square (RMS) roughness (Rq) and average roughness R_a (nm) was quantified for a single particle. RMS is defined as standard deviation of the elevation (Z values) within the given area calculated as:

$$\boldsymbol{R_q} = \sqrt{(\boldsymbol{Z_i} - \boldsymbol{Z_{ave}})}\Big/\boldsymbol{N}$$

Where, $\boldsymbol{Z_{ave}}$ is the average of the z values within the given area, $\boldsymbol{Z_i}$ is the z value for a given point, and N is the number of points within the given area. R_a is the absolute values of the height of the surface profile Z(x) and is calculated as: