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Probing Particle Behavior: Characterization of Rice Flour Flowability using FT4 Powder Rheometer

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Abstract: The present study was conducted to characterize the flow properties of the rice flour. A number of powder properties were measured including particle size (65.3µm), bulk and shear properties. Basic flow energy (197.42 mJ) was found higher in rice flour thus, required more energy to flow. Higher compressibility (41.20%) created difficulty in bulk handling by making it more cohesive. Less flow function (2.12) indicated the poor flowability of the rice flour. Overall, flowability of rice flour was found to be poor hence, creating bulk handling difficult.

Keywords: Rice flour, particle size, flowability, shear.

Research Paper

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INTRODUCTION

The major cereal crop and staple food for three quarters of the Indian population is rice. World paddy production in 2016 is 746.8 million tonnes (496.0 million tonnes, milled basis). There are large quantity and variety of food materials produced, stored and handled in powder form in industries, and there is a need for information about their handling. Powders/flours are the least predictable of all materials in relation to flowability. Since the flour/ powder characteristics vary, fundamental understanding on the flow characteristics is far from being completely developed. Lack of understanding leads to process downtime, structural damages and financial losses to the powder handling and processing industry. Even though there has been significant progress made in the recent past to better understand how bulk solid materials act under different conditions inside storage vessels, the literature linking the process behaviour and the specific powder properties is limited. Hence present research focuses on bulk and shear properties of the rice flour whose understanding would aid in the refinement of rice flour handling and storage technologies available with the rice based processing industry.

Rice flour is primarily made from polished broken rice. In cereal industry, rice powders obtained by milling of rice grains are largely used as main raw materials for a large number of food applications. The processing, handling, and production parameters depend on the inherent powder characteristics and their bulk behavior as influenced by environmental conditions. (Ambrose et al., 2016). Bulk behaviour of rice flour during processing and handling such as flow from hoppers and silos, mixing, compression, and packaging are affected by bulk properties, thus measurement of these properties are important (Peleg, 1978; Fitzpatrick et al., 2004). Particle size has a major influence on powder flowability. The reduction in flowability at smaller particle size is due to the increased surface area per unit mass of powder. Jan et al., 2016 has studied the effect of particle shape on the rice flour flowability. This research work focuses on developing a fundamental understanding on the bulk characteristics of the rice flour affecting flowability. Thus, the present objective was to determine the bulk and shear properties of the rice flour.

MATERIALS AND METHODS

Sample collection

The commercial rice flour sample under the brand name of Hypervalue (FSSAI Licence no: 11214334000722) was obtained from the local market of longowal Punjab for comparison of the flow property and is stored in closed containers at 4ºC till further analyses.

Proximate analyses

The rice flour sample was analysed for protein, fat, fiber, and ash content according to AOAC Standards (1995). The moisture content of the flour sample was kept constant at 11 % (wet basis) by oven dry method.

Particle size Analysis

Laser diffraction particle size analyzer (Cilas, Model 1190, Madison, WI) of wet mode was used for the particle size determination of rice flour. Approximately 1 g of sample was dispersed in deionised water. Agitation was performed to ensure proper dilution of the sample in the deionised water. The suspension was then introduced into the ultrasonic bath. 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.

Flow properties

FT4 powder rheometer (Freeman Technology Ltd. Worcestershire, UK) was used to analyze the flow properties of rice flour.

Compressibility

The FT4 Powder Rheometer was used to test the compressibility of the flours. A sample was first placed in an 85 ml cylindrical vessel and preconditioned by a pass-through of a dynamic blade. Then, it is slowly consolidated with a vented piston by applying a normal load σ in small increments between 0.5 to 15 kPa. Afterwards, the compressibility (percentage change in volume after compression) was plotted against the normal stress σ and the ratio between the density and bulk density for each compaction step was calculated.

Basic flowability energy (BFE)

The energy needed to displace a conditioned and stabilised powder at a given flow pattern and flow rate, typically -5° helix downwards and 100 mms^{-1} blade tip speed (BFE = Energy Test 7) is calculated from the work done in moving the blade through the powder from the top of the vessel to the bottom, i.e. during the downward traverse.

Stability Index (SI)

This test was designed to assess the flow energy requirement changes during repeat testing. It is the combination of repetitive conditioning and test cycles of identical parameters. External variables such as flow rate or air velocity were not involved in this test. Thus, any change in the flow energy is directly related to the change in powder flow properties. 7 test cycles were used for the stability test program. For stability measurement, 100 mm/s blade tip speed were used for conducted all test cycles with the blades moving transversely down the vessel. The stability index (SI) was calculated using the following relationship:

$$SI = \frac{Energy\ test\ 7}{Energy\ test\ 1}$$

Shear Cell test/ Shear Properties

Shear cell measurements are widely used to assess the flowability of powders for applications that involve powder discharge. These tests were originally used to design hoppers and silos, but have become increasingly useful for general characterization of granular materials. Shear Cell tests are performed on consolidated powders/flours and are intended to determine how easily a previously at rest sample can be made to move.

Briefly, the powder sample is first conditioned by a pass-through of a dynamic blade to achieve a homogeneous reproducible initial state, and then slowly pre-compacted under a determined normal load (9 kPa) with a vented piston. After this “preconsolidation step”, the sample is pre-sheared to achieve a “critically consolidated state” (Schulze, 2008). The normal load σ is then lowered, and the shear stress τ necessary to cause failure and create flow is measured. In that way, five data points are obtained which can be plotted in a two dimensional coordinate system (the coordinates for a point are defined by one level of normal stress (σ) and the corresponding shear stress (τ)). The line passing through these five points is called the yield locus and was the basis of the parameters obtained during the shear test. The pre-shear/shear sequence was repeated 5 times at decreasing normal loads σ. Using Mohr's circle analysis, various important parameters may be extracted from these results: (Freeman, 2007)

- Cohesion (Co) (kPa)
- Unconfined yield strength (UYS) (kPa)
- Major principle stress (MPS) (kPa)
- Angle of internal friction (φ)
- Flow function coefficient (FF or ffc)

RESULTS AND DISCUSSION

Proximate Analyses

A proximate analysis was performed for commercial rice flour. Moisture content of the rice flour sample was kept uniform at 11 % wet basis by loss on drying method. It is revealed that the rice flour contained fat 2.57%, protein 7.02%, ash 1.15%, crude fibre 1.02% and carbohydrate 77.24%. It has been reported by the Fitzpatrick et al. (2004) that presence of fat impedes the flow characteristics as it increases the cohesion between the particles.

Particle size analysis

The average particle size (D_{50}) of the rice flour was found 65.3µm as shown in table 1. The size distribution of the flour was significantly different. The results showed that particle diameter of rice flour had a widest size distribution (Table 1). It is generally.

Table1: Particle size analysis of rice flour

	Particle diameter (μm)			
Rice flour	**D_{10}**	**D_{50}**	**D_{90}**	**Span (d90-d10/d50)**
	36.7±0.2	65.3±0.09	179.5±0.7	2.1

The values are means ± standard deviation of three replicates.

Considered that powders with particle sizes larger than 200 μm are free flowing, while fine powders are subject to cohesion and their flowability is more difficult. An increase in flow difficulties as shown in table 2 and cohesiveness in conjunction with a reduction in particulate size is observed for the selected rice flour. The effect may be due to the reducing particle size tends to increase cohesion behaviour because the particle surface area per unit mass increases, favours a greater number of contact points for interparticulate bonding and additional interactions, resulting in more cohesive and less free flowing powders (Fitzpatrick et al., 2004; Teunou et al., 1999). Jan et al., (2016) has also presented the similar results for wheat flour.

Measurement of flow properties

Compressibility

Though compressibility is not a direct measure of flowability but can be used for predicting whether the flour/powder is free flowing or cohesive. High compressibility is often associated with high cohesivity of the powders in addition to other factors such as bulk density and packing structure. Particle size is considered as an important parameter as it has a great impact on compressibility. Results showed that the compressibility at 15kPa was 41.20% this is considered as a high compressibility which could be due to the less particle size of the rice flour as shown in table 1 because of the deformation and rearrangement of smaller particles in the rice flour. Similar results were reported by **Bian et al. (2015)** for soft and hard wheat flour.

Basic flow energy (BFE) and Stability index (SI)

High BFE (197.42mJ) was found for rice flour as shown in table 2 which can predicted that higher energy was required to flow the rice flour. The plausible reason could be small particle size of the rice flour. Lindberg et al. (2004) and Jan et al. (2017c) reported that higher packing density and the higher forces were required to cause the powder to flow under compaction. So, it can be concluded that particles of rice flour was forced to flow at the blade face and can be accommodated by the air pockets that exist between agglomerates. The resulting flow or stress transmission zone is relatively localised and thus, more difficult to handle when in bulk.

As per the standard range of the stable powder, rice flour is slightly unstable. Normal stable powder range is considered as $0.9 < SI < 1.1$ and values of above or below this range would be categorized as unstable. However, the stability index (SI) of the rice flour was 1.09 as shown in the table 2. Similar results were concluded by Jan et al. (2017a) for soft and hard wheat flour.

Shear properties

Yield loci using mohr's circles were established at pre-consolidation normal loads of 9kPa. The flow functions (σ_c vs. σ_1) obtained for the rice flour are presented in Table 2 and is shown in fig 1. Rice flour was found cohesive in nature as shown in table 2 and is also confirmed by the fig 1. Reason could be the less particle size of the flour particles. Fitzpatrick et al. (2004); Jan et al. (2017b) also reported the similar results for the different cohesive powders. According to the classification given by Jenike (1964), rice flour showed the cohesive nature (2.12 flow function) which depicted its poor flow as the lower the flow function value, the difficult the bulk solids can flow from bins and silos. Possible reason could be the higher density (0.52g/ml) of the flour thus had higher packing efficiency.

Table 2: Flow properties of rice flour

Flow Properties	**Rice Flour**
Compressibility (%)	41.20±0.86
Conditioned bulk density (g/ml)	0.52±0.07
Basic flow energy (mJ)	197.42±0.72
Stability index	1.09±0.10
Applied pressure 6 kPa	
Major principle stress (kPa)	7.76±0.05
Unconfined yield stress (kPa)	3.67±0.07
Angle of internal friction (°)	36.09±0.11
Cohesion (kPa)	1.28±0.02
Flow function coefficient	2.12±0.04

The values are means ± standard deviation of three replicates

The derived higher unconfined yield strength or compression strength and cohesion of the rice flour determined that the discharge from a hopper will cease due to the formation of a stable bridge during discharge from storage bins. Angle of internal friction (AIF) at 6 kPa for the rice flour was much higher (36.09º) than expected and can be used as an indicator for measuring the interparticle friction. Similarly results were reported by Schulze (2008).

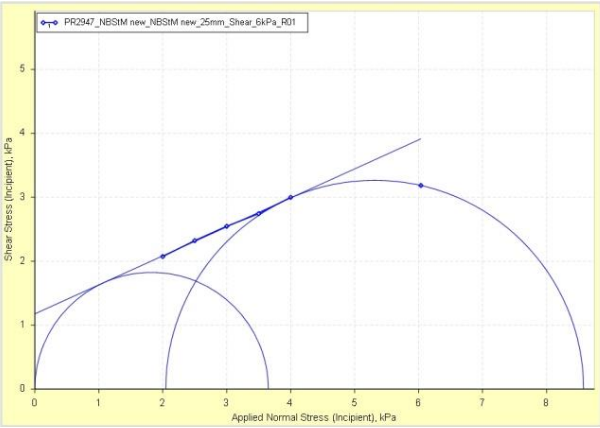

Figure 1: Shear properties of rice flour using mohr's circles

CONCLUSION

In this study, flowability of rice flour was measured with respect to particle characterization. Shear and dynamic properties of rice flour were analyzed along with particle size. Highest compressibility of rice flour indicated that there could be difficulty in bulk handling due to less particle size. Basic flow energy and stability indices clearly showed that more energy was required to flow the rice flour. Highest value of AIF (at normal stress) of rice flour indicated the interparticle friction which could resist its flow during bulk handling. Overall, poor flowability was found for the rice flour.

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