Effect of Physical Properties on Flow ability of Commercial Rice Flour/Powder for Effective Bulk Handling

Shumaila Jan
Department of Food Engineering and Technology
Sant Longowal Institute of Engineering and Technology, Longowal- 148106 (India)

Syed Insha Rafiq
Department of Food Engineering and Technology
Sant Longowal Institute of Engineering and Technology, Longowal- 148106 (India)

D.C.Saxena
Department of Food Engineering and Technology
Sant Longowal Institute of Engineering and Technology, Longowal- 148106 (India)

ABSTRACT
This work evaluates the physical properties affecting the flowability of the commercial rice flour. This flour/ powder were selected because of the flow issues encountered by the mills/ industries during bulk handling. A number of powder physical properties, including moisture content, particle size distribution, bulk density, compressibility index, angle of repose and co-efficient of friction were measured. Powder flowability was measured in terms of cohesive index, caking strength and powder flow speed dependency. These properties are used in interpreting the flow behaviour of the commercial rice flour.

General Terms
Flowability, bulk handling, commercial rice flour.

Keywords
Physical properties, cohesive index, caking strength, powder flow speed dependence.

1. INTRODUCTION
Food powders are mostly used materials, handled both in industry as well as in households all around the world and are considered among the most difficult materials to characterise. Much research regarding handling and storage characteristics of bulk solids has been conducted over the years. The powders are mostly surrounded by air (or other fluid) and the bulk properties of the powder are determined by its solid plus fluid combination and the amount of fluid can be variable. Powders are the least predictable of all materials in relation to flowability because of the large number of factors that can change their rheological properties. Powders are blends of solids, liquids and gases, usually air. Their flow properties or rheology may be affected by perhaps 100 or more factors. Broadly, powders are either cohesive or non-cohesive. A free flowing powder is non-cohesive wherein particles are separate and when unconfined are able to move individually. Generally speaking the interparticle forces are negligible in such case. As long as the powder is free flowing, the major obstruction to flow is the internal friction.

The most vulnerable industrial powder problems are obtaining reliable and consistent flow out of hoppers and feeders without excessive spillage and dust generation. These problems are usually associated with the flow pattern inside the silo and hoppers. The worst-case scenario is no flow. This can occur when the powder forms a cohesive arch across the opening, which has sufficient strength within the arch to be self-supporting. Another flow which is termed as mass flow is the ideal flow pattern where all the powder is in motion and moving downwards towards the opening. Funnel flow is where powder starts moving out through a central ‘‘funnel’’ that forms within the material, after which the powder against the walls collapse and move through the funnel. This process continues until the silo empties or until another no-flow scenario occurs with the development of a stable rathole [1] Furthermore, these flow properties could be again governed by the material physical properties, for instance; particle size and shape, the granular surface structure and particle density, the packing properties and other external factors. External conditions could include water content, temperature and the presence of other materials or ingredients [2]**.**

Physical properties of granular solids play a significant role in their resulting flow behaviour and storage and thus are essential to design appropriate, efficient, and economic bulk solids handling and storage equipment and structures. These properties are important in determining the flow behaviour of the flour, thus being helpful in their proper handling during the various stages of processing, conveying and storage. Bulk density, kernel density and porosity affect the structures, loads and in sizing grain hoppers and storage facilities. The angle of repose is important in designing of storage and transporting structures. The static coefficient of friction of the grain, against the various surfaces is used to determine the angle at which the grains or their flour must be positioned in order to achieve consistent flow of material [3, 17]**.**

In addition, it is also important in the designing of conveyors because friction is necessary to hold the grains or flour to the conveying surface without slipping or sliding backward. The frictional properties data will be useful in hopper design, since inclination angle of the hopper walls should be greater than the angle of repose to ensure the continuous flow of the crops (gravity flow) thus these parameters are also necessary in designing of conveying, transporting and storing structures. The Hausner ratio and Carr’s index are two widely used measurements to indicate flowability of bulk solids, and are commonly referred to as the compressibility index [17]**.** The present study has been conducted with the commercial rice flour which has been assessed for particle size analysis, bulk density, tapped density, compressibility index, angle of repose, static co-efficient of friction cohesive index, caking strength and powder flow speed dependency test.

2. MATERIALS AND METHODS

2.1. Physical properties

2.1.1. Procurement of sample:

Rice flour sample was obtained from local Flour Mill, Longowal, Sangrur (Punjab).

2.1.2. Particle size analysis

Particle size analysis was done by using Laser Diffraction Particle Size Analyzer (Model SLAD-2300, M/s. SHIMADZU Corporation, Kyoto, Japan). Measuring method used was laser diffraction and laser scattering intensity pattern, with a measuring range of 0.017µm to 2500µm. Light source used was semi-conductor laser with a wavelength of 680nm and an output of 3Mw. Operating temperatures were 10^oC to 30^oC, with an operating humidity of 20% to 80% (with no condensation). A suspension was prepared with 0.5g powder and 1ml ethanol (refractive index: 1.36) by continuous stirring on a magnetic stirrer for 3-5 min. The prepared sample was filled into the cuvette and readings were taken.

2.1.3. Moisture content

Moisture content (wet basis) was measured by weighing 5 g of a sample before and after drying in an oven at 105^oC for 3 hours. Each test was carried out in triplicates.

2.1.4. Bulk density and loose density of rice flour

The loose bulk density of rice flour was determined by carefully filling a standard graduated cylinders of Vankle's design (100 ml) (M/s. Standard Instrument Corporation, Patiala, India) with a sample. Initially, the material was filled up to the 25 ml volume of the cylinder. At this point, the material was weighed. The cylinder was tapped on a flat surface about 10 times to allow the material to settle. The cylinder was further filled with material. The material was again weighed, and the bulk and tapped density were calculated based on the volume of the cylinder and weight of material [4].

$$\rho_l = \frac{W_l}{V_l} \qquad (1)$$

$$\rho_t = \frac{W_t}{V_t} \qquad (2)$$

The bulk and tapped densities were used to calculate the Hausner ratio (HR) (Eq. 3) and Carr's index (CI) (Eq. 4). Hausner ratio (HR) was expressed in decimals; and is defined as the ratio of a material tapped bulk density to its loose bulk density **[5, 6]** and is given as:

$$\text{CI} = 100 \times [(\rho t - \rho l) / \rho t] \qquad (3)$$

$$\text{HR} = \frac{\rho_t}{\rho_l}, \qquad (4)$$

Where ρ_l and ρ_t are the bulk densities (kg m^{-3}), W_l and W_t are the masses (kg), V_l and V_t are the volumes (m^3) of flour in loose and tapped fill conditions, respectively.

2.1.5. Angle of repose

The angle of repose is the angle formed by the horizontal base of the bench surface and the edge of a cone-like pile of granules. The cylinder was placed over a plain surface and rice flour was filled in. Tapping during filling was done to obtain uniform packing and to minimize the wall effect if any. The tube was slowly raised above the floor so that whole material could slide and form a natural slope. The height of heap above the floor and the diameter of the heap at its base were measured and the angle of repose (φ) was measured by following relations.

$$\text{Angle of Repose } \phi\ (°) = tan^{-1}\frac{2h}{D}$$

where, Φ = angle of repose (◦);h = height of the pile (mm);D = diameter of the pile (mm).

2.1.6. Co efficient of friction

The coefficient of static friction (µ) was determined from three structural materials namely glass, galvanized steel sheet and plywood. A plastic cylinder of 30 mm diameter and 35 mm height was placed on an adjustable tilting flat plate faced with the test surface and filled with the sample. The cylinder was raised slightly so as not to touch the surface. The structural surface with the cylinder resting on it was inclined gradually, until the cylinder just started to slide down. The angle of tilt was noted from a graduated scale [7, 8, 9] The angle of inclination was calculated as:

$$\mu = \tan \alpha$$

2.1.7. Flow property measurement by powder flow analyzer

2.1.7.1. Cohesion index

Cohesion Index (CI), which is defined as the ratio of "Cohesion Coefficient/sample weight", was measured by using a Stable Micro Systems TA.XT2i Plus texture analyzer. The cohesion coefficient (g.mm) is the work required to lift the blade up through the powder column during the decompression phase at the speed of 50 mm sec^{-1}, which is determined by integrating the negative areas under the force displacement curve

$$\text{CI (mm)} = \frac{Cohesion\ coefficient\ \ (g.mm)}{Sample\ \ weight\ (g)}$$

2.1.7.2. Caking test

During the caking process, the rotor moves to a force of 5 g at 20 mm/s. This step levels off the powder and allows to record the rate at which the column height reduces. Once target force is reached, the data is recorded as it moves down through the powder column at 20mm/s until it reaches a force of 500 g. Then the rotor moves upwards at 10 mm/s subjecting powder column to minimum displacement. This is repeated for five compactions. Lastly, the rotor slices through the compacted cake recording hardness of the cake, i.e. the force required to get the compacted powder flowing freely. Finally the rotor moves back to the top. The data analysis is done using the data on column height at the start of each compaction cycle, the distance at the point the final 500 g force is reached (the cake height) for each cycle, and finally the mean force and work required (g.mm) to slice through the caked area. Cake height ratios (ratio of the initial column height) and also the cake strength (both as the mean force and also the work required the area under the curve) are calculated [16].

2.1.7.3. Powder Speed Flow Dependence (PFSD) test

This test measures the flow stability index i.e. the interparticle friction of the powder. The data is recorded to measure the resistance of the powder to being pushed at a controlled flow. In this, first the rotor moves down through the powder column at 10 mm/s. At the bottom of the powder column, the rotor slices through the powder to avoid hard compact. The rotor then moves up through the powder at 20 mm/s twice followed by two cycles of 50 mm/s, two cycles at 100 m/s, and two cycles at 10 mm/s. The analysis is performed on both the positive (force vs distance) and negative areas. The average is taken for the two areas for the compaction (as the rotor moves down through the powder column) at each flow rate. These are recorded as the compaction coefficient at 10, 20, 50 and 100 mm/s. The compaction coefficient for the final two cycles at 10 mm/s is averaged and ratio with that from the initial two cycles at 10 mm/s to assess whether the powder has broken down during the testing to get a value of PFSD. A value close to 1 means it has not changed at all during the testing. If the figure is >1 means the product has changed during testing (giving a higher compaction coefficient) if <1 means it has changed giving it a lower compaction coefficient [16].

3. RESULTS AND DISCUSSION

3.1 Particle size analysis

Particle size analysis of commercial rice flour is shown in **Fig. 1** and the data are summarized in **Table 1.** The particles of commercial rice flour showed a unimodal distribution profile for granular size. The results showed that particle diameter of commercial rice flour had a widest size distribution with a median granule diameter of 102.429 µm. It is generally 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. Our results indicate a slight contribution of physical factors mainly due to median particle size. An increase in flow difficulties and cohesiveness in conjunction with a reduction in particulate size is observed for the selected commercial 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 [10,11,12]**.** Similar results have been obtained for wheat flour [13].

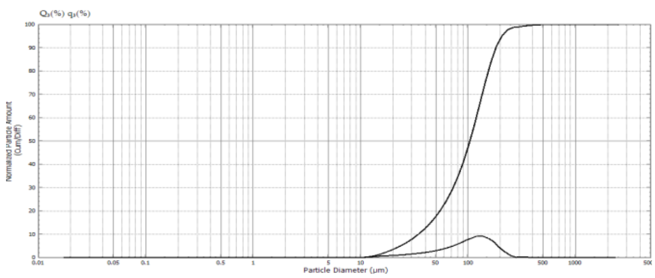

Fig. 1: Particle size analysis of commercial rice flour

TABLE 1. Physical properties and flow characteristics

Properties	Values
Moisture Content (%)	11.6
Particle size (µm)	102.429
Loose bulk density (kg m^{-3})	0.644
Tapped bulk density(kg m^{-3})	0.762
Angle of repose (^{o})	66.571
Carr's index	15.480
Hausner ratio	1.183
Flow stability index	0.987
Cake strength (gmm)	322.097
Cohesion index	14.18

3.2 Moisture content

The commercial rice flour had 11.6% moisture content. The test results showed that small quantities of adsorbed moisture can have a significant effect on the flow properties of rice flour. As, rice flour is hygroscopic, this leads to a gain in the cohesive strength because of the formation of liquid bridges between neighbouring particles, causing difficulties in flow.

3.3 Bulk density and loose density of rice flour

Bulk and tapped density of commercial rice flour was measured and the results are presented in **Table 1**. As obvious, particle size of rice flour has a direct relation with bulk density. It was found that commercial rice flour had lower bulk (0.644 kg m^{-3}) and tapped (0.762 kg m^{-3}) densities.

CI is a measure of powder bridge strength and stability, and the Hausner ratio (HR) is a measure of the interparticulate friction. The Hausner ratio (HR) and Carr's compressibility index (CI, %) were calculated based on Eqn. 3, 4 respectively. CI (15.480) and HR (1.183) were shown in **Table 1**. This is in accordance with density measurements. The Hausner ratio (1.183) and Cars index (15.48) showed the fair flowability as per the scale described **Table 2** [14].

TABLE 2. Scale of flowability

Carr's Index	Angle of Repose	Hausner Ratio	Flow Characteristics
10	25-30	1.00-1.11	EXCELLENT
11-15	31-35	1.12-1.18	GOOD
16-20	36-40	1.19-1.25	FAIR
21-25	41-45	1.26-1.34	PASSABLE
26-31	46-55	1.35-1.45	POOR
32-37	56-65	1.46-1.59	VERY POOR
>38	>66	>1.60	VERY, VERY POOR

3.4 Angle of repose and Co efficient of friction

The angle of repose for commercial rice flour was found to be 66.571. The parameter is important in proper design of hoppers to maintain continuous flow of the rice flour, which must be larger than the angle of repose of rice flour. The angle of repose α_r is increased by the cohesion. The highest average values of the static coefficient of friction against plywood, glass and Galvanized steel sheet for commercial rice flour were 0.587, 0.555 and 0.682, respectively as shown in **Table 3**. However, for higher friction coefficients, more stable open bridged structures can develop within the body of the powder, creating a lower overall packing density.

TABLE 3: Co-efficient of friction of commercial rice flour

Plywood	Glass	Galvanized steel sheet
0.587	0.555	0.682

3.5 Cohesion index

Force vs distance curves for commercial rice flour is shown in **Fig.2**. Based on these curves recoded, cohesion index (the ratio of cohesion coefficient and the sample weight) is calculated by integrating the negative areas under the curve using the MACRO software supplied along with the texture analyzer. The results are presented in **Table 1**. Each measurement is an average of 6 cycles in each mode designed by standard operating procedure itself. As observed commercial rice flour exhibited a cohesive behaviour shown in **fig 2**. This property can be attributed to the decreased particle size of the rice flour as described by [15] for commercial Infant Formula Powders. On comparing the obtained values of rice flour with the standard scale of cohesion it was again predicted that commercial rice flour had a cohesive behaviour.

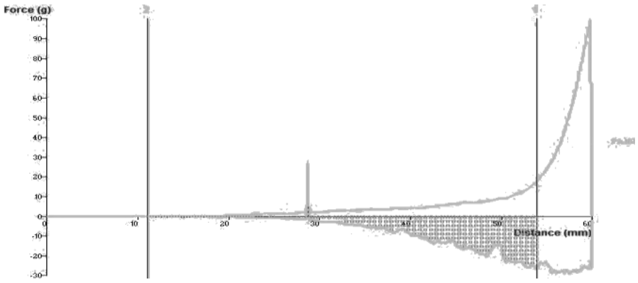

Fig 2. Cohesive index of the commercial rice flour

3.6 Caking test

A typical curve for Cake strength and mean cake strength are calculated using texture exponent software and is shown in **Fig. 3**. As received commercial rice flour showed an average cake height ratio this can be attributed to the factor that Powders with larger particles are not as submissive to caking as powders with smaller particles [15]. Results are shown in **Table 1**.

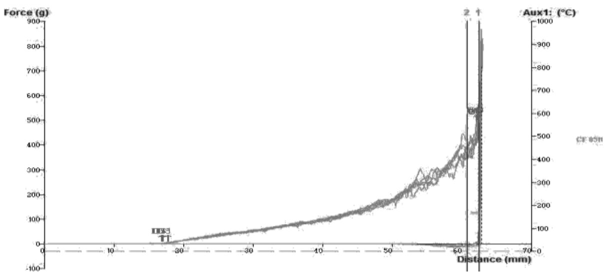

Fig. 3: Caking Strength of the commercial rice flour

3.7 Powder Speed Flow Dependence (PFSD) test

Powder flow stability distribution (PFSD) was analyzed to quantify the dependence of flow characteristics on flow rate for powders. It also measures flow stability or how the powder breaks down during testing. A typical force displacement profile for PFSD test is shown in **Fig. 4**. Values are described in **Table 1** FSI (0.987). Flow stability index below 1 is associated with granulation effects during the flowability test [13]. Flow stability index up to 1 is associated with no-granulation effects during the flowability test.

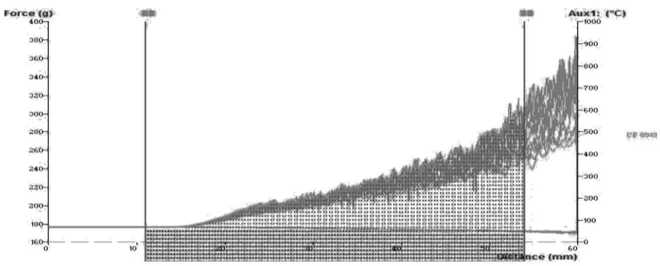

Fig. 4: Powder flow speed dependency of the commercial rice flour

4 CONCLUSION

An increase in flow difficulties and cohesiveness in conjunction with a reduction in particulate size is observed for the selected commercial rice flour. The static coefficient of friction for commercial rice flour was higher on galvanized steel plywood, followed by and glass. Cake height ratio and compaction coefficient of as-received commercial rice flour indicated the poor compactability of these powders. Powder flow analysis is an effective tool to characterize the flow properties of commercial rice flour to elucidate the effect powder granule size and their distribution on flow behaviour and subsequent compaction processing. To reach a better understanding of the contribution of physical properties of rice flour in the flowability and cohesive properties of rice flour, it would be interesting to evaluate the surface roughness, surface composition and particle shape of rice flour particles. The biochemical surface composition can be supposed to be more relevant to evaluate the flowability and cohesive properties, than the bulk composition of the flour.

5 REFERENCES

[1] Fitzpatrick J J, Barringer S A, Iqbal T, 2004. Flow property measurement of food powders and sensitivity of Jenikes hopper design methodology to the measured values. Journal of Food Engineering. 61, 399–405

[2] Abu-hardan M, & Hill S E. 2010. Handling properties of cereal materials in the presence of moisture and oil. Powder Technology 198, 16–24.

[3] Ganesan V, Rosentrater K A, Muthukumarappan K.. 2008. Flowability and handling characteristics of bulk solids and powders – a review with implications for DDGS. Bio systems engineering 101, 425 – 435

[4] Tumuluru J S, Tabil L G, Song Y. , Iroba K L, Meda V. 2014. Grinding energy and physical properties of chopped and hammer-milled barley, wheat, oat, and canola straws. Biomass and bio energy 6 0, 58- 67

[5] Grey RO, Beddow J K. 1969. On the Hausner ratio and its

[6] relationship to some properties of metal powders. Powder Technology, 2(6), 323–326Garcia RA, Flores RA, Mazenko CE. 2007. Factors contributing to the poor bulk behavior of meat and bone meal and methods for improving these behaviours. Bioresource Technology, 98(15), 2852–2858

[7] Dutta S.K., Nema V.K. and Bhardwaj R.K. 1988. Physical properties of gram. Journal of Agricultural Engineering Research, 39:259-268.

[8] Fraser B.M., Verma S.S. and Muir W.E. 1978. Some physical properties of faba beans. Journal of Agricultural Engineering Research, 23:53–57.

[9] Shefherd H. and Bhardwaj R.K. 1986. Moisture-dependent physical properties of pigeon pea. Journal of Agricultural Engineering Research, 35:227–234.

[10] Fitzpatrick, J. J., Barringer, S. A., & Iqbal, T. 2004. Flow property measurement of food powders and sensitivity of

Jenike's hopper design methodology to the measured values. Journal of Food Engineering, 61, 399‑405.

[11] Katikaneni, P. R., Upadrasha, S. M., Rowlings, C. E., Neau, S. H., & Hileman, G. A. 1995. Consolidation of ethylcellulose: Effect of particle size, press speed, and lubricants. International Journal of Pharmaceutics, 117, 13‑21.

[12] Teunou, E., & Fitzpatrick, J. J. 1999. Effect of relative humidity and temperature on food powder flowability. Journal of Food Engineering, 42, 109‑116.

[13] Landillon V, Cassan D, Morel MH, Cuq B. 2008. Flowability, cohesive, and granulation properties of wheat powders. Journal of Food Engineering 86,178–193

[14] Igathinathane C, Jaya ST, Sokhansanj S, Bi X, Lim CJ, Melin S, Mohammad E. 2010. Simple and inexpensive method of wood pellets macro-porosity measurement. Bioresource Technology, 101(16), 6528–6537

[15] Benkovic M, Bauman I. 2009. Flow Properties of Commercial Infant Formula Powders. World Academy of Science, Engineering and Technology 30.

[16] Shah RB, Tawakkul MA and Khan MA. 2008. Comparative Evaluation of Flow for Pharmaceutical Powders and Granules, AAPS Pharm Sci Tech, 9(1): 250–258

[17] Gani A, Hussain A, Ahmad M, Baba WN, Gani A, Masoodi FA, Wani SM, Shah A, Wani IA, Maqsood S. 2015. Engineering and functional properties of four varieties of pulses and their correlative study. Food Measure, DOI 10.1007/s11694-015-9242-7