CHAPTER – 3

GRINDING AND FLOUR CHARACTERIZATION

3.1 INTRODUCTION

Rice (Oryza sativa L.) a major cereal crop with important source of energy make it a desirable grain to be used in value-added products. Basmati rice, a long slender grain rice is liked for its exquisite nut-like fragrance during cooking and a delicate, almost buttery flavor due to presence of 2-acetyl-1-pyrroline (Bergman et al., 2004). It falls in the category of non-waxy, non-glutinous rice with intermediate amylose content, and does not stick on cooking. The broken rice, which is cheaper than corn starch and is available in abundance, thus can be used in the production of rice flour. Basmati rice flour offers potential for traditional and newer product development due to inherent characteristics fragrance/aroma with health benefits as per its higher protein content and lower glycemic index.

Pusa 1121 is a promising Indian basmati rice variety known for its extra long slender grains with extra fragrance and aroma. High yielding characteristics and more linear elongation on cooking associated with this variety, not only replaced traditional rice varieties but also gaining popularity among Indian farmers (Prasad et al., 2012). The extent of breakage is much higher being extra long rice kernels and thus degree of milling affects the head rice yield. The quality of rice based products depends on particle size distribution pattern, physico-chemical, pasting and other associated characteristics.

Grinding is one of the important size reduction technique applied often to produce small particulate matter following compression, impact, attrition or cutting
forces. Grinding time controls the particle size and the processing techniques provided to rice or paddy controls the particle size distribution, which may be considered as the key factors for the powder characteristics and its suitability for various rice flour based preparations. Generally, there are three methods used to prepare rice flour: wet grinding, semidry grinding and dry grinding (Chiang and Yeh, 2002). Wet grinding is a traditional method used to prepare rice flour followed by soaking, adding excess water during grinding, filtering, drying, and sieving (Yeh, 2004). Dry grinding uses no water, does not generate waste water, and moreover, consumes less energy. In the semidry grinding process, the properties of flour are to those of both dry and wet ground flour. The semidry grinding process has intermediate steps: soaking and drying to remove excess water before grinding (Naivikul, 2004). The type and method of grinding potentially has a profound impact on the physico-chemical characteristics of the rice flour produced. Many parameters of the rice grinding process affect the characteristics of flour such as the grinding method, involvement of soaking process, rice cultivar and particle size (Chen et al., 2003).

The rice flour is an important ingredient in both traditional and novel foods prepared across the world (Villareal et al., 1993). Some of the traditional rice flour based products in India are puttu, made by steaming rice flour and grated coconut, and appam, a cake formed by mixing rice flour and fermented coconut milk, Idlis and dosas are delicacies also made from rice flour batter (Prasad et al., 2012). Rice flour exhibits a number of unique characteristics and can be a better substitute of other starch sources in a number of food applications, to prepare baby foods, noodles, soups, thickener, extruded products and blending with other ingredients (Juliano, 1984). Amylose content in rice has been reported upto 33% and has been specified as waxy, very low, low, intermediate and high amylose, respectively (Juliano, 1992). In
addition to amylose and amylopectin, some constituents, such as fat and protein are also present in rice flour. It seems highly probable that flour obtained from different grinding methods will vary in different physico-chemical and rheological properties.

Rice flour properties depend on the physico-chemical characteristics such as mean granule size, size distribution, amylose content and other associated parameters (Madsen and Christensen, 1996; Singh et al., 2003). The particle size distribution of rice flour is known to play an important role in its chemical composition (amylose, protein, and amylopectin) and the quality of end products. Fourier transform infrared (FTIR) spectroscopy and x-ray diffraction (XRD) pattern have been considered important in evaluating structural changes at physical and macroscopic level indicating changes associated with gelatinization processes.

Considering grinding as a reproducible size reduction process adopted for most of the rice based product formulations in developing countries, the objective “To study the effect of grinding methods on flour characteristics of milling susceptible rice variety” was undertaken in further two phases as following:

1. To study the grinding behavior and powder characteristics of basmati rice brokens.
2. Effect of grinding processes on flour characterization of Pusa 1121 basmati rice brokens.

3.2 MATERIALS AND METHODS

3.2.1 Materials

Pusa 1121 rice brokens obtained during shelling and polishing through previous objective (Chapter 2) were used as the raw material for the present study. Corn flour (Weikfield Foods Pvt. Ltd., India) was procured from local market of Sangrur (India).
Rice brokens was ground to flour using three methods (Dry grinding, DG; Semi dry grinding, SDG; Wet grinding, WG) of grinding (Figure 3.1). The sieve fractionations (100 BSS) were used for flour characterization.

![Flow chart for different grinding process](image)

**Figure 3.1  Flow chart for different grinding process**

3.2.2 Dry grinding characteristics

Hundred grams of broken rice kernels were subjected to grinding process in a dry grinder (Make: Sujata, India; Model: Dynamix, 810Watts). Ammeter was used to measure the current drawn for the evaluation of energy consumption during grinding operation. The obtained samples subjected to grinding for 0-15-30-60-120-180-240 seconds were analysed for particle size with the selected set of seven standard sieves 12-20-30-48-72-120-200 BSS using a vibratory sieve shaker (Make: Nihal Engineering Corporation, New Delhi, India). Weight fractions were obtained as the
ratio of individual fractions to total sum fractions and used to determine the time dependent particles size, fineness modulus and grinding law constants.

3.2.2 Theory

Milling is the trade term used relative to the reduction of grain into flour by mechanical means in such a way to maintain the chemical characteristics unaltered. The performance thus characterized by the milling capacity, power required per unit of milled material, the size and shape of raw and milled material and particle size distribution of the resultant product (Henderson and Perry, 1976). The particles undergo milling may be from macroscopic to microscopic range. The particle size classification system in form of fineness modulus (FM) as devised by D. A. Abrams, the sum of the per cent weight fraction retained above the selected sieves was determined to calculate the average particle size using the modified formula as:

\[ D, \text{mm} = 0.0587 \times 1.632^{\text{FM}} \] (3.1)

The fundamentals of product size, shape and of energy requirements are however common to most machines employing size reduction principles. It is feasible to understand the grinding characteristics with the help of different theories such as Kick’s, Rittinger’s and Bond laws. Size reduction of broken rice was enumerated by the comparison made between the new surface areas generated to the energy consumed for generating that area. Three empirical relationships (Kick, Rittinger and Bond) have been suggested for determining energy. Each model assumes that the energy input per unit mass \( \partial E \) required to change the size of material by a fractional amount \( \partial d \) is proportional to the particle size and can be expressed as:

\[ \frac{\partial E}{\partial d} = Kd^n \] (3.2)

Where, \( \partial E \) is energy required, \( \partial d \) is the change in typical dimension, K and n are constants (Earle, 1996; Smith, 2010).
Kick assumed as \( n = -1 \) to estimate energy required for size reduction, that is proportional to the new surface created. Hence by putting value of \( n \) in Eqn. (3.2)

\[
\frac{\partial E}{\partial d} = Kd^{-1}
\]  \( (3.3) \)

\[
\int_0^E \partial E = K_K \int_{d_1}^{d_2} n^{-1} \partial d \n \]  \( (3.4) \)

\[
E = K_K \ln \frac{d_1}{d_2}
\]  \( (3.5) \)

Where, \( K_K \) is Kick’s constant which has units of J.kg\(^{-1}\). In Kick’s law the energy input is proportional to the size reduction ratio.

Rittinger assumed that \( n = -2 \), Hence energy input for size reduction by putting value of \( n \) in Eqn. (3.2) is

\[
\frac{\partial E}{\partial d} = Kd^{-2}
\]  \( (3.6) \)

\[
\int_0^E \partial E = K_R \int_{d_1}^{d_2} n^{-2} \partial d
\]  \( (3.7) \)

\[
E = K_R \left( \frac{1}{d_2} - \frac{1}{d_1} \right)
\]  \( (3.8) \)

Where, \( K_R \) is Rittinger’s constant which has units of J.m.kg\(^{-1}\). Rittinger’s equation tends to apply for particles which do not deform before breakage, in other words for brittle materials and for fine grinding. It suggests that the energy required is proportional to the increase in surface area per unit mass. In using either of the models due to Kick and Rittinger the relevant constant must be obtained by experiment using both the same equipment and the same material.

The Bond’s law, who proposed that the work input is proportional to the square root of the surface-volume ratio of the product, by putting \( n = -3/2 \) in Eqn. (3.2) and thus

\[
\frac{\partial E}{\partial d} = Kd^{-3/2}
\]  \( (3.9) \)

\[
\int_0^E \partial E = K \int_{d_1}^{d_2} n^{-3/2} \partial d
\]  \( (3.10) \)
Where \( q = \frac{d_1}{d_2} \). Bond put the constant equal to 5\( W_I \), where \( W_I \) is known as the work index and is defined as the energy required reducing unit mass of material from an infinite size to a size where 80% of the material is below 100 μm (Smith, 2010). Hence,

\[
E = W_I \left( \frac{100}{d_2} \right)^{1/2} \left[ 1 - \left( \frac{1}{\sqrt{q}} \right) \right]
\]  

(3.14)

### 3.2.3 Powder Characteristics

The weight of samples was recorded using electronic balance (Ishida Co. Ltd., Japan) to an accuracy of 0.001 g. The bulk density (BD) of the sample was evaluated using the methods suggested by Williams et al. (1983). The true density (TD) was determined using liquid displacement technique (Shepherd and Bhardwaj, 1986). Toluene as liquid was used in spite of water, to prevent absorption and also to get the benefit of low surface tension (Ogut, 1998). The porosity (POR) of samples was computed from the values of true density and bulk density using the following relationship by Mohsenin (1980):

\[
POR = \frac{TD - BD}{TD} \times 100
\]

(3.15)

The angle of repose (AOR) was determined using the relationship:

\[
AOR = \tan^{-1} \left( \frac{2H}{D} \right)
\]

(3.16)

Where, \( H \) and \( D \) are the height and diameter of the heap in mm.

The static coefficient of friction (\( \mu \)) was determined for four frictional materials namely glass (CFG), galvanized iron sheet (CFGI), plywood surfaces with...
horizontal movement (CFPH) and vertical movement (CFPV). A plastic cylinder of 50 mm diameter and 60 mm height was placed on an adjustable tilting flat plate faced with the test surface and filled with nearly 100 g sample. The cylinder was raised slightly to avoid touching the surface. The structural surface with material filled cylinder on it was inclined gradually, until the cylinder just started to slide.

3.2.4 Chemical analysis

3.2.4.1 Moisture Content

Moisture content was determined by employing the standard method of analysis (AOAC, 2000). Ten gram sample was weighed in a petri dish and dried in an oven at 105°C for six hours or till a constant weight was obtained. The sample was weighed after cooling it in a desiccators.

\[
\text{Moisture, } \% = \frac{\text{Loss in weight (g)}}{\text{Weight of sample (g)}} \times 100
\]  

(3.17)

3.2.4.2 Amylose content

Method of Williams et al., (1958) was followed for estimating amylose content.

Reagents

i) *Iodine-Potassium iodide reagent*: 200 mg of iodine and 2 g of potassium iodide were dissolved in about 50 ml of water and then total volume was made to 100 ml.

ii) *Potassium hydroxide (0.5N)*: Dissolved 28.05 g of potassium hydroxide in water and diluted to one litre with water.

iii) *Hydrochloric acid (0.1N)*: Added 8.72 ml of concentrated HCl in water and made it to one litre with water.
**Estimation:** Twenty mg of sample was taken in a 100 ml conical flask. Then 10 ml of 0.5 N KOH was added. After an hour, the flask was stirred for 3 minutes to homonize the contents. The final volume was made to 100 ml by adding water. Ten ml of dispersion was taken in 50 ml volumetric flask and acidified it with 5 ml of 0.1N HCl. For the development of color 0.5 ml of iodine potassium iodide reagent was added and then the final volume was made to 50 ml. After 30 minutes, absorbance was read at 590 nm after adjusting the zero absorbance using a blank. Amylose content was determined by referring to a standard curve.

**3.2.4.3 Protein content**

**Estimation:** Crude protein content was estimated by multiplying per cent nitrogen by factor 6.25. Total nitrogen in flour was estimated by Micro-Kjeldahl method (AOAC, 2000).

**Regents**

i) 40% (w/v) sodium hydroxide: Dissolved 40 g of sodium hydroxide in water and diluted to one litre with water.

ii) 4% (w/v) boric acid: Dissolved 4 g of boric acid in water and diluted to one litre with water.

iii) $K_2SO_4:CuSO_4.5H_2O$: These were mixed in a ratio of 10:1.

iv) Bromocresol green and methyl red indicator: One part 0.2% methyl red in ethanol and 5 parts 0.2% bromocresol green in ethanol were mixed. The mixed indicator was added to boric acid solution @ 5 ml per litre.

**Digestion:** A well ground sample (250 mg) was taken in a macro digestion tube. 1g mixture of $K_2SO_4:CuSO_4.5H_2O$ and then 10 ml of concentrated sulphuric acid were added. Digestion at 405°C was carried out on the digestion block (KES O6L, Pelican
Equipments, Chennai) till clear blue solution was obtained. After cooling the tubes, the digest was made to 100 ml with water and stored in a plastic bottle till further use. Blank sample was prepared by taking only sulphuric acid and the K₂SO₄:CuSO₄ mixture.

**Distillation:** Distillation of the digested sample was carried out on a semi-automatic distillation unit (DISTYL EM, Pelican Equipments, Chennai). 10 ml of the digest was transferred into a distillation tube. After adding 10 ml of 40% NaOH, distillation was carried out for 3 minutes. The distillate was collected in 10 ml of 4% boric acid solution containing mixed indicator. It was titrated against 0.01 N H₂SO₄ and the volume of sulphuric acid used was recorded. Per cent nitrogen was calculated following the formula:

\[
N, \% = \frac{[\text{ml} \ H_2SO_4 \text{ used (sample distillate)} - \text{blank distillate}]}{\text{Amount of sample taken}} \times \text{Normality} \times 14 \times 100
\]  

(3.18)

### 3.2.4.4 Fat content

**Extraction and estimation:** Fat from sample was extracted in petroleum ether (40-60°C) on SOCS PLUS system (Pelican Equipments, Chennai). Ten gram sample was taken into a cellulose thimble of 25 mm x 80 mm size (Whatman, England) fixed onto the thimble holder. The thimble was suspended in pre-weighed extraction beaker containing petroleum ether. The extraction beaker holding the thimble was then kept on the hot plate of the equipment. The beaker was then fixed with the collecting vessel ensuring a proper connection between these. For complete extraction of fat, the process was carried out for at least two and half hour. Level of the extraction solvent was maintained by putting extra solvent from the top of collecting vessel so that during the extraction period whole of the sample in the thimble was continuously in contact with the solvent. Extraction was stopped by blocking the flow of petroleum
ether from collecting vessel to the extraction beaker by tightening the valve. The excessive solvent in the extraction beaker was allowed to evaporate and was collected in the collecting vessel. Then extraction beaker containing oil and petroleum ether was removed from the hot plate and transferred into an oven maintained at 55 °C for evaporating traces of the solvent. The beaker containing oil was weighed. The defatted sample removed from the thimble was stored in a refrigerator till further use. The empty thimble was reused for the next sample. The amount of oil was calculated by taking difference between the weight of beaker before and after extraction. Results are expressed as per cent of dry sample.

3.2.4.5 Ash content

Ash content was determined by employing the standard method of analysis (AOAC, 2000). Accurately weighted sample was put in to a dish, previously dried and weighed. The dish with sample was heated gently on a flame at first and then heated in a muffle furnace at 550±10°C for 4-5 hours, until ash was formed, cooled in a desiccator and weighed.

\[
\text{Ash, } \% = \frac{\text{(weight of dish with ash--weight of empty dish)}}{\text{weight of dish with sample--weight of empty dish}} \times 100
\]  

\hspace{1cm} (3.19)

3.2.4.6 Water absorption index (WAI) and water solubility index (WSI)

WAI and WSI were determined according to the method developed for cereals (Stojceska et al., 2008). The ground sample was suspended in water at room temperature for 30 min, gently stirred during this period, and then centrifuged at 3000 rpm for 15 minutes. The supernatant was decanted into an evaporating dish of known weight. The WAI was the weight of sample obtained after removal of the supernatant per unit weight of original dry solids. The WSI was the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample.
3.2.4.7 Carbohydrate content

Carbohydrate content (%) of the sample was determined by difference method.

3.2.5 Particle size analysis

The particle size analysis was done using laser diffraction particle size analyzer (Malvern Instrument Ltd., Malvern, England). Small quantity (0.20 g) sample dispersed in non absorbing solvent was placed in a borosilicate cuvette, positioned in the laser path and measured the particle size while under continuous stirring for quantifying the size and size distribution of subjected particles. The cumulative weight percent particle size plots and the mean particle size were provided by the instrument’s software. All the measurements were done in triplicate.

3.2.6 Cake strength

Caking test was also performed using Texture Analyzer Plus Powder Flow Analyzer (Stable Micro Systems, Surrey, United Kingdom). The test began with two conditioning cycles. The blade leveled the top of the powder column and measured the height of the column, after which it moved down through the column and compacted the powder to a predefined force (2000 g). When the blade reached the required force it sliced up through the powder and repeated the compaction cycle four more times.

At the beginning of every cycle the blade measured the height of the column and the height of the powder cake was recorded when the target force was reached. The fifth time the target force was reached the blade cut through the formed powder cake at the bottom of the vessel and measured the force required to perform the task.
This force was recorded as the cake strength and represented the work required to cut the cake (g.mm) and the mean cake strength was the average force to cut the cake expressed in grams. The column height ratio (current cycle column height divided by the initial column height) and the cake height ratio (current cycle cake height divided by initial column height) were recorded to give information about the settlement and compaction of the powder column.

3.2.7 Morphological properties

Scanning electron micrographs were obtained with a scanning microscope (Jeol JSM-6100, Jeol Ltd, Tokyo, Japan). The samples were mounted on aluminum stubs with a double sided tape and coated with gold–palladium (60:40) at an accelerated voltage of 15 kV in accordance with the method described by Suksomboon and Naivikul (2006).

3.2.8 Pasting properties

Pasting properties of rice flour were studied by using Rapid Visco Analyzer (Newport Scientific Pty Ltd, Australia). The dispersion (28 g total weight) was equilibrated at 50 °C for 1 minute. Viscosity profiles of flour from different samples were recorded and the temperature–time conditions included a heating step from 50 to 95 °C, a holding phase at 95 °C, a cooling step from 95 to 50 °C. From the Rapid Visco Analyzer (RVA) profiles, pasting temperature, peak time, peak viscosity, trough, final viscosity, breakdown (peak viscosity minus trough viscosity) and setback (final viscosity minus trough viscosity) were calculated.

3.2.9 X-ray diffraction (XRD) pattern

The X-ray diffraction technique was applied to obtain the X-ray diffraction (XRD) pattern using an X-ray diffractometer (Rigaku Denki Co. Ltd., Japan) with the following operating conditions: 40 kV, 30 mA using Cu-Kα X-rays of wavelength (λ)
= 1.54056 Å and data was taken for the 2θ range of 10–40° with a resolution of 0.05° step size.

3.2.10 Fourier transform infrared (FTIR) spectroscopy

Transmission infrared spectra of the films were recorded at room temperature using a FTIR spectrometer (Perkin–Elmer, Beaconsfield, Buckinghamshire) from 16 scans in the range 700–4000 cm\(^{-1}\). The sample was placed directly in the sample holder. A background was collected before each sample was analyzed then subtracted from the sample spectra prior to further analysis. After every scan, a new reference air background spectrum was taken. The ATR crystal was carefully cleaned between samples with acetone. The cleaned crystal was examined for spectral authenticity to ensure that no residue remained from the previous sample.

3.2.11 Statistical analysis

The data reported in the tables were average of triplicate observations. The mean ± standard deviation (SD) was calculated for each treatment. In order to determine any statistically significant effects prevailed, Duncan multiple range test and critical difference (CD) at P ≤ 0.05 was analyzed using SPSS 16.0 and Microsoft excel software package (Microsoft Corporation, USA).

3.3 RESULTS AND DISCUSSION

3.3.1 Grinding characteristics

The effect of grinding time on particle size distribution of Pusa 1121 rice broken represented in Figure 3.2 shows that the dependency of grinding time on type of sample and particle size. With the increase in grinding time, the particles on grinding became finer (Table 3.1). The shear and cutting forces are involved to achieve the particle size reduction and energy consumption for grinding increased with time or the fineness of the grinding particles. The relationship between the
fineness modulus and average particle size was calculated using the Eqn. (3.1), which is graphically represented in Figure 3.3.

Table 3.1  Time dependent fineness modulus and average particle size kinetics of ground rice fractions

<table>
<thead>
<tr>
<th>Grinding time (Sec)</th>
<th>Fineness Modulus</th>
<th>Average Particle Size, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.29</td>
<td>0.783</td>
</tr>
<tr>
<td>15</td>
<td>4.34</td>
<td>0.491</td>
</tr>
<tr>
<td>30</td>
<td>3.80</td>
<td>0.377</td>
</tr>
<tr>
<td>60</td>
<td>3.25</td>
<td>0.288</td>
</tr>
<tr>
<td>120</td>
<td>2.94</td>
<td>0.248</td>
</tr>
<tr>
<td>180</td>
<td>2.66</td>
<td>0.216</td>
</tr>
<tr>
<td>240</td>
<td>2.49</td>
<td>0.198</td>
</tr>
</tbody>
</table>

Figure 3.2  Time dependent particle size distribution kinetics of ground rice fractions
Figure 3.3  Relationship between the fineness modulus and average particle size

Figure 3.4  Time dependent grinding law constants

The energy consumed by the grinder for size reduction were used to calculate the constants for Kick’s, Rittinger and Bond’s law both considering the fractional
time interval are represented in Figure 3.4. The trend of constant reflects that the grinding process is energy intensive and requirement of energy increases till increase in the compression and impact forces. Further, the grinding helps in the reduction of uneven particle size to uniform particle size distribution to follow trend of normal distribution (Figure 3.4). Excessive grinding of rice brokens for longer time further lead to damage the native structure of the biomaterial and thus affect the characteristics of the product to be prepared out of it (Unpublished data).

### 3.3.2 Powder Characteristics

The gravimetric and frictional characteristics (Figure 3.5) of Pusa 1121 rice mass fractions were assessed. The bulk density (BD) of rice fractions was observed decreasing trend with increase in grinding time and ranged in 781.89 to 979.45 kg/m$^3$ for rice fractions. It may be attributed to grinding increases the volume with higher rate than that of mass. The trend of true density (TD) was first decrease then increase with highest as 1356.72 kg/m$^3$ for the rice fractions. The variations in porosity (POR) were found dependent on bulk as well as on true densities.

The experimental values of angle of repose (AOR) show the increasing trend with increase in grinding time and varied from 35.40° to 52.18° (Figure 3.5). The static coefficient of friction for raw and parboiled rice fractions was determined with respect to four different surfaces and for glass (CFG) ranged from 0.239 to 0.627, for galvanized iron sheet (CFGI) ranged from 0.293 to 0.450, for plywood surface with horizontal movement (CFPH) ranged from 0.329 to 0.676 and plywood surface with vertical movement (CFPV) ranged from 0.457 to 0.754. This variation in the frictional properties thus may very well be used for the development of storage and handling equipments.
Figure 3.5  Gravimetric and frictional characteristics of time dependent ground rice fractions
3.3.3 Chemical analysis

Chemical characteristics of dry, semi dry and wet ground rice flour of Pusa 1121 variety and corn flour are shown in Table 3.2. The initial moisture content of dry, semidry and wet ground rice flour of Pusa 1121 variety were 11.23±0.54, 11.77±0.15 and 12.11±0.26 %, respectively on dry basis. The amylose content of flours ranged from 18.52 to 21.76 % significantly different among different grinding methods. The amylose content of dry ground rice flour was higher than the other two grinding methods and was significantly different at p≤0.05 (Table 3.2). It was found that grinding method and the source significantly affected the protein content, found highest in case of flour obtained by dry grinding method (7.84 %). The semi-dry and wet grinding process involved soaking of rice kernels, which resulted in leaching out of protein and other soluble substances from the surfaces of the starchy rice kernels. Chen (1995) and Juliano and Hicks (1996) also concluded that some soluble protein, sugars and non-starch lipids were washed away during soaking of rice kernels which were subjected to semi-dry or wet grinding. The WAI (water absorption index) of different flours ranged from 2.70 to 2.77 (Table 3.2). The increase in the WAI has always been associated with the increase in the amylose leaching and solubility, and loss of starch crystalline structure. The high WAI of flour could be attributed to the presence of higher amount of carbohydrates in this flour. WSI (water solubility index) is related to the presence of soluble molecules differed significantly among different flours. WSI of different flours varied from 6.79 to 8.53 (Table 3.2), it was observed that decrease in WSI with the semi dry and wet grinding process.
Table 3.2  Physico-chemical characteristics of rice flour and corn flour

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Rice flour</th>
<th>Corn flour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Semi dry</td>
</tr>
<tr>
<td>Moisture, %</td>
<td>11.23±0.54C</td>
<td>11.77±0.15B</td>
</tr>
<tr>
<td>Protein, %</td>
<td>7.84±0.25A</td>
<td>7.26±0.18B</td>
</tr>
<tr>
<td>Fat, %</td>
<td>1.19±0.05A</td>
<td>1.16±0.03B</td>
</tr>
<tr>
<td>Ash, %</td>
<td>0.59±0.02A</td>
<td>0.53±0.01B</td>
</tr>
<tr>
<td>Carbohydrate, %</td>
<td>79.15±0.59D</td>
<td>79.28±0.81C</td>
</tr>
<tr>
<td>Amylose, %</td>
<td>21.76±0.31A</td>
<td>20.08±0.28B</td>
</tr>
<tr>
<td>*WAI</td>
<td>2.70±0.14B</td>
<td>2.71±0.11B</td>
</tr>
<tr>
<td>*WSI</td>
<td>8.53±0.21A</td>
<td>8.41±0.28B</td>
</tr>
</tbody>
</table>

*Water Absorption Index, *Water Solubility Index

3.3.4  Particle size analysis

Particle size analysis was performed to obtain the particle size distribution and to assess the average particle size (Figure 3.6). Flour samples were assessed after the sieving process with 100 BSS sieve size. The results revealed that the semidry ground rice flour was composed the smallest range in particle size. The particle size distribution showed an increased volume of fine particle sizes compared with dry grinding process. Since wet grinding involves a soaking process, rice kernels are softened and easily broken (Chiang and Yeh, 2002). In addition to flour composition, flour quality is also influenced by flour particle size distribution. Higher amount of smaller flour particles leads to a less extensible and less fluidable.
Figure 3.6 Particle size distribution of Pusa 1121 broken rice flour as affected by grinding methods

3.3.5 Cake strength

The tendency of any flour to cake can provide important information about the properties and behavior of the flour on storage and transportation. Caking properties assessed during the test are shown in Figure 3.7. All the samples exhibited an increasing cake height ratio, indicating susceptibility towards caking. Higher cake strength values could be seen for rice flour with wet grinding method. The difference in heights was probably due to the fact that the powder was compacted hard during the very first cycle than the next cycles. Caking takes place because of the transformation of powders into undesirable lumps ranging from small and soft aggregates that can be broken easily to hard lumps resulting in loss of flow ability. Cake strength and mean cake strength are calculated using texture exponent software. It is evident from plot of cake height ratio with 5\textsuperscript{th} number cycle shown in Figure 3.7.
Figure 3.7  Powder flow characteristics of Pusa 1121 broken rice flour as affected by grinding methods

3.3.6  Morphological properties

The granular structure of rice flours obtained from different grinding methods showed significant variation in size and shape when viewed by scanning electron micrographs (Figure 3.8). The flour granules were observed to be polyhedral and irregular in shape. Flour from dry grinding mainly consisted of large size polyhedral granules with few small and irregular granules, while the semi dry and wet grinding flour showed small size irregular granules in a fairly large number. The small particles (starch granules) were generally round in shape with a smooth surface, whereas the large particles (flour particles) had a rough surface and irregular shape. Round to polygonal granules of rice flour were agglomerated and very small in diameter having a narrow size distribution which is in agreement with Vallons et al., (2011) and Naruenartwongsakul et al., (2008).
Figure 3.8  Morphological characteristics of Pusa 1121 broken rice flour as affected by grinding methods

3.3.7 Pasting properties

The pasting behavior of flour samples were analyzed using the Rapid Visco Analyser (RVA). The pasting behavior and the typical pasting curves obtained from the RVA are shown in Figure 3.9. The flour characteristics analysed by the RVA were found to be influenced by the grinding methods. The dry ground flour showed higher peak viscosity than the semidry grinded rice flour (Figure 3.9), as the peak viscosity is
a measure of the water holding capacity of the starch in terms of the resistance of swollen granules. The dry grinding rice flour having highest cool paste viscosity (6523 cP) followed by wet, semidry ground flour and corn flour (4371 cP). This may be because of flour having low amylose would swell easier indicating a weaker binding force in that starch granule and upon heating its viscosity could increase at lower temperature. Higher setback value for dry grinded flour further indicated the degree of re-crystallization of the gelatinized starch during cooling. The variable nature of pasting behavior, dependent on grinding method and having higher viscosity thus reflects the suitability of dry ground Pusa 1121 flour as a suitable thickening ingredient having more nutritional and functional values in place of corn flour.

Pasting characteristics of different rice flours are shown in Table 3.3. The pasting properties are also influenced by granule size, starch molecule characteristic and the thermal process involved in gelatinization of the starch (Lai, 2001). Pasting temperature of different rice flour samples ranged from 81.40 to 86.45 °C, highest for semidry grinding sample. The increase in viscosity with temperature may be attributed to the removal of water from the exuded amylose by the granules as they swell (Ghiasi et al., 1982). The lower peak viscosity in dry ground flour is probably because of the higher damage caused to starch during the dry grinding process (Yoenyongbuddhagal and Noomhorm, 2002). The breakdown viscosity is regarded as a measure of the degree of disintegration of granules and shows paste stability. During the breakdown, the granules are disrupted and the amylose molecules will leach out into the solution.
Figure 3.9  Pasting behavior of ground Pusa 1121 rice flour and corn flour

Table 3.3  Pasting characteristics of Pusa 1121 broken rice flour and corn flour

<table>
<thead>
<tr>
<th>Particulars</th>
<th>Rice flour</th>
<th>Corn flour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry</td>
<td>Semi dry</td>
</tr>
<tr>
<td>Peak viscosity, cP</td>
<td>5353</td>
<td>4962</td>
</tr>
<tr>
<td>Trough, cP</td>
<td>3307</td>
<td>3022</td>
</tr>
<tr>
<td>Breakdown, cP</td>
<td>2046</td>
<td>1940</td>
</tr>
<tr>
<td>Final Visosity, cP</td>
<td>6523</td>
<td>5874</td>
</tr>
<tr>
<td>Setback, cP</td>
<td>3216</td>
<td>2852</td>
</tr>
<tr>
<td>Peak Time, Min.</td>
<td>5.4</td>
<td>6.27</td>
</tr>
<tr>
<td>Pasting Temp., °C</td>
<td>81.4</td>
<td>86.45</td>
</tr>
</tbody>
</table>
3.3.8 X-ray diffraction (XRD) analysis

The effects of grinding methods on XRD pattern for Pusa 1121 broken rice flour is shown in Figure 3.10. The XRD pattern indicated the presence of A-type patterned starch with strong peaks at around 15.1, 18.07 and 23.2° 2θ and feeble peaks at 19.85, 26.4 and 30.3° 2θ (Vansteelandt and Delcour 1999; Noosuka et al., 2005). Higher crystallinity could be associated with the presence of sharp peaks, which are found in the semi-dry or wet ground flours. This may be attributed to the degree of grinding and associated conversion of starch into more amorphous form. The results from the physical damage of the native amylopectin lead to degradation of the starch into low molecular weight fragments which may disrupt the glycosidic linkages and the disulphide bonds of the native grain.

![Figure 3.10](image)

*Figure 3.10* X-ray diffraction pattern of Pusa 1121 broken rice flour as affected by grinding methods
3.3.9 Fourier transform infrared (FTIR) spectroscopy

The infra-red spectrum (700-4000 cm\(^{-1}\)) as obtained for the rice flours obtained by different grinding methods is presented in Figure 3.11. Comparing the peaks it may be concluded that insignificant difference exist between the different ground flours other than the reduced peak at 3330 wave number for the dry ground flour. This may be due to less moisture present in the dry ground rice powder.

![Figure 3.11 Fourier Transform Infra-Red spectroscopy profile of Pusa 1121 broken rice flour as affected by grinding methods](image-url)
3.4 CONCLUSION

The study showed that the grinding duration was found to be having the role in deciding the ultimate size of ground particles with the particle size distribution and confirmed its direct influence on the characteristics of rice broken. The grinding constants (K_k, K_r, W_l) for different laws reflected the dependency on grinding duration. Rice flour obtained through various grinding methods showed significant differences in physico-chemical, morphological and pasting properties. The grinding process reduces the rice flour particle size and affects the particle distribution characteristics significantly.

Powder flow analysis is an effective tool to characterize the flow properties of powders to elucidate the effect of powder morphology, granule size and their distribution on flow behavior and subsequent processing. The effect of grinding methods indicated the conversion of particles into more amorphous form. The different grinding methods results variations in pasting characteristics of rice flours and found rice flour contributes more viscosity than corn flour for specific uses. Moreover, dry grinding method for making the rice flour was found optimal based on the pasting behavior.