Studies on Ground Corn Flowability as Affected by Particle Size and Moisture Content

H. T. Jadhav
*Iowa State University*, harish@iastate.edu

Chinwendu Ozoh
*Iowa State University*, cfozoh@iastate.edu

Sai Teja Marripudi
*Iowa State University*

Xiong Cao
*Iowa State University*

K. A. Rosentrater
*Iowa State University*, karosent@iastate.edu

Follow this and additional works at: [http://lib.dr.iastate.edu/abe_eng_conf](http://lib.dr.iastate.edu/abe_eng_conf)

Part of the [Agriculture Commons](http://lib.dr.iastate.edu/abe_eng_conf), and the [Bioresource and Agricultural Engineering Commons](http://lib.dr.iastate.edu/abe_eng_conf)

The complete bibliographic information for this item can be found at [http://lib.dr.iastate.edu/abe_eng_conf/523](http://lib.dr.iastate.edu/abe_eng_conf/523). For information on how to cite this item, please visit [http://lib.dr.iastate.edu/howtocite.html](http://lib.dr.iastate.edu/howtocite.html).
Studies on Ground Corn Flowability as Affected by Particle Size and Moisture Content

H. T. Jadhav¹, Chinwendu Ozoh², Sai Teja Marripudi², Xiong Cao³, and K. A. Rosentrater³

¹ Ph.D. Candidate, ² Former Graduate Students, and ³ Associate Professor
Agricultural and Biosystems Engineering Department, Iowa State University, Ames, IA-50011.

Written for presentation at the
2017 ASABE Annual International Meeting
Sponsored by ASABE
Spokane, Washington
July 16-19, 2017

ABSTRACT. Corn is the primary feed grain in the U.S., and it accounts for more than 90 percent of total feed grain production and use. Besides this, corn is the primary input for the U.S. ethanol industry. This results in tremendous infrastructure for handling and storage of corn and byproducts throughout the year. The flow properties of ground corn, which is a principal ingredient of animal feed, are very complex in nature. Many physical and chemical properties viz. angle of repose, bulk density, moisture of the product, protein content in the surface layer, etc. affects the flow properties of corn and its products. Flow through a hopper is a typical example of complex flow. Bridging or caking of feed material in feed hoppers are common problems, and many times blocks the flow completely leaving animals without feed. Daily changes in temperature and relative humidity affect the equilibrium moisture content of feed. Size of corn particles affect angle of repose, bulk density and cohesive forces between particles, and thus flow characteristics of the feed. In this study, flow characteristics of ground corn were examined as functions of particle size and moisture content. Feed utilization was historically maximum (i.e. minimum ratio of feed consumption to weight gain), when mean particle size diameter is about 822 microns for roller milled corn flour. In recent times, livestock producers have found that feed efficiency can increase as particle size decreases. Furthermore, excess moisture makes flour sticky and hampers free sliding of particles over each other during flow. Keeping this in view, different combinations of particle sizes and product moisture content were studied with the objectives of understanding and enhancing corn flour flowability.

Keywords. Ground corn, flowability, particle size, moisture content, Hausner ratio, Carr index
**Introduction**

Corn is the primary feed grain in the United States, and it accounts for more than 90 percent of total feed grain production and use. Also, corn is the primary input for the U.S. ethanol industry. Therefore, large scale handling and storage of corn and co-products become integral operation of the feed and ethanol industries. In handling, free flow properties or flowability of corn and co-products play the important role. And in reality, the flow properties of ground corn, which is a principal ingredient of animal feed, are very complex in nature (Rosentrater, 2006).

Rosentrater (2006) defined flowability as the ability of granular solids and powders to flow during discharge from transportation or storage containments. Flowability is a natural material property, and also a consequence of several interacting properties simultaneously influencing material flow. Flowability is affected by a number of synergistically interacting factors which includes product moisture, storage temperature, particle size distribution, relative humidity, time, compaction of the product mass, vibrations during transport, and variations throughout storage process. Other factors that may affect flowability include chemical composition of the product as well as the addition of flow agents. Rosentrater (2006) also summarized that the flow behavior of a feed material is multidimensional and no single test completely describes the flow behavior of the material. Ganesan et al. (2008b) studied the flowability of dried distiller’s grain with soluble (DDGS) and stated that the flowability of DDGS is a multivariate phenomenon and may be affected by storage moisture, temperature or temperature variations, relative humidity, particle size, storage time, and other such factors. Teunou et al. (1999b) stated that it is necessary to use flow function (and not a flow index) for describing the effect of temperature and relative humidity on the flowability of food powders (tea, wheat flour and whey permeate), as flowability being a multivariate phenomenon.

Moisture is the key factor which affects the flowability of grain particle products (Ganesan et al., 2008b). Moisture sorption mostly increases the cohesiveness of grain particle products mainly because of inter-particle liquid bridge formation. Moisture content, particle size and its distribution affect the flowability significantly. A decrease in particle size increases the surface area of granular material and this decrease the flowability of the material. Not only physical properties but also the chemical changes that would occur during the storage of product affect the flowability of powders. Teunou et al. (1999) studied the flow properties of four powders – tea, whey permeate, skim milk and wheat flour. The Study classified wheat flour as a highly cohesive and difficult to flow powder, but its flowability not changed significantly as relative humidity changed from 25 to 66 %. Water sorption isotherms of whey permeate and skim milk powders shows that they do not take up much water with increasing relative humidity and hence their flow property was not affected significantly with increasing relative humidity. However, these powders readily turn into cakes at lower relative humidity due to the presence of amorphous lactose and hence their flow properties are affected greatly when relative humidity changes from 36 to 66%.

Several types of flow problem occur in the bin or silo (Wilson, 2001). Mostly no or little flow occur upon opening the gate of a silo or after starting the feeder. One of the common problems is the formation of the arch (also called dome or bridge), just before the outlet and mostly in hopper section of the bin. The arch or bridge supports the entire content of silo above it and blocks the smooth flow of material. Other flow disturbing causes include – rathole (also core or pipe) formation, rathole and arch forming in the same silo and segregation in a product composed of different particle size. Flow problems result in limited live storage in a bin, spoilage or caking and shaking or vibrations in the bin due to sudden failure of arches or ratholes; which sometimes may lead to structural failures too. Flow properties of bulk materials directly affect the storage bin design. Proper design of bin or hopper is required to avoid frequent equipment failure and increased downtime.

There are different ways of flowability measurement. The primary equipment used to measure the flow properties of the material are shear testing equipment and they also measure the bulk strength of materials as well as the amount of compaction. Another approach to measuring flow properties of granular materials involves - measuring four important physical properties viz. compressibility, angle of repose, angle of spatula, and coefficient of uniformity (e.g. cohesion) (Rosentrater, 2006). No single and simple test is available to completely characterize the flow properties of a powder (Lumay et al., 2012). Six tests commonly used to measure flowability of powders includes: 1) compressibility index or Hausner ratio, 2) flow in the rotating drum, 3) flow through an orifice, 4) the angle of repose, 5) shear cell and 6) powder rheometers. The method used for flowability measurement should be easy to use, sensitive and reproducible. Also, the results obtained should be meaningful and easily interpretable and usable. Table 1 below indicates supposed relations among Hausner ratio, angle of repose and flowability of the powder (Lumay et al., 2012).

<table>
<thead>
<tr>
<th>Flow property</th>
<th>Angle of repose (°)</th>
<th>Hausner ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>&gt; 66</td>
<td>&gt; 1.60</td>
</tr>
<tr>
<td>Good</td>
<td>56-65</td>
<td>1.46-1.59</td>
</tr>
<tr>
<td>Fair</td>
<td>46-55</td>
<td>1.35-1.45</td>
</tr>
<tr>
<td>Poor</td>
<td>41-45</td>
<td>1.26-1.34</td>
</tr>
<tr>
<td>Very poor</td>
<td>36-40</td>
<td>1.19-1.25</td>
</tr>
<tr>
<td>Very very poor</td>
<td>31-35</td>
<td>1.12-1.18</td>
</tr>
<tr>
<td>Poor</td>
<td>25-30</td>
<td>1.00-1.11</td>
</tr>
</tbody>
</table>

Many researchers studied the flow properties (flowability) of different granular and powdery materials to fix the peculiar...
problems associated with the flow of these materials. DDGS particles having higher fat content have lower flowability or worse flow problems (Bhadra et al., 2008). Also, the more the amount of protein thickness as compared to carbohydrate thickness in surface layers of DDGS results in the lower flow function index and greater cohesiveness. The study conducted by Teunou et al. (1999b) on the flowability of food powders revealed that the instantaneous flow function increases with temperature and relative humidity (range 20 to 66 %), but showed a less significant effect on the flowability of wheat flour. Teunou and Fitzpatrick (2000) studied the effect of storage time and time consolidation on flow properties of wheat flour, tea and whey permeate. All the three powders showed time consolidation effects and their flowability reduced with increasing consolidation time. The wheat flour and tea powder, being more cohesive, showed greater sensitivity to time consolidation than that of whey permeate.

Flowability, cohesive and granulation properties of wheat powders vary greatly at low moisture content. Also, particle size distribution of wheat particles significantly affects the flowability and cohesion properties at low moisture content (Landillon et al., 2008). At higher moisture content, the flowability and cohesive properties of wheat particles were found to be partly dependent on biochemical (due to plasticizing effect of water on the wheat particles) and physiochemical mechanisms. Ganesan et al. (2008) studied the effect of moisture content and soluble level on flow properties of DDGS. The results highlighted that the caking issue in DDGS is mostly results from storage moisture changes, storage period and physical or chemical interactions between the particles. The flowability of DDGS generally declined significantly with an increase in moisture content. Guan and Zhang (2009) studied the effect of moisture content and compaction on the strength of arch formation in wheat flour in a steel model bin - 475 mm in height and 600 X 375 mm in cross-section. The moisture content of wheat flour and compaction pressure had a noticeable effect on arching. The hopper opening for the arch-free flow was 42% greater for 14.2% MC as compared to that of 8.6% MC. The hopper opening increased from 82 mm to 122 mm for 14.2% MC and from 50 mm to 82 mm for 8.6% MC when compacted at about 5 kPa. Also, the effect of compaction pressure on arch formation was found negligible beyond 5 kPa.

Ganesan et al. (2006) tried to improve the flowability of DDGS with an addition of flow agent. Flow Agent - Calcium Carbonate with 0, 1 and 2% wb addition levels and DDGS moisture levels of 10, 15, 20 and 25 % db were used to study its (DDGS) flow properties (Carr indices) at varying soluble percentages (10, 15, 20, and 25 % db). The addition of flow agent (CaCO3) not shown the significant effect in improving the flow properties of DDGS with different moisture content and soluble levels. Wilson (2001) mentioned very specifically that the extreme methods like vibrators and air blasters, sledgehammers, etc. are required to restart the stuck flow (due to caking or time consolidation or similar reasons) of granular or powder particles.

Cereal grains are the primary energy source in the animal diet. In an overall Swine or Poultry production costs, 65 to 75 % cost goes towards feed material. Hence, increased feed utilization efficiency have tremendous impact on cost effective production. In a study conducted by Goodband et al. (2002) on testing effect of particle size of corn based diets on starter pig performance, corn milled with roller mill having 822 microns mean particle size diameter yielded 1.81 feed consumption/weight gain ratio; while, 1147 microns particle size yielded 1.92 feed consumption to weight gain ratio. Hence, finer feed particle size is preferred in an animal diet to achieve better feed utilization; though energy consumption in milling of cereal grains for making animal feed increases exponentially when mean particle size diameter goes below 600 microns (Wondra et al., 1995). Also, finer particles affect flowability of feed material negatively.

The objective of this study was to understand the flow properties of corn milled with a roller mill at different moisture content and to get different particle sizes. Study of the flow characteristics of ground corn was essential since it is the main ingredient used for animal feed and would influence the flow of the feed in the hopper greatly.

Materials and Methods

A roller mill was used to grind the corn. The clearance/gap between the rollers of the mill was changed to get ground corn samples of different particle size distributions. The particle size of ground corn was measured by following standard procedure used in Ro-Tap sieve analysis. The main objective of this experiment was to study flow behaviors of ground corn under the influence of its different particle sizes and the moisture contents. The detailed procedure and instruments used to quantify different flowability indices and the procedure used to change moisture content of the ground corn samples is outlined below.

Angle of Repose

A rapid method for assessing the behavior of granular mass is to measure its 'angle of repose'. If a solid ground material is poured onto the plane surface, it will form an approximately conical heap, and the angle between the sloping side of the cone and the horizontal is the angle of repose. When determined in this manner, it is referred as the dynamic angle of repose or the poured angle. The angle of repose ($\theta$) is the angle with the horizontal at which the materials will stand when piled (Mohsenin, 1978). In this study, a heap was made but the samples. Then, the height and base length of the heap were measured; the angle created by the heap was measured using equation 1.
Bulk Density and Tapped Density

The bulk density of a material is its mass divided by the volume occupied by it. The bulk density of a material is also referred to as the untapped mass of a material that can be packed into a specific volume. The volume includes the spaces between particles as well as the envelope volumes of the particles themselves (WHO, 2012). Hence, the bulk density depends on both the density of powder particles and the spatial arrangement of particles in the powder bed. In this study bulk density was measured using the instrument-volumeter, the ground corn was poured into the hopper, with a one-litre cylindrical vessel of stainless steel was placed directly under it as shown in figure 1. The opening of the volumeter was opened and the ground corn was allowed to flow freely into the vessel. Then the top of the cylindrical vessel was levelled using a ruler in a zigzag motion, and the weight of the ground corn was measured.

\[ \theta = \tan^{-1}\left(\frac{\text{height of the heap}}{0.5 \times \text{base length}}\right) \]  

FIGURE 1. VOLUMETER - THE EQUIPMENT USED TO MEASURE BULK DENSITY OF THE GROUND CORN SAMPLES.

Tapped density is an increased bulk density attained after mechanically tapping a container containing the granular material. The tapped density is obtained by mechanically tapping a graduated measuring cylinder or vessel containing the powder sample. After observing the initial powder volume or mass, the measuring cylinder or vessel is mechanically tapped, and volume or mass readings are taken until little further volume or mass change is observed. The mechanical tapping is achieved by raising the cylinder or vessel of known volume and allowing it to drop, under its own mass, from a specified height. In this study, the capacity/volume of the vessel was increased by using removable rubber ring (attached at top end of the vessel) as shown in figure 2, and the vessel was tapped 50 times from the height of 5 cm (2 inches). Then the top of the vessel is levelled in a zigzag motion using the ruler and the weight was measured. The unit for both bulk and tapped density is gm/liter or Kg/m³. The formulae to calculate bulk density and tapped density are shown in equations 2 and 3 respectively.

\[ \text{Bulk density} = \frac{\text{untapped mass}}{\text{volume of the vessel}} \]  

\[ \text{Tapped density} = \frac{\text{tapped mass}}{\text{volume of the vessel}} \]
Hausner Ratio and Carr Index

Hausner ratio is a number that is correlated to the flowability of a material. It is the ratio of tapped density and the bulk density of a material (equation 4). A Hausner ratio greater than 1.25 is considered to be an indication of poor flowability.

\[ \text{Hausner ratio} = \frac{\text{tapped density}}{\text{bulk density}} \] (4)

The Carr index is frequently used in pharmaceutics as an indication of the flowability of a powder. In a free-flowing powder, the bulk density and tapped density would be close in value, therefore, the Carr index would be small. On the other hand, in a poor-flowing powder where there are greater inter-particle interactions, the difference between the bulk and tapped density observed would be greater, hence, the Carr index would be larger. A Carr index greater than 25 is considered to be an indication of poor flowability, and below 15, of good flowability. The formula used to calculate Carr’s index is shown in equation 5.

\[ \text{Carr Index} = \frac{(\text{tapped density} - \text{bulk density}) \times 100}{\text{tapped density}} \] (5)

Moisture Content

Moisture content was determined by weighing about 2 gm of the ground corn samples, before and after drying in a Thermo-scientific Heratherm oven at 135˚C for 2 hours. The drying and weighing procedure was done with 3 replicates and the average was obtained. The moisture contents of the some of the ground samples used in the study were altered as we wanted to get readings/data points at different moisture levels. This hydration of material was accomplished by direct addition of water to the samples, plus mixing until a homogenous consistency was obtained. The amount of distilled water added \( (Q, gm) \) was calculated using the equation 6 (Sacilik et al., 2003). The moisture content of the ground corn samples was tested after water addition, using the procedure mentioned above to check whether the required moisture level was attained or not. It was assumed that the samples were at equilibrium with the temperature and relative humidity of the room i.e. at 24.6 ±2.2°C and 18.2 ±5.7 %, respectively.

\[ Q = \frac{W_i(M_f - M_i)}{(100 - M_f)} \] (6)

Where, \( W_i = \) the initial weight of ground corn sample, gm
\( M_i = \) initial moisture content of ground corn sample, % db
\( M_f = \) final moisture content of ground corn sample, % db

Mass Flow Rate

Mass flow rate is the mass of a substance which passes per unit time. The unit used for this study is kg/s. The mass flow rate was calculated using a laboratory scale hopper with an opening (figure 3) and a stopwatch. The material was poured inside the silo and the gate at the bottom end of the hopper was opened fully. Then, the time taken by the sample to exit completely was recorded. Then, the mass flow rate (Kg/s) was calculated as the amount of sample that exited hopper bottom end in a unit time. Each test was replicated thrice.
Results and Discussion

The ground corn samples having different particle size distributions were tested to determine their flow properties at different moisture content. The five different particle sizes selected for the study were 1076, 1178, 1271, 1949 and 1996 micron. The moisture content of the ground corn samples ranged from about 7 % wb to 15 % wb. In actual experimentation, the original moisture content of the ground corn was measured and if that moisture content was found less than about 15 % wb, then that (moisture content) was increased till it became about 15 % wb. Actually, the moisture was increased in the steps of 3%, till it reached to the desired moisture content of about 15 % wb. The results depicting effects of particle size and moisture content on the flowability of ground corn samples are presented and discussed in this section. Further, each flowability test was replicated thrice. The average flow rates of ground corn samples through the flowmeter for the different treatments (combinations of particle sizes and moisture contents) are presented in table2. Also, the effect of particle size and moisture content on bulk and tapped density are shown in figure 4.

The bulk density and tapped densities for all the treatments varied between 539.67 to 615.33 Kg/m$^3$ and 637 to 740.33 Kg/m$^3$, respectively. Bulk density and tapped density are significantly affected by particle size distribution, but the effect of moisture content on both the densities was non-significant. Both bulk and tapped densities increased with increasing particle size. In case of the flow rate of the ground corn samples, the combined effect of particle size and moisture content showed that the flow rates are different (table 2), but the individual effects of particle size and moisture content on flow rate showed the weak correlation. The flow rates for all the treatments were varied between 0.70 to 1.12 kg/s. In general, flow rate decreased with decreasing particle size of ground corn samples, and it showed increasing trend with the moisture content. But no significant effect of moisture content on flow rate was observed. Similar results were reported by Teunou et al. (1999) for wheat flour. Landillon et al. (2008) added that the flowability, cohesive and granulation properties of wheat
powders vary greatly at low moisture content. Also, particle size distribution of wheat particles significantly affects the flowability and cohesion properties at low moisture content only.

Table 2. Effect of particle size and moisture content on the flow rate of ground corn.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Particle size, micron</th>
<th>Moisture content, % wb</th>
<th>Flow rate, Kg/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(^{[a]}) (6.97(^{[b]}))</td>
<td>1996</td>
<td>6.97 (± 0.89)</td>
<td>1.03 (± 0.109) a, b(^{[c]})</td>
</tr>
<tr>
<td>A(12.11)</td>
<td>1996</td>
<td>12.11 (± 0.39)</td>
<td>0.99 (± 0.06) a, b</td>
</tr>
<tr>
<td>A(13.53)</td>
<td>1996</td>
<td>13.53 (± 1.04)</td>
<td>0.99 (± 0.08) a, b</td>
</tr>
<tr>
<td>A(15.36)</td>
<td>1996</td>
<td>15.36 (± 0.26)</td>
<td>1.01 (± 0.059) a, b</td>
</tr>
<tr>
<td>B(9.42)</td>
<td>1271</td>
<td>9.42 (± 0.40)</td>
<td>0.70 (± 0.03) c</td>
</tr>
<tr>
<td>B(12.07)</td>
<td>1271</td>
<td>12.07 (± 0.28)</td>
<td>1.02 (± 0.06) a, b</td>
</tr>
<tr>
<td>B(14.76)</td>
<td>1271</td>
<td>14.76 (± 0.76)</td>
<td>0.92 (± 0.04) a, b, c</td>
</tr>
<tr>
<td>C(10.10)</td>
<td>1076</td>
<td>10.10 (± 0.30)</td>
<td>1.07 (± 0.18) a</td>
</tr>
<tr>
<td>C(11.57)</td>
<td>1076</td>
<td>11.57 (± 1.08)</td>
<td>1.12 (± 0.07) a</td>
</tr>
<tr>
<td>C(16.17)</td>
<td>1076</td>
<td>16.17 (± 2.35)</td>
<td>1.17 (± 0.11) a</td>
</tr>
<tr>
<td>D(12.09)</td>
<td>1178</td>
<td>12.09 (± 0.04)</td>
<td>0.83 (± 0.06) b, c</td>
</tr>
<tr>
<td>D(14.55)</td>
<td>1178</td>
<td>14.55 (± 0.34)</td>
<td>0.96 (± 0.02) a, b</td>
</tr>
<tr>
<td>E(15.85)</td>
<td>1949</td>
<td>15.85 (± 0.51)</td>
<td>1.06 (± 0.01) a, b</td>
</tr>
</tbody>
</table>

\(^{[a]}\) The capital letters indicate the average particle size of the ground corn samples.

\(^{[b]}\) The numbers indicate average moisture content of different ground corn samples used for the test.

\(^{[c]}\) The flow rates not connected by the same small letters are significantly different from each other.

The data collected on other flow properties viz. Angle of Repose, Hausner Ratio and Carr Index are presented in table 3.

Table 3. Other flow indices of ground corn samples as affected by different treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Angle of repose, (°)</th>
<th>Hausner ratio</th>
<th>Carr index</th>
</tr>
</thead>
<tbody>
<tr>
<td>A(^{[a]}) (6.97(^{[b]}))</td>
<td>30.36 (± 2.65)</td>
<td>1.20 (± 0.00)</td>
<td>16.88 (± 0.29)</td>
</tr>
<tr>
<td>A(12.11)</td>
<td>34.62 (± 0.57)</td>
<td>1.23 (± 0.01)</td>
<td>18.79 (± 0.66)</td>
</tr>
<tr>
<td>A(13.53)</td>
<td>34.02 (± 0.62)</td>
<td>1.26 (± 0.00)</td>
<td>20.64 (± 0.10)</td>
</tr>
<tr>
<td>A(15.36)</td>
<td>34.7 (± 0.45)</td>
<td>1.24 (± 0.01)</td>
<td>19.29 (± 0.65)</td>
</tr>
<tr>
<td>B(9.42)</td>
<td>31 (± 0.33)</td>
<td>1.28 (± 0.05)</td>
<td>21.68 (± 3.21)</td>
</tr>
<tr>
<td>B(12.07)</td>
<td>34.92 (± 0.45)</td>
<td>1.24 (± 0.01)</td>
<td>19.1 (± 0.73)</td>
</tr>
<tr>
<td>B(14.76)</td>
<td>34.42 (± 0.58)</td>
<td>1.28 (± 0.02)</td>
<td>21.97 (± 0.99)</td>
</tr>
<tr>
<td>C(10.10)</td>
<td>31.25 (± 0.71)</td>
<td>1.26 (± 0.02)</td>
<td>20.92 (± 1.30)</td>
</tr>
<tr>
<td>C(11.57)</td>
<td>35.62 (± 1.00)</td>
<td>1.29 (± 0.01)</td>
<td>22.24 (± 0.84)</td>
</tr>
<tr>
<td>C(16.17)</td>
<td>35.70 (± 1.22)</td>
<td>1.30 (± 0.02)</td>
<td>23.30 (± 1.08)</td>
</tr>
<tr>
<td>D(12.09)</td>
<td>34.26 (± 2.16)</td>
<td>1.27 (± 0.00)</td>
<td>21.11 (± 0.21)</td>
</tr>
<tr>
<td>D(14.55)</td>
<td>35.42 (± 1.65)</td>
<td>1.29 (± 0.01)</td>
<td>22.27 (± 0.69)</td>
</tr>
<tr>
<td>E(15.85)</td>
<td>25.32 (± 1.17)</td>
<td>1.24 (± 0.01)</td>
<td>19.27 (± 0.73)</td>
</tr>
</tbody>
</table>

\(^{[a]}\) The capital letters indicate the average particle size of the ground corn samples.

\(^{[b]}\) The numbers indicate average moisture content of different ground corn samples used for the test.

The angle of repose of all the treatments varied between 25.32° to 35.70°. Comparing with supposed values of angle of repose listed for different flow properties of the powdery material (Lumay et al., 2012), this range of angle of repose indicates that all the corn flour samples tested had good flow properties. The angle of repose was lower (25.32°) for treatment E(15.85). Angles were higher (35.62° and 35.70° respectively) for treatments C(11.57) and C(16.17). The data also indicated that the angle of repose was higher for the ground corn samples having lower particle size. That means these samples (having the higher angle of repose) of ground corn must have minimum flow properties among all the samples tested during the experiment. Also, the angle of repose was significantly different for various treatments, bearing negative correlation with particle size. However, the effect of moisture content on the angle of repose was non-significant for different ground corn samples.

The Hauser ratio for all the treatments ranged from 1.20 to 1.30. Again, comparing with supposed values of Hausner ratio for different flow properties of the powdery material (Lumay et al., 2012), the flow properties of tested ground corn
samples ranged between fair to passable. It will be important to mention that the angle of repose flow index classified these samples as materials with excellent to good flow properties. Hausner ratio was found higher for lower particle size and significantly varied with the particle size of the samples. Hausner ratio was increasing with increase in moisture content, but the effect of moisture content was found non-significant.

The Carr index ranged from 16.88 to 23.30 for the treatments. Carr index was found higher for lower particle size values and was significantly varied with the particle size of the samples. It was found increasing with moisture content, and moisture content effect on Carr index of the samples was found significant.

**Summary and Conclusions**

Flow properties of ground corn play an important role while handling the product in the feed manufacturing industry as well as during the transport of the feed at various levels. In this study, a roller mill was used to grind the corn. The clearance/gap between the rollers of the mill was changed to get ground corn samples of different particle size distributions. The five different particle sizes of ground corn viz. 1076, 1178, 1271, 1949 and 1996 micron were selected for the study. The moisture content of the samples was maintained approximately between 7 to 15% and the combined effect of the particle sizes and moisture contents on the flow properties of the ground corn samples was studied. The different flow indices such as flow rate, the angle of repose, Hausner ratio, and Carr index were determined for the study. Results showed that the effect of moisture content of the ground corn samples on its bulk and tapped density was non-significant. The combined effect of particle size and moisture content showed that the flow rates of the ground corn samples are different (significant effect), but the individual effects of particle size and moisture content on the flow rate showed the weak correlation between them. In conclusion, it was observed that the particle size of the ground corn samples tends to have more effect on their flow properties than the moisture.

**References**


