FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Engineering properties of high and low altitude rice varieties from Kashmir valley at different processing levels

Raees Haq*, Muzamil Wani and Kamlesh Prasad

Abstract: The knowledge of engineering properties such as gravimmetrical properties (1,000 grain mass, bulk density, true density, and porosity), dimensional properties (length, width, thickness, aspect ratio, surface area, geometric mean diameter, and sphericity), frictional properties (angle of repose and coefficient of friction), and aerodynamic properties (drag coefficient and terminal velocity) are necessary parameters related to machine design for different agricultural process operations such as handling, harvesting, threshing, cleaning, conveying, sorting, drying, processing, and storage. India is a vast country and contributes 20% of the total world’s rice production with cultivars ranging from the scented long grain ones to the sticky short grains. The Kashmir valley cultivates mainly short–medium bold varieties as temperate conditions in the valley are not suitable for the cultivation of long grain scented basmati rice. The most steps in cultivation and postharvest processing are manual and the aim of this work is to emphasize which variety sustains the processing steps to produce high yield quality rice for strengthening the economic conditions of the people.

Subjects: Agricultural Engineering; Agriculture; Crop Science; Food Engineering

Keywords: paddy; milling; husk; aerodynamic property; head rice

ABOUT THE AUTHORS

Raees-ul Haq obtained his postgraduation from Islamic University of Science and Technology, Awantipora and is currently a doctoral research fellow at Sant Longaul Institute of Engineering and Technology, Sangrur in Food Engineering and Technology Department.

Muzamil Manzoor Wani is a graduate student at Brindavan College of Engineering, Bangalore.

Kamlesh Prasad is a professor at Department of Food Engineering and Technology, Sant Longaul Institute of Engineering and Technology, Sangrur.

PUBLIC INTEREST STATEMENT

The present study was conducted to examine different engineering properties of various paddy varieties grown in Kashmir valley. The conditions of growth in the region are highly challenging due to prolongation of cooler conditions in April and May. The varieties grown here are different than the ones grown in other parts of the country and are more tolerant to cooler conditions. The engineering properties of the varieties grown in Kashmir valley have not been attempted by any study and the data for the same is lacking. The mechanization of paddy cultivation and harvest requires knowledge of different engineering properties. The work functions as data compilation of engineering properties, that may be used up by engineers in designing and manufacturing different agriculture equipment.
1. Introduction

Rice (*Oryza sativa* L.) is one of the commonly consumed cereals throughout the world sustaining about two-third of global population (Zhou, Robards, Helliwell, & Blanchard, 2002) and is principle food cereal source next only to wheat in terms of yearly food consumption (Ghadge & Prasad, 2012). The global rice production increased from 605 million tons (MT) to 741 MT from 2004 to 2013 of which more than 90% is produced in Asia and about 22% in India. Rice production in India has witnessed a spectacular increase with figures of 5.25% from 2010 to 2013 and is approximately one-fourth of the total rice production of the world. The rice production of India was 701 MT in 2010 that rose to 741 MT in 2013. Rice is the second major crop cultivated in India next only to sugarcane in terms of annual production (FAOSTAT, 2015). Rice is cultivated in the plain regions of the Kashmir valley and is the staple food crop of the region as with more than world’s half population (Prasad, Prakash, & Prasad, 2010).

Kashmir has a temperate climate (temperature −10 to 30°C and altitude 200–7,000 meters above sea level or masl) mainly dominated by cooler temperatures with summers lasting few months (June–September) whose average temperatures are always below 30°C mark. Crops for such harsh conditions must be cold tolerant and therefore the varieties grown in the valley are different from the rest of country. Crop yield at these locations is a major problem as a slight change in weather conditions can spoil the whole production. Development of cold-tolerant- and fast-growing rice varieties is necessary for the above said topography. Various cold-tolerant varieties that grow on plains as well as in hilly areas have been developed by Rice Research Institute Khudwani (Kaw, 1985) with some prominent ones include Shalimar 1, 2 and 3, Jehlum, Chenab, Kohsar, Barakat and so on whose average yield is 6–7 tons/ha. Lower temperature in April delays sowing and to overcome the problem germinated grains are sown in sunny days so as to facilitate their growth. Major parts of the Kashmir region cultivating rice has a relatively plane area with an altitude of 1,300–2,000 masl belonging to mid-altitude region, whereas the higher altitude regions have an altitude greater than 2,000 masl (Anon, 2008). The major areas of rice production in valley include Anantnag, Baramulla, Budgam, Pulwama, and Srinagar ordered, respectively, by their decreasing production.

The engineering properties of paddy could affect its milling quality parameters like head rice yield (HRY) and degree of milling (DOM). The faulty designed machines and operations may result in the production of low-quality rice by cracking and breakage of the rice kernel and proper knowledge of their engineering properties can be used to overcome the mentioned fault (Irtwanage, 2012). The dimensions of paddy grains are used in selecting sieve separators for grading, calculating the power requirement during rice milling process, calculating kernel volume and surface area, and determining quantities like, aspect ratio, surface area, sphericity, and geometric mean diameter that are necessary for the modeling of grain during drying, heating, cooling, and aeration (Varnamkhasti et al., 2007). Thousand grain mass of rough rice or paddy is used for calculating the HRY, which is three-fourth or more in size than whole milled rice grains (USDA, 1990). High HRY and total milled rice yield are important parameters for any rice variety to be commercially successful. Thousand grain weight of paddy is also used to determine the expected milling output at the laboratory, by taking weights of 1,000 milled head rice grains, corresponding them to 1,000 grain weight of paddy, and is expressed as percent weight of milled whole rice grains. Milling loss is quite evident when there is any shortfall in actual milling output due to breakage of grain (Sarker & Farouk, 1989), relative amount of dockage (foreign material) within a given paddy lot and presence of shriveled immature kernels (Luh, 1980).

The grain’s bulk density, true density, and porosity is useful in sizing grain hoppers, storage facilities, and affects mass and heat transfer rates of moisture during aeration and drying processes. The ratio of the inter-granular void space volume and bulk volume of grain is porosity (Mohsenin, 1986) and includes the voids within and among the particles. Drying of a grain bed with low porosity increases the water vapor escape resistance that can be overcome using higher power to drive the aeration fans (Jouki & Khazaei, 2012). The differences between specific gravity and bulk density of the grain is the principle used for gravity cleaning of paddy separators to separate materials that have little difference in size and total mass (De-Datta, 1993). The volume, specific gravity, moisture
content, and porosity of agricultural products are the basic parameters required for their drying, storage, and previewing quality loss of material until its marketing time (Corrêa, da-Silva, Jaren, Afonso, & Arana, 2007). The static coefficient of friction, the ratio of frictional force (force due to the resistance of movement) to normal force on surface wall, is employed for determining the positional angle of chutes in order to maintain a consistent flow of materials through the chute. The static coefficient of friction finds its application in sizing motor requirements for grain transportation, handling, and designing conveying equipment (Varnamkhasti et al., 2008). The coefficient of friction is also necessary for safe designing of equipment and silo wall surfaces to facilitate grain handling equipment, their processing, and storage (Lawton, 1980; Mohsenin, 1986; Suthar & Das, 1996). The angle between the base and slope of cone formed by free vertical fall of granular material is the angle of repose that finds use in designing packages and storage structures, mainly for calculating hopper sidewall slope angle (Razavi & Farahmandfar, 2008). The flowability of agricultural grains is usually measured using angle of repose that is a measure of grain internal friction between them and hence finds its use in hopper design, whose wall inclination angle must always be greater than angle of repose in order to maintain continuous material flow by gravity (Zareiforoush, Mohtasebi, Tavakoli, & Alizadeh, 2010).

Designing of the air conveying systems and the equipment for cleaning, handling, aeration, storing, and processing requires the knowledge of terminal velocity (Güner, 2007), which is equal to the air velocity at which particle remains in suspended state in vertical pipe. The role of terminal velocity is important in grain cleaning by removing impurities like chaff, dockage, immature, and hollow grains. The separation process by an air stream in grain mix depends on the ratio between terminal and air velocity of particles, and their entrained particle quantity in unit volume of air flow (Varnamkhasti et al., 2008).

The present investigation studied hulling and milling characteristics of four different paddy cultivars sown in mid- and high-altitude ranges of Kashmir region. The processing of paddy yielded brown and white rice that were studied for different engineering properties. Lack of mechanization from cultivation to processing of rice in Kashmir valley was the primary objective to acquire and make it available for engineers for designing of different equipment.

2. Materials and methods

2.1. Milling
Four varieties of Paddy/Rice seeds [Shalimar 1, Chenab, Kohsar and Barkat] were collected from Rice Research Center Khudwani Anantnag, J&K. Shalimar 1 and Chenab varieties are suited and grown in mid-altitude range of about 1,300–2,000 masl, whereas Kohsar and Barkat varieties are suited for high-altitude areas with an altitude greater than 2,000 masl. The brown and white rice samples were obtained by the hulling in a rubber roll mill followed by their milling in a polisher for 30 s to separate the bran. The time of polishing was set by performing trials at different periods of time. The grains were cleaned manually by removing all foreign matter such as dirt, stones, and broken rice. The rice recovery (hulling and milling), brown rice, white rice, brokens, husk, and bran were determined during processing of paddy to white rice. Paddy, brown rice, and its white form from Shalimar 1, Chenab, Kohsar, and Barkat varieties are shown in Figure 1.

2.2. Dimensional properties
The dimensional properties were determined by the procedures as adopted by Mohsenin (1986). Ten grains from four varieties were selected randomly at each level of processing and were measured for three major linear dimensions, length (L), width (W), and thickness (T) using the grain meter (Mitutoyo Corporation, Japan) with an accuracy of 0.01 mm. These dimensions were used for calculating other physical properties like surface area, sphericity, geometric mean diameter, and aspect ratio.
2.3. Gravimetric properties

Thousand kernel weight was calculated by counting the hundred grains from each sample and weighing them in a precision electronic balance (Ishida Japan) reading to an accuracy of 0.001 g and were subsequently multiplied by 10 to give mass of 1,000 grains (Nalladurai, Alagusundaram, & Gayathri, 2002). The true density ($\rho_t$) was determined using the toluene displacement method (Mohsenin, 1986) as it is less absorbed by grains and with its low surface tension it fills even shallows dips in a grain. The bulk density ($\rho_b$) was determined by filling a graduated cylindrical container with grains and the top was leveled taping a couple of times followed by weighing the sample (Mohsenin, 1986; Paksoy & Aydin, 2004). Porosity ($\epsilon$) is the percent void space existing in bulk grain entraining air was determined by Equation (1) (Jain & Bal, 1997; Mohsenin, 1986)

$$
\epsilon = \left[ 1 - \frac{\rho_b}{\rho_t} \right] \times 100
$$

(1)

2.4. Frictional properties

The static coefficient of friction (COF) for the grains was measured against four frictional surfaces, namely plywood parallel, plywood perpendicular, galvanized iron sheet, and glass. A cylindrical piece of pipe open at both ends with dimension 33 mm (diameter) and 20 mm (height) was placed on an adjustable sloping surface. The cylinder was raised gradually to ensure its ends do not touch surface that may hinder originality of COF. The structural surface with the cylinder resting on it, was gradually lifted resulting in the formation of inclined surface from the horizontal one that goes on to become steeper upon lifting until a point when the cylindrical object starts to slide down the surface. The angle of slope ($\alpha$) was determined from measured base of the equipment. The static coefficient of friction ($\mu$) as calculated by Equation (2) (Mohsenin, 1986; Razavi & Milani, 2006).

$$
\mu = \tan(\alpha)
$$

(2)

Angle of repose represents the angle with the horizontal surface at which the material will form when piled. The height and diameter of the resting cone was measured that were used for calculating angle of repose using the following formula (Ozguven & Kubilay, 2004).

$$
\theta = \tan^{-1} \left\{ \frac{2H}{D} \right\}
$$

(3)

where, H and D, respectively, represent height and diameter of the heap.
2.5. Aerodynamic properties

The terminal velocity (Vt) was measured using an air column apparatus. A cylindrical glass pipe posed vertically with a fitted air blower from the bottom side and an arrangement for controlling the air velocity. The sample grains were dropped into the pipe and the air velocity was adjusted so that the grains remain in a suspended position. The air velocity (terminal velocity) was measured with an anemometer used to calculate the drag coefficient, \( C_d \), as following (Mohsenin, 1986).

\[
C_d = \frac{2mg}{AVt^2}
\]

where, \( m \) and \( A \) are the mass and surface area of the grain
\( g \) is acceleration due to gravity (9.8 m/s\(^2\))
\( Vt \) is the terminal velocity (m/s)
\( \rho \) is the density of the fluid (for air = 1.25 kg/m\(^3\))

3. Results and discussion

3.1. Milling

The results of hulling and milling processes are presented in Table 1. The milling recovery did not show a significant change among the varieties but Kohsar and Chenab, respectively, yielded highest and lowest head rice yield/whole rice (Figure 2), which may be attributed to grain dimensions that are highest for Chenab and lowest for Kohsar. The large-sized grain is more susceptible to breakage during the milling process. Chenab yielded a slightly higher husk than other varieties, whereas brokens from Kohsar were lowest (Figure 2).

3.2. Dimensional properties

The dimensions of all the four varieties decreased considerably with increasing the processing levels (Table 2) as supported by different studies (Singh, Kaur, Singh Sodhi, & Singh Sekhon, 2005; Sujatha, Ahmad, & Rama Bhat, 2004; Varnamkhasti et al., 2008). The geometric mean diameter and surface area of all varieties decreased upon processing (Table 1) with the former used in the estimation of particle projected area during its movement in turbulent regions of an air stream, and ease of separation of foreign impurities from it during cleaning by pneumatic means (Omobuwajo, Akande, & Sanni, 1999). The sphericity levels increased with processing levels showing values greater than the study of Reddy and Chakraverty (2004). The relation between sphericity and surface area is presented in Figure 3. Increase in processing increases sphericity of the grain while as its surface area decreases equally for all forms of grain types. The aspect ratio increased for all varieties during the various processing levels that is an indication of rice grain changing to an oblong shape.

3.3. Gravimetric properties

The mean values for bulk density of different paddy and milled rice ranged from 595.97 to 825.78 (S1); 556.29–776.48 (Chenab); 607.78–828.66 (Kohsar); 627.03–812.94 Barkat kg m\(^{-3}\) (Table 3). The removal of husk and bran increased the bulk density of rice grains at different levels of processing.

| Parameter               | Varieties          |
|-------------------------|--------------------|
|                         | Shalimar 1 | Chenab    | Kohsar    | Barkat    |
| Hulling recovery (%)    | 79.567 ± 0.491  | 78.106 ± 0.994 | 78.783 ± 1.177 | 79.253 ± 0.765 |
| Milling recovery (%)    | 72.301 ± 0.866  | 71.393 ± 1.499 | 70.445 ± 0.905  | 72.547 ± 1.730  |
| Husk (%)                | 20.433 ± 0.491  | 21.894 ± 0.994 | 21.217 ± 1.177  | 20.747 ± 0.765  |
| Whole white rice (%)    | 57.946 ± 2.512  | 54.622 ± 0.872 | 59.055 ± 2.361 | 55.964 ± 1.759  |
| Broken rice (%)         | 14.355 ± 1.655  | 16.772 ± 1.010 | 11.390 ± 1.576 | 16.584 ± 1.388  |
| Bran (%)                | 7.266 ± 0.426  | 6.712 ± 0.506  | 8.338 ± 1.687  | 6.705 ± 1.185  |
Figure 2. Graphical representation of products obtained after hulling and milling of four paddy cultivars.

Table 2. Dimensional properties of Shalimar 1, Chenab, Kohsar, and Barkat at different processing levels

| Parameter                  | Levels of processing | Shalimar 1 | Chenab  | Kohsar | Barkat |
|----------------------------|----------------------|------------|---------|--------|--------|
| Length (mm)                | Rough rice           | 8.433 ± 0.227 | 8.888 ± 0.522 | 8.099 ± 0.279 | 8.575 ± 0.090 |
|                            | Brown rice           | 5.846 ± 0.286 | 6.174 ± 0.286 | 5.341 ± 0.610 | 6.006 ± 0.247 |
|                            | White rice           | 5.543 ± 0.168 | 5.856 ± 0.219 | 5.379 ± 0.208 | 5.607 ± 0.162 |
| Width (mm)                 | Rough rice           | 3.069 ± 0.123 | 3.056 ± 0.140 | 2.928 ± 0.115 | 2.899 ± 0.040 |
|                            | Brown rice           | 2.660 ± 0.108 | 2.536 ± 0.052 | 2.480 ± 0.147 | 2.523 ± 0.128 |
|                            | White rice           | 2.487 ± 0.081 | 2.424 ± 0.155 | 2.452 ± 0.148 | 2.441 ± 0.103 |
| Thickness (mm)             | Rough rice           | 2.200 ± 0.058 | 2.113 ± 0.115 | 2.089 ± 0.119 | 2.052 ± 0.058 |
|                            | Brown rice           | 1.843 ± 0.038 | 1.835 ± 0.035 | 1.830 ± 0.061 | 1.816 ± 0.094 |
|                            | White rice           | 1.844 ± 0.046 | 1.811 ± 0.087 | 1.747 ± 0.047 | 1.757 ± 0.076 |
| Geometric mean diameter (mm)| Rough rice           | 3.838 ± 0.065 | 3.857 ± 0.192 | 3.671 ± 0.113 | 3.708 ± 0.039 |
|                            | Brown rice           | 3.060 ± 0.099 | 3.062 ± 0.080 | 2.890 ± 0.156 | 3.018 ± 0.119 |
|                            | White rice           | 2.939 ± 0.013 | 2.950 ± 0.112 | 2.845 ± 0.100 | 2.886 ± 0.108 |
| Arithmetic mean diameter (mm)| Rough rice           | 4.561 ± 0.060 | 4.686 ± 0.250 | 4.372 ± 0.133 | 4.509 ± 0.030 |
|                            | Brown rice           | 3.450 ± 0.133 | 3.515 ± 0.117 | 3.217 ± 0.229 | 3.448 ± 0.129 |
|                            | White rice           | 3.291 ± 0.030 | 3.364 ± 0.125 | 3.193 ± 0.116 | 3.268 ± 0.111 |
| Square mean diameter (mm)  | Rough rice           | 8.493 ± 0.248 | 8.750 ± 0.871 | 7.795 ± 0.470 | 8.067 ± 0.130 |
|                            | Brown rice           | 5.209 ± 0.369 | 5.276 ± 0.300 | 4.598 ± 0.551 | 5.111 ± 0.388 |
|                            | White rice           | 4.764 ± 0.034 | 4.869 ± 0.364 | 4.482 ± 0.329 | 4.642 ± 0.331 |
| Equivalent diameter (De) mm| Rough rice           | 5.630 ± 0.119 | 5.764 ± 0.437 | 5.279 ± 0.237 | 5.428 ± 0.065 |
|                            | Brown rice           | 3.906 ± 0.200 | 3.951 ± 0.165 | 3.568 ± 0.311 | 3.859 ± 0.211 |
|                            | White rice           | 3.665 ± 0.022 | 3.728 ± 0.200 | 3.506 ± 0.181 | 3.599 ± 0.183 |
| Sphericity (%)             | Rough rice           | 45.538 ± 1.623 | 43.413 ± 0.650 | 45.340 ± 0.924 | 43.249 ± 0.635 |
|                            | Brown rice           | 52.373 ± 0.977 | 49.641 ± 1.110 | 54.505 ± 4.548 | 50.273 ± 1.519 |
|                            | White rice           | 53.067 ± 1.652 | 50.378 ± 0.803 | 52.905 ± 1.312 | 51.467 ± 0.602 |
| Surface area (mm²)         | Rough rice           | 40.503 ± 1.179 | 41.449 ± 4.111 | 37.116 ± 2.288 | 38.276 ± 0.706 |
|                            | Brown rice           | 25.085 ± 1.696 | 25.349 ± 1.403 | 22.348 ± 2.475 | 24.580 ± 1.875 |
|                            | White rice           | 23.089 ± 0.191 | 23.467 ± 1.748 | 21.655 ± 1.514 | 22.383 ± 1.618 |
| Aspect ratio               | Rough rice           | 0.362 ± 0.021 | 0.364 ± 0.008 | 0.362 ± 0.013 | 0.338 ± 0.008 |
|                            | Brown rice           | 0.455 ± 0.016 | 0.411 ± 0.016 | 0.469 ± 0.057 | 0.420 ± 0.020 |
|                            | White rice           | 0.449 ± 0.027 | 0.414 ± 0.025 | 0.456 ± 0.019 | 0.435 ± 0.007 |
with each level indicating significant difference between four cultivars, due to intrinsic characteristics of each variety (Corrêa et al., 2007; Muramatsu, Tagawa, Sakaguchi, & Kasai, 2007; Varnamkhasti et al., 2008). A distinct void space filled with air exists in the paddy grains between the husk and caryopsis, which decreases its bulk density upon processing (Araullo, De-Padua, & Graham, 1976). The same trend was observed for true density with paddy showing minimum value due to the low specific gravity of paddy than that of brown or white rice (Araullo et al., 1976; Corrêa et al., 2007; Varnamkhasti et al., 2008). The higher density values may be due to the spherical nature of grains as spherical size has more ordered and compact arrangement. The porosity in the paddy decreased upon processing and could be due to presence of more void spaces in paddy grain that are considerably reduced upon processing or difference in cell structures can be a reason (Corrêa et al., 2007).

### 3.4. Frictional properties

The static coefficient of friction (Table 4), on different surfaces, decreased for all the varieties upon hulling and milling of the grains as reported by Varnamkhasti et al. (2008). The surface of the paddy grains are covered with hard glass-like spines made of cellulosic and fibrous tissue that causes increase in friction with rough surface materials viz. plywood. The aluerone layer is beneath the husk whose cells are somewhat hexagonal to spherical making the grain surface smoother (Araullo et al., 1976; Corrêa et al., 2007; Mohsenin, 1986). The coefficient of friction is used to determine the angle at which the chutes must be positioned to achieve a consistent flow of materials (Olajide & Igbeka, 2003). The angle of repose did not show any significant change but there was a slight decrease in their values upon processing (Mohsenin, 1986). The parameter is important in proper design of hoppers to maintain continuous flow of the grain, which must be larger than the grain angle of repose.
3.5. Aerodynamic properties

The terminal velocities of the varieties increased upon processing from paddy to white rice while the drag coefficient decreased (Table 3). The terminal velocity values were larger for the Chenab varieties. Increase in terminal velocity by hulling can be attributed to increased true density of the grains making them harder to lift than paddy due to their lower surface area. The terminal velocity can be utilized for separation of the extraneous matter from the grains through pneumatic means.

In processing of paddy, air is used to separate husk from the brown rice during dehulling due to lower terminal velocity of bran but problem remains with the brokens as they are often separated through sieves that are associated with problems when the grains major axis is perpendicular to the flow direction.

Table 4. Frictional properties of Shalimar 1, Chenab, Kohsar, and Barkat on four different surfaces with exception to angle of repose

| Parameter | Levels of processing | Shalimar 1 | Chenab | Kohsar | Barkat |
|-----------|----------------------|------------|--------|--------|--------|
| Angle of repose (deg) | Rough rice | 42.967 ± 2.102 | 41.051 ± 2.232 | 42.620 ± 1.585 | 42.204 ± 2.403 |
| | Brown rice | 43.728 ± 1.505 | 41.490 ± 1.073 | 42.598 ± 2.009 | 42.620 ± 1.585 |
| | White rice | 44.075 ± 1.791 | 41.859 ± 1.599 | 41.490 ± 1.073 | 41.098 ± 1.073 |
| | Broken rice | 34.598 ± 2.143 | 37.767 ± 1.801 | 33.169 ± 2.020 | 36.642 ± 1.893 |

| COF plywood parallel | Rough rice | 0.542 ± 0.027 | 0.543 ± 0.033 | 0.542 ± 0.030 | 0.544 ± 0.031 |
| | Brown rice | 0.439 ± 0.041 | 0.372 ± 0.019 | 0.374 ± 0.010 | 0.424 ± 0.017 |
| | White rice | 0.428 ± 0.008 | 0.448 ± 0.027 | 0.431 ± 0.009 | 0.462 ± 0.024 |
| | Broken rice | 0.379 ± 0.036 | 0.416 ± 0.010 | 0.431 ± 0.019 | 0.388 ± 0.039 |

| COF ply-perpendicular | Rough rice | 0.554 ± 0.012 | 0.512 ± 0.029 | 0.605 ± 0.036 | 0.618 ± 0.018 |
| | Brown rice | 0.480 ± 0.035 | 0.410 ± 0.026 | 0.435 ± 0.015 | 0.447 ± 0.044 |
| | White rice | 0.502 ± 0.021 | 0.505 ± 0.010 | 0.484 ± 0.022 | 0.484 ± 0.031 |
| | Broken rice | 0.454 ± 0.017 | 0.437 ± 0.014 | 0.458 ± 0.008 | 0.431 ± 0.009 |

| COF GI sheet | Rough rice | 0.497 ± 0.023 | 0.504 ± 0.029 | 0.509 ± 0.019 | 0.542 ± 0.025 |
| | Brown rice | 0.444 ± 0.029 | 0.455 ± 0.017 | 0.440 ± 0.017 | 0.493 ± 0.010 |
| | White rice | 0.473 ± 0.011 | 0.510 ± 0.010 | 0.476 ± 0.012 | 0.453 ± 0.006 |
| | Broken rice | 0.411 ± 0.006 | 0.431 ± 0.010 | 0.452 ± 0.012 | 0.429 ± 0.013 |

| COF glass | Rough rice | 0.526 ± 0.027 | 0.499 ± 0.024 | 0.521 ± 0.011 | 0.542 ± 0.010 |
| | Brown rice | 0.488 ± 0.017 | 0.466 ± 0.023 | 0.503 ± 0.018 | 0.469 ± 0.017 |
| | White rice | 0.496 ± 0.019 | 0.486 ± 0.018 | 0.454 ± 0.014 | 0.500 ± 0.022 |
| | Broken rice | 0.442 ± 0.015 | 0.451 ± 0.011 | 0.517 ± 0.011 | 0.488 ± 0.013 |

Figure 3. Relation between sphericity and surface area of paddy, brown, and white rice designated within brackets as (P), (B), and (W), respectively, obtained from four different cultivars Shalimar1 (S1), Chenab (C), Kohsar (K), and Barkat (B).
sieve surface resulting in the passage of some whole rice grains through the sieve into the brokens and thereby decreasing market value of the product. The knowledge of the aerodynamic properties can help overcome this problem by grading white rice effectively from brokens and rough rice grains. There is an evident difference in terminal velocities of brokens with respect to white head rice (Figure 4) and this difference can be used in their effective separation with or without using meshes. Terminal velocities of paddy are lowest for all four varieties and find application in its separation from other forms of rice during process (brown, white, and brokens).

4. Conclusion
The milling recovery of all varieties was almost same in exception to Kohsar that showed relatively declined value due to its higher percentage of bran. The grains of Kohsar variety were slightly superior to other cultivars due to its increased HRY and lowest amount of brokens. The presence of higher amounts of bran makes its nutritionally more sound when given some pre-treatments, like parboiling, enabling nutrient transfer from bran to kernel. All cold-tolerant varieties studied in this study can be separated by aerodynamically into their individual forms due to their varying terminal velocities. The determination of different engineering properties, as studied in current study, can readily be used in machine designing and equipment handling during different agricultural processes viz. cleaning, sorting, sowing, conveying, harvesting, and so on.

Abbreviations used:
- masl: meters above sea level
- MT: million tons
- HRY: head rice yield
- $\rho_b$: bulk density
- $\rho_t$: True density
- $\varepsilon$: Porosity
- $\mu$: Static coefficient of friction
- $\theta$: Angle of repose
- $C_d$: Drag coefficient
- $V_t$: terminal velocity
- $\rho$: Density of air
- $g$: acceleration due to gravity
Acknowledgment
Sincere thanks to Directorate of Rice Research Center Khudwani, Kulgam for providing the seeds of different paddy varieties.

Funding
The authors received no direct funding for this research.

Competing interests
The authors declare no competing interest

Author details
Raees Haq1
E-mail: raeeswan@gmail.com
ORCID ID: http://orcid.org/0000-0002-8854-5456
Muzamil Wani2
E-mail: wanimuzamil191@gmail.com
Kamlesh Prasad1
E-mail: dr_k_prasad@rediffmail.com
1 Department of Food Engineering and Technology, Sant Longauli Institute of Engineering & Technology, Punjab 148106, India.
2 Department of Civil Engineering, Brindavan College of Engineering & Technology, Bangalore 560063, India.

Citation information
Cite this article as: Engineering properties of high and low altitude rice varieties from Kashmir valley at different processing levels, Raees Haq, Muzamil Wani & Kamlesh Prasad, Cogent Food & Agriculture (2016), 2: 1133371.

References
Anon. (2008, April 6). ICAR Directorate of rice research newsletter. Retrieved March 12, 2015, from http://www.drricar.org
Arallo, E. V., De-Padua, D. B., & Graham, M. (1976). IRRI Directorate of rice research.

Prasad, K., Prakash, P., & Prasad, K. K. (2010). Food Science and Technology, 3, 175–180.

http://dx.doi.org/10.1016/j.foodeng.2006.08.010

Irtwange, S. (2012). Engineering properties of African yam bean (Sphenostylis stenocarpa). Soarbrucks: LAP Lambert Academic.

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. Journal of Agricultural Engineering Research, 66, 85–91.

http://dx.doi.org/10.1016/j.jer.1996.06.011

Jouki, M., & Khazaei, N. (2012). Some physical properties of rice (Oryza sativa) grain and various silo wall materials. Journal of Agricultural Engineering Research, 913. http://dx.doi.org/10.1016/j.jfoodeng.2006.05.017

Mohsenin, N. N. (1986). Physical properties of plant and animal materials (2nd ed.). New York, NY: Gordon and Breach Science.

Muramatsu, Y., Tagawa, A., Sakaguchi, E., & Kasai, T. (2007). Prediction of thermal conductivity of kernels and a packed bed of brown rice. Journal of Food Engineering, 80, 241–248. http://dx.doi.org/10.1016/j.jfoodeng.2006.05.017

Nolloduradi, K., Alagusundaram, K., & Gayathri, P. (2002). PH—Postharvest technology. Biosystems Engineering, 83, 67–75. http://dx.doi.org/10.1016/bioe.2002.09.009

Olojide, J. O., & Ibjeke, J. C. (2003). Some physical properties of groundnut kernels. Journal of Food Engineering, 58, 201–204. http://dx.doi.org/10.1016/s0260-8774(02)00323-0

Ozhugan, F., & Kubilay, V. (2004). Some physical, mechanical and aerodynamic properties of pine (Pinus pinea) nuts. Journal of Food Engineering, 68, 191–196.

Olajide, J. O., & Igbeka, J. C. (2006). Some physical properties of low altitude rice varieties from Kashmir valley at different processing levels, Raees Haq, Muzamil Wani & Kamlesh Prasad, Cogent Food & Agriculture (2016), 2: 1133371.

References
Anon. (2008, April 6). ICAR Directorate of rice research newsletter. Retrieved March 12, 2015, from http://www.drricar.org
Arallo, E. V., De-Padua, D. B., & Graham, M. (1976). Rice: Postharvest technology. Ottawa: International Development Research Center.

Corrêa, P. C., da-Silva, F. S., Jaren, C., Afonso, P. C., & Araujo, I. (2007). Physical and mechanical properties in rice processing. Journal of Food Engineering, 79, 137–142. http://dx.doi.org/10.1016/j.jfoodeng.2006.01.037

De-Datta, S. K. (1993). Principles and practices of rice production. New York, NY: Wiley Press.

FADSTAT. (2015). Rice production statistics. Retrieved April 5, 2015, from http://fadstat.fao.org

Ghadge, P. N., & Prasad, K. (2012). Some physical properties of rice kernels variety PR-106. Journal of Food Process Technology, 3, 175–180.

Güner, M. (2007). Pneumatic conveying characteristics of some agricultural seeds. Journal of Food Engineering, 80, 904–913. http://dx.doi.org/10.1016/j.foodeng.2006.08.010

Irtwange, S. (2012). Engineering properties of African yam bean (Sphenostylis stenocarpa). Soarbrucks: LAP Lambert Academic.

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. Journal of Agricultural Engineering Research, 66, 85–91.

http://dx.doi.org/10.1016/j.jer.1996.06.011

Jouki, M., & Khazaei, N. (2012). Some physical properties of rice (Oryza sativa) grain and various silo wall materials. Journal of Agricultural Engineering Research, 913. http://dx.doi.org/10.1016/j.jfoodeng.2006.05.017

Mohsenin, N. N. (1986). Physical properties of plant and animal materials (2nd ed.). New York, NY: Gordon and Breach Science.

Muramatsu, Y., Tagawa, A., Sakaguchi, E., & Kasai, T. (2007). Prediction of thermal conductivity of kernels and a packed bed of brown rice. Journal of Food Engineering, 80, 241–248. http://dx.doi.org/10.1016/j.jfoodeng.2006.05.017

Nolloduradi, K., Alagusundaram, K., & Gayathri, P. (2002). PH—Postharvest technology. Biosystems Engineering, 83, 67–75. http://dx.doi.org/10.1016/bioe.2002.09.009

Olojide, J. O., & Ibjeke, J. C. (2003). Some physical properties of groundnut kernels. Journal of Food Engineering, 58, 201–204. http://dx.doi.org/10.1016/s0260-8774(02)00323-0

Ozhugan, F., & Kubilay, V. (2004). Some physical, mechanical and aerodynamic properties of pine (Pinus pinea) nuts. Journal of Food Engineering, 68, 191–196.

Olajide, J. O., & Igbeka, J. C. (2006). Some physical properties of low altitude rice varieties from Kashmir valley at different processing levels, Raees Haq, Muzamil Wani & Kamlesh Prasad, Cogent Food & Agriculture (2016), 2: 1133371.

References
Anon. (2008, April 6). ICAR Directorate of rice research newsletter. Retrieved March 12, 2015, from http://www.drricar.org
Arallo, E. V., De-Padua, D. B., & Graham, M. (1976). Rice: Postharvest technology. Ottawa: International Development Research Center.

Corrêa, P. C., da-Silva, F. S., Jaren, C., Afonso, P. C., & Araujo, I. (2007). Physical and mechanical properties in rice processing. Journal of Food Engineering, 79, 137–142. http://dx.doi.org/10.1016/j.jfoodeng.2006.01.037

De-Datta, S. K. (1993). Principles and practices of rice production. New York, NY: Wiley Press.

FADSTAT. (2015). Rice production statistics. Retrieved April 5, 2015, from http://fadstat.fao.org

Ghadge, P. N., & Prasad, K. (2012). Some physical properties of rice kernels variety PR-106. Journal of Food Process Technology, 3, 175–180.

Güner, M. (2007). Pneumatic conveying characteristics of some agricultural seeds. Journal of Food Engineering, 80, 904–913. http://dx.doi.org/10.1016/j.foodeng.2006.08.010

Irtwange, S. (2012). Engineering properties of African yam bean (Sphenostylis stenocarpa). Soarbrucks: LAP Lambert Academic.

Jain, R. K., & Bal, S. (1997). Properties of pearl millet. Journal of Agricultural Engineering Research, 66, 85–91.

http://dx.doi.org/10.1016/j.jer.1996.06.011

Jouki, M., & Khazaei, N. (2012). Some physical properties of rice (Oryza sativa) grain and various silo wall materials. Journal of Agricultural Engineering Research, 4, 1846–1849.

Kaw, R. N. (1985). Characterization of the most popular rice varieties in low temperature areas of India and Nepal. Philippines Journal of Crop Science, 10, 1–6.

Lawton, P. J. (1980). Coefficients of friction between cereal grain and various silo wall materials. Journal of Agricultural Engineering Research, 25, 75–86. http://dx.doi.org/10.1016/0021-8634(80)90049-9

Luh, B. S. (1980). Rice: Production and utilization. Westport, CT: AVI Press.
