International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2018; 6(2): 2197-2201

Received: 23-01-2018
Accepted: 27-02-2018

SK Alekksha Kudos
Regional research center, ICAR-CIAE, Bhopal, Madhya Pradesh, India

Chandan Solanki
ICAR-Central Institute of Post-Harvest Engineering & Technology, Ludhiana, Punjab, India

Correspondence
SK Alekksha Kudos
Regional research center, ICAR-CIAE, Bhopal, Madhya Pradesh, India

Evaluation of physical properties of amaranth grain (*Amaranthus paniculatus*)

SK Alekksha Kudos and Chandan Solanki

Abstract
Amaranth (*Amaranthus paniculatus*) is an important crop in the category of pseudo cereals generally consumed by it's an excellent nutrient profile. They have been used as nutritious ingredients in gluten-free formulations. Some of the most attractive features of these pseudo cereals like amaranth include high quality protein and abundant quantities of fibre and minerals such as calcium and iron. They are also a source of many bioactive compounds with health promoting effects. They are particularly high in lysine, an amino acid that is low in other grains. The protein is of an unusually high quality. Hence, the knowledge about the physical properties of amaranth is important for designing processing machineries. In this regard, the study of the physical properties of amaranth in the moisture content range of 7% to 21% wb. Was conducted Six different levels of moisture content in this range were selected. Thousand seed weight, bulk density, true density, porosity, angle of repose and coefficient of friction on plywood, mild steel and galvanized iron were determined in this range. At the given moisture levels, thousand grains weight linearly increased from 0.79g to 0.90g in this moisture range, the bulk density decreased linearly from 830.77 to 810.21 kg/m^3 and true density varied from 1389 to 1538 kg/m^3 respectively and porosity increased linearly from 40% to 47%. In the selected moisture range, the angle of repose decreased from 26.43° to 24.60°. The coefficient of friction of amaranth over mild steel varied non linearly from 0.250 to 0.300.

Keywords: Amaranth, physical property, moisture content

Introduction

Amaranth grain is a highly nutritional pseudo cereal with a superior amount of proteins when compared to true cereals. It is a reasonably well-balanced food with functional properties that have been shown to provide medicinal benefits. The health benefits attributed include decreasing plasma cholesterol levels, stimulating the immune system, exerting an antitumor activity, reducing blood glucose levels and improving conditions of hypertension and anemia. In addition, it has been reported to possess anti-allergic and antioxidant activities. Amaranth is produced and used as a grain or leafy vegetable in India. Over 60 species of amaranth are known worldwide. Amaranth grains are lentil-shaped and 1 mm in diameter. Amaranth grain is particularly high in lysine, an amino acid that is low in other grains. The protein is of an unusually high quality, according to Educational Concerns for Hunger Organization (ECHO). Amaranth has long been cultivated as a miner crop in Central and South America and some areas of Asia and Africa. China is the top amaranth producer in the world. A single plant can produce more filled produce more than 500g of grains. The average yield in the northwest hills of India is 2250 kg/ha. The amaranth grains are extremely small. Seed coat color ranges among black, brown, yellow and white. Seed embryo is circular.

Traditional foods are made from amaranth grains in many countries, e. g. "alegria" and "atole" in Mexico, "alboroto" in Guatemala, "bollos" in Peru, "Chapati" in Himalayas, "laddoos" in India, and "sattoo" in Nepal. Modern food applications of amaranth grains include breakfast foods, infant/weaning food formulations, breads, pastas, flakes, drinks and beverages, etc. Grain amaranth can be used as grains or flour to make products such as cookies, cakes, pancakes, bread muffins, crackers, pasta and other bakery products. Consumption of grain amaranth is reported to have nutritional and health benefits, ranging from a general improvement in well-being to prevention and improvement of specific ailments and symptoms including recovery of severely malnourished children and an increase in the body mass index of people formerly wasted by HIV/AIDS.

The physical properties of amaranth grains, like other grains, are essential and important for designing the processing equipment for further handling and post-harvest processing. Various types of cleaning, grading and separation equipment are designed on the basis of physical properties of grains (*Sahay & Singh, 1994*) [24]. Physical properties affect conveying characteristics of solid materials by air or water and cooling and heating loads of food materials.

The knowledge on the physical properties of a crop is essential for proper design of processing equipment. The size distribution and characteristic dimensions of grain is important for the design of equipment for cleaning, sorting and separation (*Kachru et al. 1994*) [12]. The bulk density is used to determine the capacity of storage and transport, while the true density is useful to design proper separation equipment. Moreover, porosity of the grain mass determines the resistance to airflow during aeration and drying operation (*Brooker et al. 1992* [6]; *Kachru et al. 1994*) [12]. Frictional properties such as angle of repose and coefficient of friction are important properties for the design of grain containers and other storage structures (*Vilche et al. 2003*) [32]. These properties are affected by factors such as size, form and moisture content of the grain. The review of literature showed that there is a lack of information on physical properties of amaranth grains for wide ranges of moisture content.

Hence, the knowledge of these physical properties are necessary for designing processing machines after harvesting like cleaner, grader and dehusker. The properties of different types of grains and seeds have been determined by other researchers also (*Deshpande & Ojha, 1993* [8]; *Dutta, Nema, & Bhardwaj, 1988* [7]; *Joshi, Das, & Mukherji, 1993* [11]; *Oloso & Clarke, 1993* [20]; *Singh & Goswami, 1996* [25]; *Suthar & Das, 1996*) [27]. They studied the physical properties of different commodities but no one determined the physical properties of amaranth grains which needs to be processed properly and hygienically in continuous mode.

Materials and Method

Sample Preparation

Amaranth grains were procured from local market of Ludhiana. The average initial moisture content was found to be 9.78% wb. The grains were cleaned using sets of sieve to separate all foreign matter, dust, dirt, twigs, broken and immature grains. Moisture content of the sample was determined by hot air oven method as described by *Nimkar and Chattopadhyay 2001* [19]. The grain moisture content range was selected between 7% to 21% wet basis because the harvesting is being practiced at about 21% and transportation, storage, handling and processing operations of the crop are performed at about 7%.

The weight of the samples was recorded on an analytical balance (Model: TB403, Denver Instrument) of accuracy 0.001g in triplicate, and their average value was recorded. The sample was divided into lots that were conditioned for moisture content in the range of 7-21% wb. By adding predetermined amounts of distilled water calculated from the following relationship:

$$Q = W \times \frac{(Mf - Mi)}{(100 - Mf)}$$

Where,

Q= mass of water to be added (g);

W= Quantity of sample (g);

M_i= initial moisture content of the sample (% wb.);

M_f= desired moisture content of the sample (% wb.).

The sample were kept at 5 °C in a refrigerator for one week for uniform distribution of moisture throughout the sample. Before each test, the required quantity of sample was taken out of refrigerator and allowed to attain ambient temperature before carrying out the experiment.

Measurement of Properties

Thousand grain weight

Thousand grain weight was determined by randomly selecting 100 grains from the overall sample, measuring their weight on a digital electronic balance with an accuracy of 0.001 g, and multiplying by 10 to get the mass of 1000 grains (*Altuntas et al. 2005*) [2].

Density Measurements

Bulk density (ρ_b) was considered as the ratio between the mass of a sample of grain and the total volume occupied by it. It was determined using a container of known volume (*Deshpande et al. 1993* [8]; *Vilche et al. 2003*) [32].

True density (ρ_t), defined as the ratio between the mass of the sample grains and the actual volume occupied by it, and was determined for five moisture contents (in the range of 7% 21% wb. using toluene displacement method with three replications (Singh and Goswami, 1996) [25]

Porosity (ε) of the grain bed was defined as the fraction of space in a bed of grains that is not occupied by the grains. The percentage porosity was calculated using the following equation (*Mohsenin, 1986*) [17]:

$$\varepsilon = (1 - \frac{\rho b}{\rho t})\ 100$$

Angle of Repose

Angle of repose is the angle with the horizontal at which the material will stand when piled. The angle of repose was determined using a topless and bottomless cylinder of known dimensions. The cylinder was placed at the center of a raised circular plate and was filled with amaranth grains. The cylinder was raised slowly until the grains formed a cone on the circular plate of known diameter. To determine the dynamic angle of repose, the grains were allowed to fall freely from a hopper over a disc of known diameter to assume a natural slope. The angle of repose was then calculated from the measurement of the height and the radius of the cone (*Kaleemullah and Gunasekar, 2002*) [14] using the following relationship:

$$\emptyset = \tan^{-1}\frac{2H}{D}$$

Where,

θ= Angle of repose, degrees,

H= Height of cone formed, mm, and

D= Diameter of cone, mm.

Coefficient of Friction

Coefficient of friction (μ) of amaranth grains was determined for the displacement of grains on mild steel with three replications. A wooden box was filled with amaranth grain and placed on mild steel surface as mentioned above. The total weight required to move the box with grains was recorded. This value was used to calculate the coefficient of friction at this surfaces.

The total weight required to make the box with grain slide uniformly over the friction surface was used to measure the coefficient of friction (*Kaleemullah, 1992*) [13].

$$\mu = \frac{F}{N}$$

Where,
F = Force required just to move the box with grain, N, and
W = Weight of box + grain, N.

Statistical Analysis
The experimental results were subjected to analysis of variance (ANOVA) using AGRES (version 7.01) software and least significant difference test was used to describe the means with 95% confidence.

Results and Discussion
Thousand Grain Weight
The variation of thousand grain weight of amaranth grain with moisture content, is presented in Fig. 1, which showed that thousand grain weight increased from 0.79g to 0.90g as the moisture content increased from 7 to 21% wb. ($p \le 0.01$). It was found to be a linear function of moisture content and the relationship could be expressed using the following equation:
$W_s = 0.0003m^2 + 0.3768m + 57.981$ $R^2 = 0.9858$

Where,
W_s = Thousand grain mass, g, and
m = Moisture content, % wb.

Similar linear increase had been noted by *Dutta et al. 1988* [7] for gram, *Deshpande et al. 1993* [8] for soybean, *Singh and Goswami 1996* [25] for cumin grains, *Altuntas and Yildiz 2007* [1] for faba bean, *Esref and Halil 2007* [9] for red kidney bean and *Sologubik et al. 2013* [30] for barley.

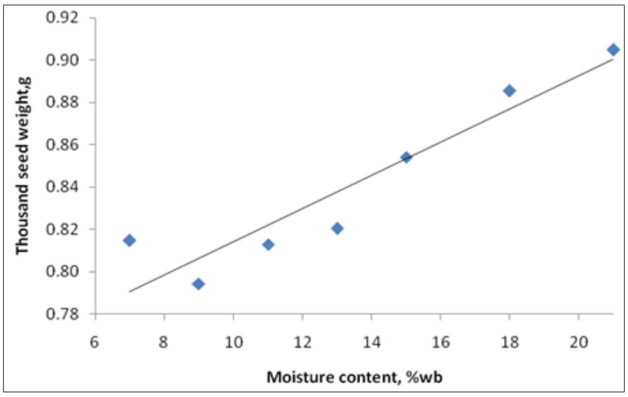

Fig 1: Effect of moisture content on thousand grain weight of amaranth grains

Bulk Density
Bulk density (ρ_b) of amaranth grains at different moisture content varied significantly ($p \le 0.01$) from 830.77 to 810.21 kg/m^3 when moisture content increased from 7 to 21% wb. Fig. 2 (a). This behavior could be attributed to the fact that the increased volume of the sample associated with increased moisture was higher than the mass increased by the grains (*Sologubik et al. 2013*) [30]. This would cause the effect of having lower compaction (lower bulk density) in wet amaranth grains compared with dry grains. The relationship of bulk density (ρ_b) of amaranth grains and moisture content can be expressed by the following equation:
$\rho_b = -0.0456m^2 - 2.4785m + 887.71$ $R^2 = 0.9856$

Parde et al. 2003 [22] also found similar trend for Koto and Manisoba cultivar at moisture content (wb.) range of 14.8%-17.9% and 13.0%-17.0%, respectively. Similar relationships have been reported for chickpea (*Konak et al. 2002*) [15] and locust bean seed (*Sobukola and Onwuka, 2010*) [29].

True Density
It was found that the true density of amaranth grains increased from 1389 to 1538 kg/m^3 as the moisture content of the amaranth grains increased from 7% to 21% wb. It could be seen from Fig. 2 (b) that true density had a nonlinear relationship with moisture content and could be represented as:
$\rho_t = 0.0298m2 - 11.731m + 1429.9$ $R^2 = 0.9851$

Where ρ_t is the true density of amaranth grains in kg/m^3.
Similar trends of bulk density and true density have been reported for various materials like guna grains (*Aviara et al. 1999*) [4], green gram (*Nimkar and Chattopadhyay, 2001*) [19], cotton (*Ozarslan, 2002*) [21], Lentil grain (*Amin et al. 2004*) [3] and barley (*Sologubik et al. 2013*) [30].

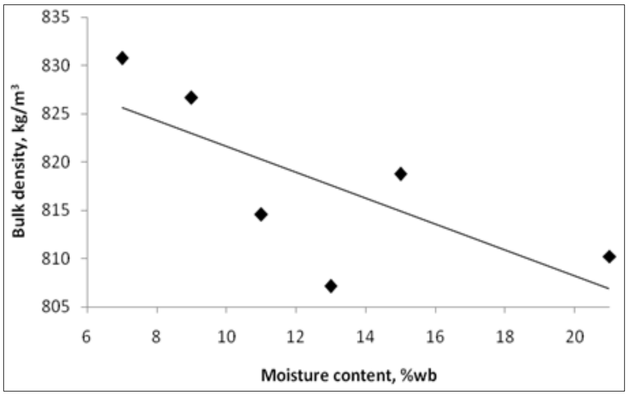

Fig 2(a): Effect of moisture content on bulk density of amaranth grains

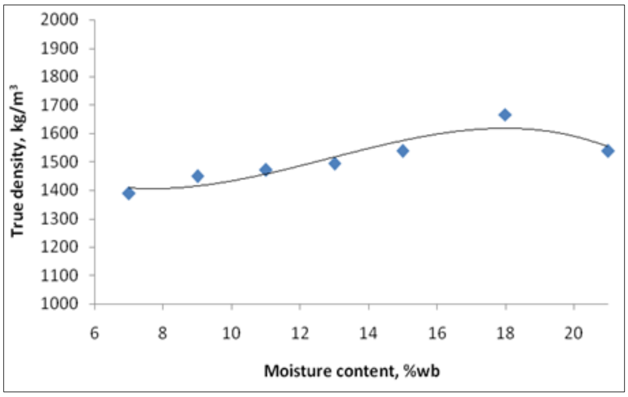

Fig 2(b): Effect of moisture content on true density of amaranth grains

Porosity
It was observed that when moisture content increased from 7 to 21% wb. Porosity increased significantly ($p \le 0.01$) from 40% to 47% as shown in Fig. 3. The relationship between the value of porosity (ε) and the moisture content can be expressed as:
$\varepsilon = 0.0009m^2 - 0.2947m + 37.591$ $R^2 = 0.8812$
Similar behaviors were reported for beniseeds, pumpkin, and pigeon pea seeds (*Shepherd and Bhardwaj 1986*) [28].

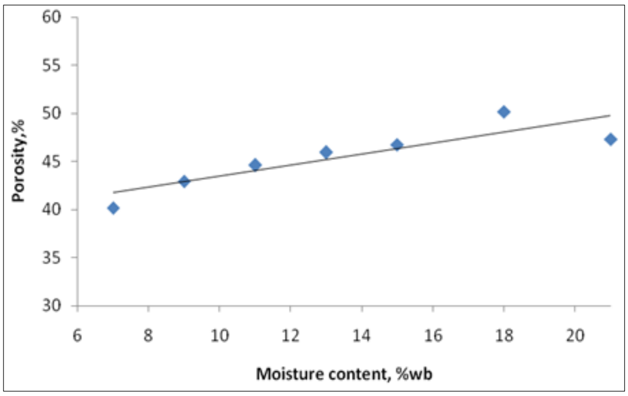

Fig 3: Effect of moisture content on porosity of amaranth grains

Angle of repose
The experimental results of angle of repose with respect to moisture content are shown in Fig. 4, exhibiting a significant decrease of angle from 26.43° to 24.60° ($p \leq 0.01$) with moisture content from 7 to 21% wb. The trend could be due to the fact that moisture in the surface layer of the grain kept them unbound together by lack of surface tension (*Pradhan et al. 2008*) [10]. The angle of repose is of paramount importance in the design of hopper openings, side walls and storage structures in the bulk of grains per ramp (*Solomon and Zewdu, 2009*) [26]. The linear relationship between the angle of repose and the moisture content can be described by the following equation:

$\Theta = 0.0203m^2 - 0.3008m + 29.194 \quad R^2 = 0.9967$

Where,
θ = Angle of repose, degree,
m = Moisture content, % wb.
Similar behavior of the angle of repose with respect to moisture content were observed for buckwheat (Koto, Koban and Manisobacvs), barley, sorghum, jatropha and karanja (*Parde et al. 2003* [22]; *Sologubik et al. 2013* [30]; *Mwithiga and Sifuna, 2006* [18]; *Garnayak et al. 2008* [10]; *Pradhan et al. 2008*) [10].

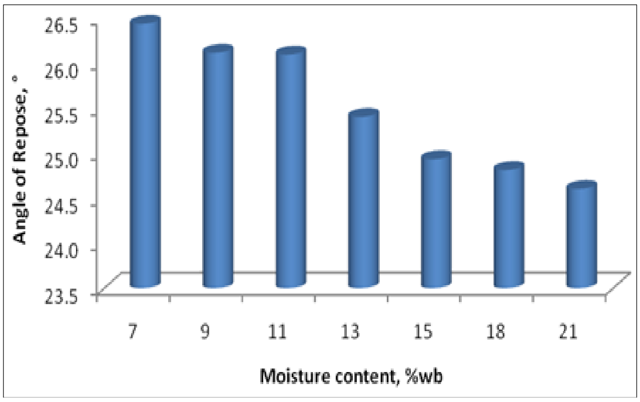

Fig 4: Effect of moisture content on angle of repose of amaranth grains

Coefficient of Friction
Variation of coefficient of friction for amaranth grains on mild steel surface with moisture content is shown in fig. 5. The coefficient of friction increased significantly with moisture content for this surface. This was due to the increased adhesion between the grain and the material surface at higher moisture contents leading to higher μ values. Similar results have been reported for faba bean (*Altuntas and Yildiz 2007*) [1]. The coefficient of friction ranged from 0.250 to 0.300 for mild steel surface in the experimental moisture content range. Variation of coefficient of friction with moisture content of amaranth grains is expressed as:
$\mu_{Ms} = 0.0174m + 0.3465 \; R^2 = 0.8854$

Parde et al. 2003 [22] found similar increase in the friction coefficient of buckwheat (Koto cultivar) with moisture content. Other researchers also found that as the moisture content increased, the coefficient of friction also increased (*Baryeh, 2002* [5]; *Altuntas and Yildiz, 2007* [1]; *Pradhan et al. 2008*) [10]. As stated by *Thompson and Ross, 1983* [31] and *Lawton, 1980*, at low moisture contents particles of grain tend to be elastic. As moisture content increased, the grain particles became more elastic and were able to deform requiring increased force to break the bonds between sliding grain and surface.

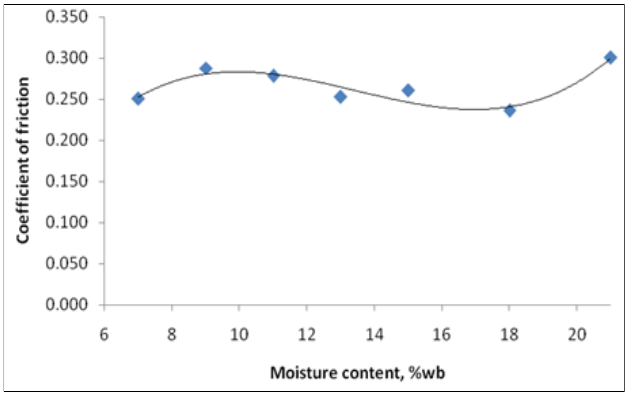

Fig 5: Effect of moisture content on coefficient of friction of amaranth

The coefficient of friction at all moisture contents was highest on mild steel. This was due to the rough surface of mild steel. The order reported for locust bean seed (*Sobukola and Onwuka, 2010*) [29] is plywood followed by mild steel and galvanized iron sheet. However, *Amin et al. 2004* [3] have reported that no variation existed between plywood and galvanized iron for lentil seeds.

Conclusions
The values of thousand grain weight in the given moisture levels, linearly increased from 0.79g to 0.90g in this moisture range, the bulk density decreased linearly from 830.77 to 810.21 kg/m3 and true density varied from 1389 to 1538 kg/m3 respectively and porosity increased linearly from 40% to 47% significantly ($p \leq 0.01$). In the selected moisture range, the angle of repose decreased from 26.43° to 24.60°. The coefficient of friction of amaranth over mild steel varied none linearly from 0.250 to 0.300. These properties will be very much helpful in designing different machineries for processing of amaranth grains.

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