Effect of Moisture Content on Physical and Aerodynamic Properties of Sorghum

Nattapol Poomsa-ad and Lamul Wiset
Faculty of Engineering/Mahasarakham University, Maha Sarakham, 44150, Thailand
Email: nattapol.p@msu.ac.th, lamulwiset@hotmail.com

Wasan Duangkhamchan
Department of Food Technology and Nutrition/Faculty of Technology/Mahasarakham University, Khamriang, Kantarawichai, Maha Sarakham, 44150, Thailand
Email: wasan.d@msu.ac.th

***Abstract*—This research was to study the physical, mechanical and aerodynamic properties of sorghum. The moisture contents of sample for 5 levels were in the range of 9.06 to 29.15 % wet basis. Each moisture content level, fifty grains were sampled. The results found that the increase in moisture content resulted in the increasing of grain width, length, thickness and geometric diameter which in the range of 3.86 to 4.16 mm, 4.45 to 4.65 mm, 2.49 to 2.72 mm and 3.50 to 3.75. mm, respectively. In addition, the sphericity, the thousand grains mass and surface area were in the range of 0.79 to 0.81, 23.37 to 28.58 g, and 38.44 to 44.07 mm^2, respectively. The porosity and angle of repose were found to increase from 35.15% to 36.75%, and 20.04° to 26.82°, respectively. The bulk and true density decreased from 815.40 to 712.60 kg/m^3, and 1257.33 to 1126.72 kg/m^3. The coefficient static friction on acrylic, wood, zinc and iron were in the range of 0.25 to 0.48, 0.40 to 0.48, 0.21 to 0.42 and 0.32 to 0.43, respectively. Terminal velocity and the drag coefficient were in the range of 8.54 to 9.73 m/s and 0.32 to 0.34.**

***Index Terms*—angle of repose, bulk density, coefficient of friction**

I. Introduction

Sorghum (*Sorghum bicolor (L.)* Moench) is a variety of the sorghum family widely cultivated in Thailand. It is known as a good source of protein and dietary energy [1], traces of minerals including calcium, phosphorus, iron and potassium [2]. Besides being cooked like rice, the sorghum can be ground into flour and made into either porridge or gruel. In order to design equipment used in handling, transportation, processing and storing, the physical properties of sorghum are needed. These properties affect not only the conveying characteristics of solid materials, but they also influence the heating loads of food materials [2].

Even though the properties of different types of grains and seeds have been reported elsewhere [3], it is still necessary to evaluate these properties of the considered variety of sorghum. Furthermore, to our knowledge, aerodynamic properties such as the drag coefficient, which is important in design of air conveying and fluidised bed systems, have not been reported yet. Consequently, the objective of this work is to evaluate various physical and the aerodynamic properties of the sorghum, cultivated in Thailand with respect to grain moisture content known as a good source of dietary and protein.

II. Materials and Methods

Sorghum grains obtained from a farm in the North-Eastern part of Thailand were first cleaned and sized to get rid of foreign matter and immature grains. They were adjusted in a range of 9 - 29%wb. The prepared samples were kept in polythene bags and stored in a cold humid chamber. Fifty grains for each moisture content level were randomly selected to measure the length, width and thickness in three mutually perpendicular directions using a digital micrometer. The geometric mean diameter (GMD) was calculated using the expression proposed by [4] as follows:

$$GMD = (LWT)^{1/3} \tag{1}$$

where L is a length (mm), W a width (mm) and T is a thickness (mm). According to [3], the grain sphericity, ϕ can be determined as follows:

$$\phi = \frac{(LWT)^{1/3}}{L} \tag{2}$$

Moreover, the grain surface area, S was calculated using the expression of [5]

$$S = \pi (GMD)^2 \tag{3}$$

After five-time determination of all dimensions, bulk and true density of grains were determined with five replications. For more details concerning their means, the reader is referred to [3]. The porosity (ε) was then calculated using the equation proposed by ref. [6], [7].

$$\varepsilon = (1 - \rho_b / \rho_t) \times 100 \tag{4}$$

Manuscript received August 31, 2013; revised November 1, 2013.

doi: 10.12720/jomb.3.3.167-170

where ρ_b and ρ_t are bulk and true density (kg/m3), respectively. The angle of repose, θ for each moisture content was determined according to [7], [8]. This value is expressed by:

$$\theta = tan^{-1}(2H / D) \quad (5)$$

where H is the height from a base to peak (mm) and D is a diameter of the base (mm).

The coefficient of static friction, μ was determined with respect to four surface materials including wood, galvanised iron, mild steel and acrylic. The sorghum grains at considered moisture content were filled into a hollow box having dimensions of 100 mm wide, 150 mm long and 40 mm high and opening at both ends. The box filled with grains was placed on an adjustable tilting table such that the box did not touch a table surface. The inclined surface was raised gradually until the box just started to slide down. The angle of the surface was subsequently recorded and used to calculate the coefficient of static friction according to [7], [8] as follows:

$$\mu = tan\,\alpha \quad (6)$$

where α is the tilting surface angle.

In addition to the grain surface area, the projection area was determined in order to further calculate the drag coefficient. Fifty grains were randomly selected to provide the scanned image. All images obtained at different moisture contents were then imported into CAD program to determine average projection area. The terminal velocity, V_t with variation of moisture content was measured using an acrylic air column with a diameter of 150 mm, 1000 mm long and 3 mm thick. The grain velocities in x- and y-directions were recorded using an anemometer, and they were then used to calculate the terminal velocity.

According to [3], the drag coefficient of grains was calculated using the following equation:

$$C_d = 2M_g / V_t^2 \rho_a A \quad (7)$$

where C_d is the drag coefficient, M the grain mass (g), g the gravitational acceleration (m/s^2), ρ_a an air density (kg/m^3) and A is the projection area (mm^2).

III. Results and Discussion

Table I shows the variations of the length, width, thickness and geometric diameter of the sorghum grains. All dimensions except the length increased linearly (8-11) with higher moisture content. The dimensions as a function of grain moisture content, M are mathematically represented as following equations:

$$W = 0.0152M + 3.6984\,;\ R^2 = 0.96 \quad (8)$$

$$T = 0.012M + 2.3679\,;\ R^2 = 0.97 \quad (9)$$

$$GMD = 0.0127M + 3.3524\,;\ R^2 = 0.92 \quad (10)$$

$$L = 0.0015M^2 - 0.0473M + 4.7497\,;\ R^2 = 0.96 \quad (11)$$

These relationships indicated the grain expansion within the moisture content range of 9.06-29.15%wb. Even though the increase in these dimensions with increasing moisture content agreed with the findings obtained by ref. [2], discrepancy of polynomial correlation found in this work was observed. It may be due to different variety of sorghum being used.

TABLE I. Dimensions of the Sorghum Grains with Various Moisture Content

Moisture content (%wb)	Width (mm)	Length (mm)	Thickness (mm)	GMD (mm)
9.06	3.86±0.14	4.45±0.14	2.49±0.10	3.50±0.90
14.36	3.89±0.15	4.38±0.12	2.53±0.12	3.51±0.10
20.68	4.01±0.15	4.40±0.17	2.59±0.13	3.58±0.12
24.58	4.06±0.15	4.54±0.18	2.68±0.12	3.66±0.11
29.15	4.16±0.15	4.65±0.21	2.72±0.16	3.75±0.13

The variations of the sphericity and surface area with moisture content are shown in Fig. 1 and Fig. 2. The sphericity ranged from 0.79-0.81, closer to that determined by ref. [2] in a range of 0.78-0.80, while disagreement in surface area was found. The relationships between these properties and moisture content can be expressed as follows:

$$\phi = -8\times 10^{-5}M^2 + 0.0039M + 0.7607\,;\ R^2 = 0.99 \quad (12)$$

$$S = 0.0144M^2 - 0.2588M + 39.524\,;\ R^2 = 0.99 \quad (13)$$

Fig. 3 displays the 1000-grain mass, M_{1000} as a function of moisture content. The grain mass increased linearly with higher moisture content, ranging from 23.37 to 28.58 g. This trend was also observed in many works [8], [9]. The variation can be expressed mathematically, as shown in (14).

$$M_{1000} = 0.2536M + 20.839\,;\ R^2 = 0.97 \quad (14)$$

The bulk and true density with moisture content, as shown in Table II. Both densities decreased with increase in moisture content. These results were similar to those of soybeans obtained by ref. [7], [8]. The relationships of the bulk density (ρ_b) and true density (ρ_t) are presented in (15) and (16), respectively.

$$\rho_b = -5.2508M + 864.54\,;\ R^2 = 0.98 \quad (15)$$

$$\rho_t = -6.8782M + 1321.6\,;\ R^2 = 0.99 \quad (16)$$

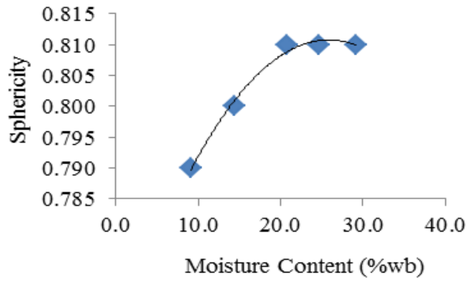

Figure 1. Sphericity as a function of moisture content

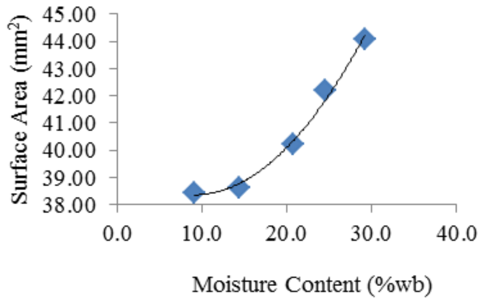

Figure 2. Surface area as a function of moisture content

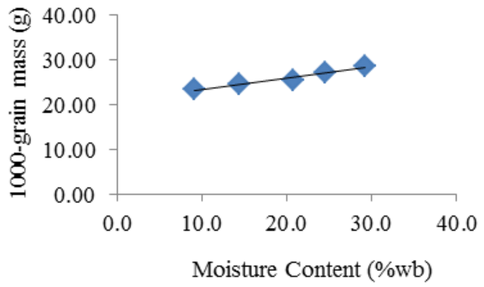

Figure 3. The 1000-grain mass as a function of moisture content.

In contrast, the porosity and angle of repose increased with increasing moisture content, ranging from 35.15 to 36.75% and from 20.04 to 26.8°, respectively. as shown in Table III. These values were correlated to moisture content as follows:

$$\varepsilon = -0.003M^2 + 0.1887M + 33.78\,;\ R^2 = 0.95 \quad (17)$$

$$\theta = 0.433M + 31.88\,;\ R^2 = 0.93 \quad (18)$$

TABLE II. BULK AND TRUE DENSITY WITH DIFFERENT MOISTURE CONTENT

Moisture content (%wb)	Bulk density (kg/m³)	True density (kg/m³)
9.06	815.40±13.32	1257.33±39.86
14.36	787.40±15.71	1231.71±16.70
20.68	766.40±12.26	1202.09±15.90
24.58	728.20±8.20	1147.42±30.22
29.15	712.60±8.88	1126.72±28.77

TABLE III. POROSITY AND ANGLE OF REPOSE WITH DIFFERENT MOISTURE CONTENT

Moisture content (%wb)	Porosity	Angle of repose (°)
9.06	35.15±1.63	20.04±3.20
14.36	36.07±1.07	21.73±1.59
20.68	36.24±0.81	22.63±3.24
24.58	36.54±2.05	24.29±0.78
29.15	36.75±2.08	26.82±2.02

The coefficient of static friction as a function of moisture content for different surface materials are displayed in Table IV. It can be found from this table that this value was different with the use of various surfaces [2]. Furthermore, the correlation between these coefficients and moisture content was found to be linear as confirmed by following equations:

$$\mu_a = 0.0128M + 0.1556\,;\ R^2 = 0.94 \quad (19)$$

$$\mu_w = 0.004M + 0.3608\,;\ R^2 = 0.89 \quad (20)$$

$$\mu_g = 0.0166M + 0.1177\,;\ R^2 = 0.91 \quad (21)$$

$$\mu_s = 0.005M + 0.2617\,;\ R^2 = 0.88 \quad (22)$$

for acrylic, wood, galvanised iron and mild steel, respectively.

TABLE IV. COEFFICIENT OF STATIC FRICTION WITH DIFFERENT MOISTURE CONTENTS FOR VARIOUS SURFACE MATERIALS

Moisture content (%wb)	$^*\mu_a$	$^*\mu_w$	$^*\mu_g$	$^*\mu_s$
9.06	0.25	0.40	0.21	0.32
14.36	0.35	0.42	0.27	0.33
20.68	0.45	0.43	0.40	0.35
24.58	0.49	0.47	0.42	0.39
29.15	0.48	0.48	0.42	0.43

* μ_a, μ_w, μ_g and μ_s denote the static coefficient of friction for acrylic, wood, gavalnised iron and mild steel, respectively

TABLE V. THE PROJECTION AREA, TERMINAL VELOCIT* μ_A, μ_W, μ_G AND μ_S DENOTE THE STATIC COEFFICIENT OF FRICTION FOR ACRYLIC, WOOD, GAVALNISED IRON AND MILD STEEL, RESPECTIVELY Y AND DRAG COEFFICIENT WITH DIFFERENT MOISTURE CONTENTS

Moisture content (%wb)	S (mm²)	V_t (m/s)	C_d
9.06	12.37±1.14	8.54±0.72	0.32
14.36	13.54±1.34	9.18±0.11	0.34
20.68	14.51±1.31	9.47±0.10	0.31
24.58	14.65±1.39	9.53±0.20	0.33
29.15	15.47±1.42	9.73±0.11	0.31

In order to calculate the projection area, terminal velocity and the drag coefficient, were determined, as depicted in Table V. As expected, the projection area increased with increase in moisture content, resulting from grain expansion when higher moisture was absorbed. Similarly, the increase in terminal velocity was found with increasing moisture content, inferring that low moisture content is appropriate for designing pneumatic equipment to reduce energy input [2]. The variations of projection area and terminal velocity with moisture content can be mathematically expressed in (23) and (24), respectively. Eventually, the drag coefficients at different moisture contents remain constantly. Table V shows these values, ranging from 0.32 to 0.34.

$$P_a = 0.182M + 12.178 \text{ , } R^2 = 0.964 \quad (23)$$

$$V_t = 0.0548M + 8{,}2186 \text{ , } R^2 = 0.9017 \quad (24)$$

IV. Conclusions

With increasing moisture content, width, thickness and geometric diameter of the sorghum grains increase linearly, while polynomial increase was found for length.

Sphericity increased nonlinearly with higher moisture content.

Surface area, 1000-grain mass, porosity and angle of repose increased with increase in moisture content, while decrease in bulk and true density was found with higher moisture content.

Static friction coefficient was different when using various surface materials, and it increased linearly with increasing moisture content.

Grain projection area increased from 13.30 to 15.47 mm^2 with a range of 9.06-25.15%wb.

Terminal velocity increased linearly with increase in grain moisture content.

The drag coefficient was found to be in a range of 0.32-0.34 with moisture content ranging from 9.06 to 29.15%wb.

Acknowledgements

The authors would like to express their sincere thanks to Faculty of Engineering, Mahasarakham University for financial support. Also, we wish to thank Mahasarakham University Development Fund for conference participation.

References

[1] P. S. Belton and J. R. N. Taylor, “Sorghum and millets: Protein sources for Africa,” *Trends Food Sci Technol*, vol. 15, no. 2, pp. 94-98, 2004

[2] E. A. Baryeh, “Physical properties of millet,” *J. Food Eng.*, vol. 5, no. 1, pp. 39-46, 2002.

[3] N. N. Mohsenin, *Physical Properties of Plant and Animal Material*, Gordon and Breach, New York, 1970.

[4] S. K. Sharma, K. Dubey, and C. K. Teckchandani, “Engineering properties of black gram, soybean and green gram,” in *Proc. Indian Soc. Agric. Eng*., vol. 3, 1985, pp. 181-185.

[5] W. L. McCabe, J. C. Smith, and P. Harriott, *Unit Operations of Chemical Eng*, McGraw-Hill, New York, 1986.

[6] R. A. Thompson and G. W. Isaacs, “Porosity determination of grains and seeds with air comparison pycnometer,” *Transactions ASAE*, vol. 10, pp. 693-696, 1967.

[7] E. Milani, M. Seyed, A. Razavy, A. Koocheki, V. Nikzadeh, *et al.*, “Moisture dependent physical properties of cucurbit seeds,” *Int. Agrophysics*, vol. 21, pp. 157-168, 2007.

[8] S. D. Deshpande, S. Bal, and T. P. Ojha, “Physical properties of soybean,” *J. Agric. Eng. Res.*, vol. 56, no. 2, pp. 89-98, 1993.

[9] H. Ö ğ, “Some physical properties of white lupin,” *J. Agric. Eng. Res.*, vol. 59, no. 3, pp. 273-277, 1998.

Nattapol Poomsa-ad has been working as a lecturer in biological and mechanical engineering in Mahasarakham University, Thailand since year 2002. He graduated B.Eng, M.Eng and Ph.D from King Mongkut's University of Technology Thonburi, Bangkok, His Ph.D. degree was energy technology. His research interest includes thermal processing for food and agricultural product drying technology and energy conservation and management.

Wasan Duangkhamchan recieved his B.Eng in food engineering from Kasetsart University, Thailand, in 1998 and recieved M.Eng in Mechanical engineering from Khonkaen University in 2003 in the same country. In 2012, he obtained his Ph.D. in Applied biological science (Food engineering) from Ghent University, Belgium. At present, he is working in faculty of Technology, Mahasarakham, Thailand, as an instructor. His research interests are CFD in food applications, encapsulation, drying and food freezing

Lamul Wiset received her Ph.D in Food Science and Technology from University of New South Wales, Sydney, Australia in year 2007. At present, she is a lecturer in biological engineering, in Mahasarakham University, Thailand. Her research interests include drying technology in particular quality of agricultural products such as rice, herbs, fruit and nut.