U. of K. J. Agric. Sci. 21(1), 116-127, 2013

Some Physical Properties of the Grains of Two Cultivars of Sorghum (*Sorghum bicolor* (L.) Moench)

Eman Abdu Abdalla[1] , Mohamed Ayoub Ismail and Abdelmoniem Elamin Mohamed

Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum, Sudan

Abstract: This study was conducted at the Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum and the Food Processing Research Center, Shambat, Sudan. The study was carried out with the objective of determining some physical properties of two local grain sorghum cultivars that affect design of processing machines, storage structures and processes. The studied of physical properties included grain size, shape, 1000 grain weight, hectoliter (test) weight, hardness, bulk density, true density and porosity. These properties were determined at initial moisture content and the results were analyzed using the t-test. The results showed that the the two cultivars were significantly different in size, shape and hardness, while they were not significantly different with respect to hectoliter (test) weight, 1000 grain weight, bulk density, true density and porosity. The studied cultivars of grain sorghum do not require different designs of milling machines, grain hoppers, aeration, drying machines and storage structures, while they differ with respect to design of sieve separators, harvesting, sizing, grinding machines and in calculating surface area and volume of grains which are important during modeling of grain drying, heating and cooling processes.

Key words: physical properties of two grain sorghum cultivars

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench), an indigenous African cereal, is a member of the grass family Poaceae. Cultivated sorghum was first domesticated some 3000 to 5000 years ago and probably originated in east central Africa near Ethiopia or the Sudan (Taylor 2001). Sorghum is ranked the fifth staple after maize, rice, wheat and barely, and the largest

---

[1] Present address: Department of Agricultural Engineering, Faculty of Agricultural & Natural Rescores, University of Bakht El Ruda, Eldduem, Sudan

producers are the United State of America, India, Nigeria, Sudan, Ethiopia, China, Burkina Faso, Argentina and Mali. World sorghum production was about 42 million metric tons in 2009, while Sudan sorghum production was about 4.2 million metric tons (FAOSTAT 2009). Sorghum is an important food cereal in many parts of Africa, Asia and the semi-arid tropics worldwide (Duodu *et al*., 2003). It feeds millions of people on a daily basis in the developing countries, providing dietary starch, dietary protein and some vitamins and minerals. In the West, it is predominantly used as an animal feed and is increasingly important as a modified starch and biomass source for ethanol production (Hill *et al*. 2012). Grain sorghum is the leader cereal crop in the Sudan and is the main staple food, prevailing throughout the country and covering more than 60% of the total cultivated cereals area. In the Sudan, the grains are either cooked and consumed as whole or reduced to flour and further processed. Sorghum flour is predominantly used in preparation of indigenous foods like *kisra* (fermented flat breads) and *aseda* (porridge) as well as in production of traditional alcoholic and non-alcoholic beverages such as *marrisa* and *hulu-mur*, respectively (Mohammed *et al*. 1991, Hamad *et al*. 1992; Hamad *et al*. 1997). Processed sorghum seeds or flour are important sources of calories and proteins for the vast majority of the population as well as for poultry and livestock (Ibrahim *et al*. 2005).

The study of physical, aerodynamic and mechanical properties of food grains is important and essential in the design of processing machines, storage structures and processes (Singh *et al*. 2010). The size (geometric mean diameter) and shape (sphericity) and mechanical behaviour of grains and beans are important in designing of separating, harvesting, sizing and grinding machines (Altuntas and Yildiz 2007; Singh *et al*. 2010). Principal (characteristic) axial dimensions of seeds are useful in selecting sieve separators and in calculating grinding power during size reduction. They can also be used to calculate surface area and volume of kernels which are important during modelling of grain drying, heating and cooling (Al-Mahasneh and Rababah 2007; Varnamkhasti *et al*. 2008). Test weight or hectoliter weight is defined as weight per unit volume of the grains and is given in kg/hectoliter. There is a significant relationship (positive correlation) between hectoliter weight and milling (flour) yield. Test weight is mainly defined as interaction of soundness and high integral quality (Phill *et al*. 1986).

The 1000 grain weight of rough or raw paddy is a useful index to 'milling outturn' in measuring the relative amount of dockage or foreign material in a given paddy and the amount of shriveled or immature kernels (Reddy and Chakraverty 2004). Thousand grain weight of rough rice grain is used for calculating the head rice yield (HRY) which is the mass percentage of rough rice that remains as head rice. Head rice is ¾ or more of the whole milled kernels separated from the total milled rice. Data on actual milling output are obtained from the millers and expressed in percentage of rough rice fed for milling. Expected milling output is determined at the laboratory by taking the weight of a thousand grains of milled head rice and the corresponding weight of a thousand grains of rough rice is expressed as a percentage of the weight of the rough rice. Any shortfall in actual milling output is considered as milling loss due to breakage of grains (Varnamkhasti *et al*. 2008).

Bulk density and porosity affect the structures loads (Altuntas and Yildiz 2007). Bulk density, true density and porosity can be useful in sizing grain hoppers and storage facilities; they can affect the rate of heat and mass transfer of moisture during aeration and drying process. Grain beds with low porosity will have greater resistance to water vapour escape during the drying process, which may lead to higher power to drive the aeration fans (Al-Mahasneh and Rababah 2007; Varnamkhasti *et al*. 2008). Bulk density, true density and porosity are important factors in designing of storage structures (Singh *et al*. 2010).

There is little research on the physical properties of grain sorghum as compared to other types of food grains. For example, Mwithiga and Sifuna (2007) investigated the effect of grain moisture content on some physical properties (characteristic dimensions, 1000 grain mass, bulk density, true density, angle of repose and hardness) of three varieties of sorghum seeds. Therefore, this study was carried out with the objective of determining some physical properties such as; size, shape, hectoliter (test) weight, 1000 seed weight, hardness, bulk density, true density and porosity of grain sorghum for two local cultivars, namely Tabat and Wad Ahmed.

MATERIALS AND METHODS

This study was conducted at the Department of Agricultural Engineering, Faculty of Agriculture, University of Khartoum and the Food Processing Research Center, Shambat, Sudan. Two local grain sorghum cultivars (Tabat and Wad Ahmed), harvested in the 2007-2008 season, were obtained from The Sorghum Research Programme, Agricultural Research and Technology Corporation, Wad Medani, Gezira State, Sudan. The grains were cleaned manually to remove broken seed fractions, soil particles and foreign material or insects, if any. After that, the grain samples were sealed in polyethylene bags and stored in a refrigerator maintained at 5°C for a week to enhance uniform distribution of grain moisture throughout the samples. The initial moisture contents of the grains for the two studied cultivars were determined according to the standard method of the Association of Official Analytical Chemists (AOAC 1990). In this method, well-mixed triplicates of grain samples, each of an initial weight of about 2 ± 0.001 g, were dried in an oven set at $105 \pm 1.0^{o}C$ for 24 hours. The initial average moisture contents of grains of Tabat and Wad Ahmed cultivars were found to be 8.24% and 6.84%, respectively.

Twenty randomly selected grains, from each of the two lots of the studied cultivars, were used to determine the principal dimensions for calculating the grains geometric mean diameter and sphericity according to the method described by CIAE (1980). For each individual grain, the three principal dimensions, namely length, width and thickness were determined using a vernier to an accuracy of 0.05 mm. The grain size (geometric mean diameter, D_p) and shape (sphericity, ϕ) were calculated from the three determined principal dimensions by using equations 1 and 2, respectively:

$$D_p = (LWT)^{1/3} \quad (1)$$

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

where,

L = grain length, mm

W = grain width, mm

T = grain thickness, mm

The hectoliter (test) weight was determined by the hectoliter measuring device model. The funnel was filled with grains of each of the two studied cultivars and leveled with a ruler, while its gate was closed. The funnel gate was opened and grains allowed to flow down into a cylinder until overflowing occurred. Then the grains were leveled by a leveler attached to the cylinder top. The grains weight was recorded and expressed as g/hectoliter (Phil *et al*. 1986).

From each of the two lots of the studied cultivars, 1000 grains were randomly selected and weighed using sensitive balance to an accuracy of 0.001 g. The recorded grains weight was then reported as the 1000 grain weight of the cultivar in consideration.

The test of grain hardness was made at the beginning of the experiment by using the hardness tester (Model 174886, Kiya Seiskusho Ltd, Tokyo, Japan). One hundred sound and un-broken grains were selected randomly from each cultivar lot. Each grain was placed in the tester and the pressure was increased gradually by winding the tester handle until the grain was broken. The pressure in Nm^{-2} used to break each grain was recorded, and the average of the one hundred grains from each cultivar was expressed as its grain hardness, adopting the method of Mohammed (2003).

The bulk density (ρ_b) was determined by calculating the ratio of the mass of a sample of grains to its total volume following the method described by Boumans (1985). From each of the two lots of the studied cultivars, about 50 g of sound grains were poured into a graduated measuring cylinder from a height of 15 cm. The measuring cylinder was tapped gently ten times on a bench so that grains were not compacted in any way. By obtaining the grains volume, the bulk density, in kg/m^3, of each of the two studied cultivars was calculated by using equation 3 as follows:

$$\rho_b = \frac{50\,g}{V\,ml} * 1000 \quad (3)$$

Following the method recommended by CIAE (1980), the true density (ρ_t) was determined by calculating the ratio of the mass of a sample of grains to the solid volume occupied by those grains. A sample of about 20 g was carefully poured into a graduated measuring cylinder containing a fixed volume of kerosene (50 ml). The increase in volume was recorded and the true density, in kg/m^3, of each of the two studied cultivars was calculated using equation 4 as follows:

$$\rho_t = \frac{20\,g}{V\,ml} * 1000 \quad (4)$$

The porosity (ε) is defined as percentage of void space in the bulk of grain which was not occupied by grains and was determined according to the method described by CIAE (1980). The porosity value was calculated using equation 5 as follows:

$$\varepsilon = \frac{\rho_t - \rho_b}{\rho_t} * 100 \quad (5)$$

The two sample independent t-test was carried out using Minitab Statistical Software, Release 13.30 to see if there is any difference in the sample means of the physical properties of the two studied cultivars.

RESULTS AND DISCUSSION

Tables 1 and 2 show the statistical analysis and mean values of the two-sample independent t-test to see if there is any difference in the sample means of the physical properties of the two studied cultivars. From Table 1 it is clear that the null hypothesis (H_o: $\mu_1 = \mu_2$) holds true, i.e. $|t_o| < t_t$ for the physical properties of 1000 grain weight, hectoliter (test) weight, bulk density, true density and porosity, whereas the alternative hypothesis (H_1: $\mu_1 \neq \mu_2$) holds true, i.e. $|t_o| > t_t$ for the physical properties of size, shape and hardness. This means that there are no significant differences between the two studied cultivars regarding 1000 grain weight, hectoliter (test) weight, bulk density, true density and porosity, whereas there are significant differences between the two studied cultivars with respect to size, shape and hardness as shows in Table 2. The significant differences between the two studied cultivars in some physical properties are in agreement with the findings of Mwithiga and Sifuna (2007). That means the two studied cultivars of grain sorghum do not differ in designing of milling, grain hoppers, aeration, drying machines and storage structures. On the other hand, they differ in designing of separating, harvesting, sizing, grinding and milling machines and in calculating surface area and volume of grains which are important during modeling of grain drying, heating and cooling processes.

CONCLUSIONS

1. The physical properties of the two studied cultivars which were significantly different included size, shape and hardness; while the physical properties which were not significantly different included 1000 grain weight, hectoliter (test) weight, bulk density, true density and porosity.

2. The two studied cultivars do not differ in designing of milling, grain hoppers, aeration, drying machines and storage structures, but they differ in designing of separating, harvesting, sizing, grinding and milling machines and in calculating surface area and volume of grains which are important during modeling of grain drying, heating and cooling processes.

Table 1. Independent t-test for the physical properties of the two sorghum cultivars

Physical property	95% confidence (CI) interval for μ_1-μ_2	μ_1-μ_2 vs $\mu_1 \neq \mu_2$			
		$\lvert t_o \rvert$	t_t	P	df
1000 grain					
Weight (g)	(-4.15,0.13)	-3.99	4.303	0.056	2
Size (mm)	(0.02,0.00)	190.87	4.303	0.015	2
Shape (mm)	(-0.01,-0.00)	-5.51	2.776	0.005	4
Hectoliter(test)					
Weight (g/hectoliter)	(3.65,13.32)	2.12	4.303	0.148	2
True density (kg/m^3)	(-0.77,0.12)	1.00	4.303	0.423	2
Bulk density (kg/m^3)	(-0.00,0.05)	3.69	4.303	0.051	2
Hardness (N/m^2)	(0.60,1.26)	0.90	4.303	0.004	2
Porosity (%)	(-5.29,3.98)	-0.39	4.303	0.715	2

μ_1 = population mean of Tabat cultivar

μ_2 = population mean of Wad Ahmed cultivar

t_o = calculated value of the test statistic (calculated t)

t_t = tabulated value of the upper $\alpha/2$ percentage point of the t-distribution (tabulated t)

P = probability or percent risk of being wrong if the null hypothesis (H_o) is rejected

df = degrees of freedom

Table .2. Mean values of the physical properties for sorghum grain cultivars at the initial moisture content

Comparison	Tabat	Wad Ahmed
1000 grain weight (g)	21.45[a]	23.49[a]
Size (mm)	0.360[a]	0.346[b]
Shape (mm)	0.823[b]	0.832[a]
Hectoliter(test) weight (g/hectoliter)	728.17[a]	723.33[a]
True density (kg/m^3)	1.25[a]	1.23[a]
Bulk density (kg/m^3)	0.748[a]	0.724[a]
Hardness (N/m^2)	6.20[a]	5.70[b]
Porosity %	40.15[a]	40.80[a]

Values followed by the same letter are not significantly different at the 5% probability level.

REFERENCES

Al-Mahasneh, M.A. and Rababah, T.M. (2007). Effect of moisture content on some physical properties of green wheat. *Journal of Food Engineering*, 79, 1467-1473.

Altuntas, E. and Yildiz, M. (2007). Effect of moisture content on some physical and mechanical properties of faba bean (*Vicia faba* L.) grains. *Journal of Food Engineering*, 78, 174-183.

AOAC. (1990). Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Washington, DC.

Boumans, G. (1985). *Grain Handling and Storage*. Nijngardam, Schoten, Belgium.

CIAE (1980). Central Institute of Agricultural Engineering. *Properties of Food Material. Technical Bulletin* No. 801715, Madhya Pradesh, India.

Duodu, K.G.; Taylor, J.R.N.; Belton, P.S. and Hamaker, B.R. (2003). Factors affecting sorghum protein digestibility. *Journal of Cereal Science* 38, 117-131.

FAOSTAT. (2009). Crop Production 2008, Statistics Division, Food and Agriculture Organization of the United Nations, Rome, Italy.

Hamad, S.H.; Boecker, G.; Vogel, R.F. and Hammes, W.P. (1992). Microbiological and chemical analysis of fermented sorghum dough for kisra production. *Journal of Applied Microbiology* 37, 728-731.

Hamad, S.H.; Dieng, M.C.; Ehrmann, M.A. and Aogel, R.F. (1997). Characterization of the bacterial flora of Sudanese sorghum flour and sorghum sour dough. *Journal of Applied Microbiology* 83, 764-770.

Hill, H.; Lee, L.S., and Henry, R.J. (2012). Variation in sorghum starch synthesis genes associated with differences in starch phenotype. *Food Chemisetry* 131, 175-183.

Ibrahim, F.S.; Babiker, E.E.; Yousif, N.E. and El Tinay, A.H. (2005). Effect of fermentation on biological and sensory characteristics of sorghum flour supplemented with whey protein. *Food Chemistry* 92, 285-292.

Mohammed, H.A. (2003). *A Study on the Susceptibility of Some Wheat Grain Varieties to Trogoderma granarium Everts Attack*. M.Sc. Thesis, Faculty of Agriculture, University of Khartoum, Sudan

Mohammed, S.I.; Stenson, L.R. and Kirleis, A.W. (1991). Isolation and characterization of microorganisms associated with the traditional sorghum fermentation for production of Sudanese kissra. *Applied and Environment Microbiology* 57(9), 2529-2533.

Mwithiga, E. and Sifuna, L. (2007). Effect of moisture content on some physical properties of sorghum (*Sorghum bicolor* (L.) Moench) grains. *Journal of Food Engineering* 80, 174-183

Phil, W.J.E.; Hani, N. and Safouh, R. (1986). *Crop Quality Evaluation Methods and Guidelines*. ICRISAT, Patancheru, India, pp.24.

Reddy, B.S. and Chakraverty, A. (2004). Physical properties of raw and parboiled paddy. *Biosystems Engineering* 88(4), 461-466.

Singh, K.P.; Mishra, H.N. and Saha, S. (2010). Moisture-dependent properties of barnyard millet grain and kernel. *Journal of Food Engineering* 96, 598-606.

Taylor, J.R.N. (2001). Developments in sorghum food technologies. *Advances in Food and Nutrition Research* 43, 217-264.

Varnamkhasti, M.G.; Mobli, H.; Jafari, A.; Keyhani, A.R.; Soltanabadi, M.H.; Rafiee, S. and Kheiralipour, K. (2008). Some physical properties of rough rice (*Oryza sativa* L.) grain. *Journal of Cereal Science* 47, 496-501.

بعض الخصائص الفيزيائية لحبوب صنفين من الذرة الرفيعة

إيمان عبده عبد الله ومحمد ايوب اسماعيل وعبدالمنعم الأمين محمد

قسم الهندسة الزراعية، كلية الزراعة ، جامعة الخرطوم، السودان

موجز البحث: أجريت هذه الدراسة بقسم الهندسة الزراعية، كلية الزراعة، جامعة الخرطوم، ومركز بحوث تصنيع الأغذية، شمبات، السودان. أجريت الدراسة بهدف تحديد بعض الخصائص الفيزيائية لحبوب صنفين محليين من الذرة الرفيعة تؤثر علي تصميم ماكينات التصنيع و مباني التخزين والتصنيع. الخصائص الفيزيائية التي درست شملت الحجم والشكل و وزن الألف حبة واختبار الوزن والصلابة والكثافة الحجمية والكثافة الحقيقة والمسامية عند محتوى الرطوبة الابتدائي. حللت النتائج المتحصل عليها باستخدام اختبار t. أظهرت النتائج أن الصنفين اختلفا معنوياً في الشكل والحجم والصلابة ، بينما لا يوجد اختلاف معنوي في وزن الألف حبة واختبار الوزن والكثافة الحجمية والكثافة الحقيقة والمسامية عند محتوى الرطوبة الابتدائي. صناف الذرة الرفيعة التي درست لاتختلف في تصميم ماكينات الطحن ومنقيات الحبوب ومباني التخزين بينما تختلف في تصميم غرابيل الفصل وماكينات الحصاد والحجم والتدريج وحساب مساحة السطح والحجم للحبوب خلال النمذجة لعمليات التجفيف والتسخين والتبريد .