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Determination of Some Engineering Properties of Acha (Digitaria exilis) and Sand Relevant to the Design of De-Stoning Machine

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ABSTRACT
This study evaluated selected physical, gravimetric, aerodynamic, and frictional properties of acha (Digitaria exilis) and sand relevant to the design of a de-stoning system. Measurements were conducted at a mean acha moisture content of 10.23% dry basis. One hundred randomly selected grains were measured for length, width, and thickness, while bulk density, true density, porosity, thousand-grain mass, angle of repose, coefficient of friction, terminal velocity, drag coefficient, and Reynolds number were determined using laboratory procedures. A sieve-gradation test was also performed on acha and sand using apertures from 2.36 mm to 106 µm. The mean length, width, and thickness of acha were 1.552, 0.853, and 0.791 mm, respectively; geometric mean diameter was 1.016 mm and sphericity was 65.50%. Mean thousand-grain mass, bulk density, true density, and porosity were 0.491 g, 598.9 kg m−3, 1127 kg m−3, and 46.90%, respectively. The mean angle of repose was 23.9°, while coefficients of friction were 0.44 on galvanized steel and 0.34 on fabric. The mean terminal velocity was 3.90 m s−1. For sand, mean thousand-grain mass, bulk density, true density, porosity, and angle of repose were 0.90 g, 1.45 g cm−3, 2.64 g cm−3, 45.08%, and 28.49°, respectively. The results indicate that density and frictional differences between acha and sand are potentially useful for gravity separation, while aerodynamic properties provide design parameters for air-assisted separation. The findings provide baseline engineering data for the development and optimization of acha de-stoning equipment.

Keywords: Acha, Engineering Properties, De-stoning

INTRODUCTION

Acha (Digitaria exilis), also known as fonio, is an indigenous West African cereal with importance for food, industrial and economic use. Studies on acha and its related species have been increased due to its nutritional, functional and processing potential (Jideani & Jideani, 2011; Jideani, 2012). In Nigeria, acha is mostly associated with the northern production areas and it is processed into a variety of traditional foods and other value-added products such as extruded snacks (Ubbor et al., 2022). The small size of the grain and the high percentage of foreign materials present in it poses some problems regarding cleaning and separation during postharvest operations.

Successful design of agricultural processing equipment is greatly dependent on the knowledge of the material properties. The linear dimensions, shape, density, porosity, angle of repose, coefficient of friction, terminal velocity and other aerodynamic parameters influence the hopper geometry, conveying behaviour, airflow requirements, screen selection and separation efficiency. Analogue engineering property studies have been carried out in order to determine the design parameters of grains and seeds like pigeon pea, African breadfruit, sesame, bottle gourd and tef (Baryeh & Mangope, 2003; Omobuwajo et al., 1999; Tunde-Akintunde & Akintunde, 2004; Pradhan et al., 2013; Zewdu, 2007).

In de-stoning, the properties of the contaminant are as important as those of the target grain. Differences in density, mass, frictional behaviour, particle size, and response to air flow can be exploited to separate grain from mineral particles. However, the study notes that the properties of foreign material are often given less attention during equipment design. The present work therefore evaluates acha and sand together so that the measured differences can be considered directly in the design of a de-stoning system.

The objective of the study was to determine selected physical, gravimetric, aerodynamic, and frictional properties of acha grains and sand, together with their sieve-size distributions, and to assess their relevance to the design of acha de-stoning equipment.

MATERIALS AND METHODS

Experimental Material and Moisture Content

Acha grains were manually cleaned to remove visible foreign matter, including sand, dirt, broken grains, and immature grains. The mean moisture content of the experimental acha sample was 10.23% dry basis. Moisture content was determined by oven drying following the procedure reported by established grain-moisture methods (Baryeh & Mangope, 2003).

Measurement of Physical Properties of Acha

One hundred acha grains were randomly selected. Length (L), width (W), and thickness (T) were measured with a digital vernier caliper with a stated accuracy of 0.001 mm. Arithmetic mean diameter, geometric mean diameter, sphericity, aspect ratio, surface area, projected area, and grain volume were calculated from the measured dimensions using standard relationships as reported by (Baryeh & Mangope, 2003; Mirzabe et al., 2013; Omobuwajo et al., 1999). The arithmetic mean diameter was calculated as $Da = \frac{L+W+T}{3}$, While the geometric mean diameter was calculated as Dg = $(LWT)^{\frac{1}{3}}$, Sphericity was expressed as the ratio of geometric mean diameter to length, and aspect ratio as the ratio of width

to length. The surface area, projected area, and volume from the corresponding geometric relationships were also calculated.

Gravimetric Properties

Thousand-grain mass was obtained by counting and weighing 1,000 randomly selected grains with a digital balance having a stated accuracy of 0.01 g. Bulk density was determined from the mass of grain occupying a known container volume. True density was determined from grain mass and the volume of water displaced. Porosity was calculated from bulk and true densities as $\delta = \frac{\rho_t - \rho_b}{\rho_t}$ x 100 %, where ρb is bulk density and ρt is true density (Pradhan et al., 2013).

Aerodynamic Properties

Terminal velocity was measured in an air-suspension column (air-velocity rig). The drag coefficient was calculated from the measured terminal velocity using the relationship given by Zewdu (2007). The Reynolds number was also determined as an indicator of the flow regime around the grain. These parameters are important for selecting and sizing air-assisted cleaning and separation components.

Frictional Properties

The angle of repose was determined using an open-ended cylinder method. The coefficient of static friction was obtained from the tangent of the measured friction angle. Measurements were made for acha and sand on galvanized steel and fabric surfaces. (Omobuwajo et al., 1999; Tunde-Akintunde & Akintunde, 2004).

Sieve-gradation Test

A 1,000-g sample of acha and sand was placed on a nested sieve set with apertures of 2.36 mm, 1.18 mm, 850 μm, 425 μm, 300 μm, 212 μm, and 106 μm, together with a pan. Mechanical shaking was performed for 10 min. The material retained on each sieve was weighed, and the procedure was repeated 10 times. Where acha and sand occurred together on the same sieve, they were separated manually, washed, oven-dried, and weighed separately. Percentage retained was calculated from the mass retained relative to the initial sample mass.

RESULTS AND DISCUSSION

Physical and Gravimetric Properties of Acha

Table 1 shows the physical (gravimetric, aerodynamic), and friction properties of acha sample at 10.23% dw mean moisture content. The grain mean length, width and thickness is 1.552, 0.853, and 0.791 mm respectively giving the mean geometric diameter of 1.016 mm. These parameters are useful in the design of sizing screens, feed openings and passages, and surfaces for separating or conveying particles.

Table 1: Determination of Some Physical Properties of Acha

Un-dehulledAcha seed	Minimum	Maximum	Mean
Moisture content (% db)	9.83	10.40	10.23
Length (mm)	1.51	1.63	1.552
Width (mm)	0.81	0.89	0.853
Thickness (mm)	0.76	0.82	0.791
One Thousand grain mass (g)	0.483	0.514	0.491
True density (kg/m3)	1126	1146	1127
Bulk density (kg/m3)	596.1	603.3	598.9
Porosity (%)	47.1	47.4	46.90
Arithmetic mean diameter (mm)	1.053	1.073	1.066
Geometric mean diameter (mm)	0.993	1.017	1.016
Sphericity (%)	62.45	67.32	65.50
Aspect ratio	0.509	0.589	0.550
Projected area (mm2)	1.06	1.38	1.140
Surface area (mm2)	3.100	3.530	3.250
Volume (mm3)	0.513	0.624	0.550
Terminal velocity(ms1)	3.88	3.94	3.90
Drag coefficient	0.35	0.47	0.41
Reynolds number	282.50	323.16	304.21
Angle of repose (o)	23.6	24.4	23.9
Coefficient of friction			
Galvanized steel (o)	0.40	0.47	0.44
Fabric material (o)	0.32	0.36	0.34

The mean sphericity of the grain was found to be 65.50%, which indicates that the grain is not very spherical in shape. The shape and size of the grain are factors that influence the flow of the grain over inclined planes and through screens. The measured thousand-grain mass of 0.491 g was very light, which is consistent with the dimensions of the grain and has implications for aerodynamic separation since the mass of the particle influences the balance between gravitational and fluid-drag forces. The mean true density (1127 kg m−3) was significantly greater than the bulk density (598.9 kg m−3), resulting in a calculated porosity of 46.90%. Bulk density is particularly important for hopper and storage design, while true density and porosity influence the flow of air through a granular bed. The measured angle of repose of 23.9° suggests that it will flow well under the conditions tested. However, the actual hopper performance will be influenced by surface roughness, moisture, and operating conditions. The coefficient of friction differed between galvanized steel (0.44) and fabric (0.34). Such differences could be exploitable in gravity-based separation if the surface as well as operating conditions yielded significantly different trajectories to separate acha and the contaminant. Similar studies confirm the significance of frictional properties for hopper, conveying system, screen, and separation equipment design

(Omobuwajoet al., 1999; Tunde-Akintunde & Akintunde, 2004).

Table 2: Determination of Some Physical Properties of Sand Relevant for Destoning

Sand	Minimum	Maximum	Mean
One thousand grain mass (g)	0.85	1.1	0.90
True density (g cm-^{3})	2.58	2.70	2.64
Bulk density (g/cm-^{3})	1.38	1.49	1.45
Porosity (%)	44.48	46.5	45.08
Angle of repose (^{o})	26.89	29.48	28.49
Coefficient of friction			
Galvanized steel	042	0.47	0.45
Fabric material	0.49	0.51	0.50

The mean true density of sand was 2.64 g cm−3 (2640 kg m−3), compared with 1127 kg m−3 for acha. The difference in true density is substantial and provides a strong physical basis for gravity-assisted separation. The mean bulk density of sand (1.45 g cm−3) was also considerably greater than that of acha (0.5989 g cm−3). The study therefore identified density difference as a major opportunity for de-stoning.

The mean angle of repose of sand (28.49°) exceeded that of acha (23.9°), indicating different flow behaviour on inclined surfaces. More importantly, the coefficient of friction on fabric was 0.50 for sand compared with 0.34 for acha, a larger contrast than that observed on galvanized steel (0.45 versus 0.44). This suggests that fabric material provide a more favourable surface for gravity-based differentiation than galvanized steel under the conditions tested.

Table 3: Particle Size Distribution of Acha and Sand

Sieve Size	Percentage Retained for Acha			Percentage Retained for Sand		
	Max. % retained	Min. % retained	Mean% retained	Max. % retained	Min. % retained	Mean% retained
2.36 mm	0	0	0	0	0	0
1.18 mm	4.53	3.17	4.08	20.61	11.77	15.26
850 µm	96.27	94.22	94.98	73.83	68.81	72.28
425 µm	1.27	0.20	0.94	8.09	5.17	6.56
300µm	0	0	0	5.66	3.00	4.25
212µm	0	0	0	2.68	0.7	1.53
106µm	0	0	0	0	0	0
Pan	0	0	0	0	0	0

The sieve analysis showed the largest retained fractions at 850-µm aperture for both materials (94.98% of acha and 72.28% of sand on average) but with a broader spread of sand in the 1.18-mm to 212-µm fractions versus acha concentration at 850 µm. This would appear to indicate that size alone is unlikely to provide complete separation and that a combined principle which includes density, friction and/or aerodynamic behaviour is more appropriate than the application of a screening principle alone.

The fact that the average sand mass of 20.57 g was found in the acha sample (approximately 2.06% of the stated 1,000-g sample) and that the 850-µm sieve had retained 918.52 g of sand and 14.86 g of acha supports the implication of the need to take into account the overlapping particle-size fraction when designing a de-stoner since such methods as might be considered based purely upon size aperture could potentially transport desired grain with the reject or leave undesirable sand with the product.

CONCLUSION

Selected engineering properties of acha (Digitaria exilis) and sand relevant to the de-stoning process were determined at a mean acha moisture content of 10.23% dry basis. Acha had mean length, width, and thickness values of 1.552, 0.853, and 0.791 mm, respectively, a geometric mean diameter of 1.016 mm, sphericity of 65.50%, thousand-grain mass of 0.491 g, bulk density of 598.9 kg m^{-3}, true density of 1127 kg m^{-3}, porosity of 46.90%, and angle of repose of 23.9°. In comparison, sand had a thousand-grain mass of 0.90 g, bulk density of 1.45 g cm^{-3}, true density of 2.64 g cm^{-3}, porosity of 45.08%, angle of repose of 28.49°, and a mean terminal velocity of 3.90 m s^{-1}, with a drag coefficient of 0.41 and Reynolds number of 304.21, based on the tabulated data. Differences in density and frictional behaviour on fabric surfaces, together with substantial overlap in particle size, provide useful insights for de-stoner design. However, the discrepancy between the reported terminal velocities of 3.90 and 3.97 m s^{-1} should be resolved using the original laboratory data, and machine-level validation is necessary to establish the optimum deck inclination, air velocity, feed rate, and separation efficiency.

REFERENCES

Baryeh, E. A., & Mangope, B. K. (2003). Some physical properties of QP-38 variety pigeon pea. *Journal of Food Engineering*, *56*(1), 59–65. https://doi.org/10.1016/S0260-8774(02)00148-6

Jideani, I. A. (2012). Digitaria exilis (acha/fonio), Digitaria iburua (iburu/fonio) and Eluesine coracana (tamba/finger millet)—Non-conventional cereal grains with potentials. *Scientific Research and Essays*, *7*(45), 3834–3843. https://doi.org/10.5897/SRE12.416

Jideani, I. A., & Jideani, V. A. (2011). Developments on the cereal grains Digitaria exilis (acha) and Digitaria iburua (iburu). *Journal of Food Science and Technology*, *48*(3), 251–259. https://doi.org/10.1007/s13197-010-0208-9

Mirzabe, A. H., Khazaei, J., Chegini, G. R., & Gholami, O. (2013). Some physical properties of almond nut and kernel and modeling dimensional properties. *Agricultural Engineering International: CIGR Journal*, *15*(2), 256–265.

Omobuwajo, T. O., Akande, A. E., & Sanni, L. A. (1999). Selected physical, mechanical and aerodynamic properties of African breadfruit (Treculia africana) seeds. *Journal of Food Engineering*, *40*(4), 241–244. https://doi.org/10.1016/S0260-8774(99)00060-6

Pradhan, R. C., Said, P. P., & Singh, S. (2013). Physical properties of bottle gourd seeds. Agricultural Engineering International: *CIGR Journal*, *15*(1), 106–113.

Satimehin, A. A., & Philip, T. K. (2012). Some physical properties of acha as affected by moisture content. Agricultural Engineering International*: CIGR Journal*, *14*(4), 231–237.

Sirisomboon, P., Kitchaiya, P., Pholpho, T., & Mahuttanyavanitch, W. (2007). Physical and mechanical properties of Jatropha curcas L. fruits, and kernels. *Biosystems Engineering*, *97*, 201–207.

Tunde-Akintunde, T. Y., & Akintunde, B. O. (2004). Some physical properties of sesame seed. *Biosystems Engineering*, 88(1), 127–129.

Ubbor, S. C., Arukwe, D. C., Ezeocha, V. C., Nwose, O. N., Iguh, B. N., & Nwibo, O. G. (2022). Production and quality evaluation of ready to eat extruded snacks from flour blends of acha-cowpea and sweet potato starch. FUDMA Journal of Sciences, 6(4), 245–253. https://doi.org/10.33003/fjs-2022-0604-1071

Zewdu, A. D. (2007). Aerodynamic properties of tef grain and straw material. *Biosystems Engineering*, *98*(3), 304–309. https://doi.org/10.1016/j.biosystemseng.2007.08.003.

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