Physical properties of acha as affected by moisture content

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Abstract: Mechanization of acha processing has been limited by dearth of data on engineering properties to aid design of equipment for its postharvest operation. Therefore, this study was undertaken to determine the particle size, bulk density, and porosity of acha as influenced by moisture content. Particle size was determined by the method of sieve analysis. The fineness modulus obtained from the analysis was used in calculating the average particle size of acha grains. Bulk density was determined by the mass of a known volume of samples, while a porosity measuring apparatus was used for measuring the porosity of acha grains at four levels of moisture content and five levels of bulk density. The results showed that acha grains increased in size from 1.745 mm to 2.366 mm in the moisture content range of 11.46 to 17.46% wet basis. A regression analysis of average grain size on moisture content showed a positive linear relationship (r = 0.887). Similarly bulk density increased with moisture content, and showed a positive linear dependency on moisture content (r = 0.997). Grain porosity was also affected individually and jointly by moisture content and bulk density. A multiple linear regression analysis showed a negative correlation of porosity with moisture content and bulk density (r = - 0.991). Therefore, moisture content and bulk density of acha are important factors to consider when designing facilities for its handling, processing, and storage.

Keywords: Acha, bulk density, moisture content, physical properties

Citation: Satimehin A. A., and T. K. Philip. 2012. Physical properties of acha as affected by moisture content. Agric Eng Int: CIGR Journal, 14(4): 231−237.

1 Introduction

Acha (Figure 1) is a cereal crop of West African origin belonging to the family *graminaea* (Gibon and Pain, 1985). The plant is an important crop in Southern Mali, Western Burkina Faso, Eastern Senegal, Northern Guinea, North-eastern Nigeria, and Southern Niger (Harlan, 1993; Jideani, 1999; Chukwu and Abdul-kadir, 2008). Almost 250,000 MT of acha are grown annually in West Africa on about 380,000 ha. of land (CIRAD, 2004). There are many varieties of acha, but the most prominent two are the white acha (Digitaria exilis) and black acha (Digitaria iburua). In Nigeria, the white acha is grown more widely (Chukwu and Abdul-kadir, 2008).

Acha contains about 85% dry matter, of which about 10% is starch (Morales-Payán et al. 2002), 5% is mineral and 7% is crude protein (Temple and Bassa, 1991). The protein of acha is higher compared with that of other grains (Chukwu and Abdul-kadir, 2008), and is reputed to contain almost twice as much methionine as egg protein does (Temple and Bassa, 1991).

Figure 1 Photograph of acha grains

Acha grain is consumed in a variety of ways such as porridge and couscous. Balami et al. (2009) studied the suitability of acha as a substitute malt grain, and

Received date: 2012-06-28 **Accepted date:** 2012-11-20

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concluded that acha grains can be modified and used in the production of malt drink comparable to drinks produced from conventional brewing grains. Also, Ayo and Nkama (2004) mixed different inclusion levels of acha grain flour in replacement with wheat flour to produce bread, and found that inclusion level of acha grain flour not exceeding 30% generally produced bread of acceptable quality.

In spite of the nutritional and economic importance of acha, there is dearth of the scientific knowledge needed for the mechanization of acha production, processing, handling, storage and distribution. In general, engineering properties of grains are essential to the design of equipment, especially for their handling, processing, and storage. Consequently, the physical and mechanical properties of many cereals have extensively been investigated and reported. Fathollahzadeh et al. (2008) gave a long list of such food substances which include gram, almond nut and kernel, hazel nuts, okra seeds, and chickpea seeds, etc. Boukouvalas et al. (2006) earlier conducted an extensive literature survey and compiled comprehensive data on density and porosity of foodstuffs. Ghadge, Vairagar and Prasad (2008) investigated some physical properties of chickpea split. The properties were geometric mean dimension, sphericity, aspect ratio, surface area, and static coefficient of friction on galvanised steel, glass and plywood surfaces. Nwakonobi and Onwualu (2009) investigated the effect of moisture content and types of structural surfaces on coefficient of friction of millet and sorghum. The authors observed that the coefficient of friction for the grains increased linearly with increase in moisture content.

However, not much scientific data are available on the engineering properties of acha to aid the design of equipment for its harvesting, threshing, cleaning, dehulling, milling, packaging, handling, storage, and aeration. As a biological material, the properties of acha are influenced by many factors such as its moisture content and bulk density. Due to lack of knowledge of the interplay between its properties and these factors, design and fabrication of machines for acha have been fortuitous. Philip and Itodo (2006) highlighted the traditional tools and manual techniques currently used in West Africa for acha cultivation, harvesting and post harvest process operations such as threshing, winnowing, hulling and de-stoning. The authors noted the tedium and drudgery associated with the manual methods, and opined that acha production had to be stimulated by initiating research activities to address its mechanization constraints.

This study is an effort towards generating scientific data that could be valuable for accurate design of efficient machines for postharvest processing operations of acha. Therefore, this study was undertaken to determine the bulk density, porosity, particle size, and particle size distribution of acha.

2 Materials and methods

2.1 Preparation of grain samples

The acha used for this study was undehulled white acha (Digitaria exilis). The grains were milk-white in colour and obtained from North Bank Market, Makurdi, Nigeria. The initial moisture content of the acha grains was determined by the oven drying method (AOAC, 1984). The bulk of the grain mass was divided into four lots with 2 kg each. The first lot was the control while the remaining lots were conditioned to provide various moisture content levels by mixing grains with predetermined amount of water in a rotary mixer for 20 min. The quantity of water required for moisture conditioning was calculated using the following formula (Equation (1)).

$$\Delta G = G(M_f - M_i) / (100 - M_f) \quad (1)$$

where, ΔG = Mass of water to be added (g); G = initial mass of grain (g); M_i = initial moisture content of the grain (% wet basis) and M_f = desired (final) moisture content of the grain (% wet basis).

2.2 Particle Size Distribution

The sieve analysis method was used to determine the particle size distribution of acha. This method was used by Ukpabi and Ndimefe (1990) to determine the particle size distribution of garri. About 120 g of acha sample was poured into the upper sieve of the set of standard sieves, manually vibrated for 15 min., and the weights retained by each sieve were recorded in percentage.

2.3 Determination of Bulk Density

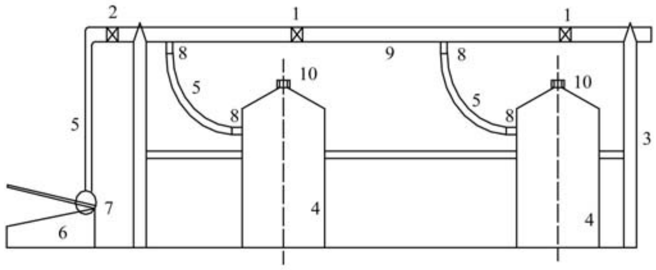
Bulk density of acha grains at various moisture contents was determined by filling a plastic container of predetermined volume (Jaliliantabar et al., 2011). The plastic container was measured 21.4 cm high and 10.7 cm inside diameter. At fixed moisture content, grains in the sample holder were consolidated to varying degrees in order to create a grain mass with different bulk density values. Consolidation was achieved by shaking and tapping around the container various numbers of times, followed by dropping the container thrice from a 10 cm height at each one-third filling. The bulk density (ρ_b) of grains was obtained by calculating the ratio of the mass (M) of grains in the plastic container to the container's volume (V_a) (Equation (2)).

$$\rho_b = M / V_a \quad (2)$$

2.4 Porosity Measurement

The porosity of acha was determined at four levels of moisture content and various bulk densities using a porosity measuring apparatus (Figure 2). The apparatus was developed in the Department of Agricultural and Environmental Engineering of the University of Agriculture, Makurdi. The design of the apparatus was based on Boyle's gas law which states that if a gas of known volume and pressure is allowed to expand, the resultant pressure can be used to calculate the new volume, provided the temperature of the system is not altered (Mohsenin, 1986).

The apparatus for this test comprised two steel cylinders of equal volume of 2,740 cm^3 each weighing 1,215.60 g. The cylinders were made of steel sheets 1.5mm thick. A polyvinyl chloride (PVC) pipe 40 cm long and 2 cm internal diameter was equipped with a non-return and three return valves. The PVC pipe was also fitted with a pressure gauge (0 to 100 psi) for air pressure measurement from which air volumes were calculated. The two cylinders and the PVC pipe were connected by means of two flexible hoses of 0.9 mm internal diameter, through which air from an air compressor was introduced into the cylinders. A wooden frame of 0.35 m long and 0.4 m high provided support for the apparatus.



COMPONENTS DESCRIPTION AND SPECIFICATIONS			
S/NO	ITEMS	QUANTITY	SPECIFICATIONS
1	RETURN VALVES	2	12 GUAGE
2	NON-RETURN VALVE	1	16 GUAGE
3	WOODEN FRAME	1	60 cm × 30 cm
4	STEEL TANKS	2	2740 cm^3
5	PLASTIC HOSE	1 YARD	ϕ0.9 cm ID
6	PEDAL-OPERATED AIRCOMPRESSOR	1	-
7	PRESSURE GUAGE	1	7kg cm^{-1} (100 psi)
8	SHORT PIPE	5	0.9cm ID
9	PVC PIPE	1	ϕ8cm × 60cm
10	BOLT	2	M12 × 30

Figure 2 Porosity measuring apparatus

The apparatus for this test comprised two steel cylinders of equal volume of 2,740 cm^3 each weighing 1,215.60 g. The cylinders were made of steel sheets 1.5mm thick. A polyvinyl chloride (PVC) pipe 40 cm long and 2 cm internal diameter was equipped with a non-return and three return valves. The PVC pipe was also fitted with a pressure gauge (0 to 100 psi) for air pressure measurement from which air volumes were calculated. The two cylinders and the PVC pipe were connected by means of two flexible hoses of 0.9 mm internal diameter, through which air from an air compressor was introduced into the cylinders. A wooden frame of 0.35 m long and 0.4 m high provided support for the apparatus.

3 Results and discussion

3.1 Average particle size and particle size distribution

The results of the sieve analysis for particle size distribution of acha grains are presented in Table 1. From the Table 1, only a little fraction (less than 1%) of the grains passed through the 0.425 mm sieve. Most of the grains (more than 96%) were retained by the 600 µm sieve and sieves with larger openings. Clearly then, the diameter of acha grain is more than 600 µm. The sieves were ranked from seven to one: the largest sieve was ranked as number seven as suggested by Henderson and Perry (1976), while the sieve with the smallest aperture was ranked as number one. Using the rankings to multiply the percentage retained, the fineness modulus (FM) of the grain was calculated at each moisture content level. The fineness modulus was used in determining the average particle size by applying Equation (3) (Henderson and Perry, 1976). The calculated values of particle size are presented in Table 2.

$$D = 0.0041\times2^{FM} \quad (3)$$

where, D is the average particle size in inch and FM is the fineness modulus. In Table 2 the values of D are multiplied by 25.4 to convert its unit to millimetre.

Table 1 Particle size distribution of acha at different moisture contents

Sieve number	Diameter of sieve opening /μm	Moisture content (wet basis)							
		11.46%		13.46%		15.46%		17.46%	
		Weight retained	Percentage retained	Weight retained	Percentage retained	Weight retained	Percentage retained	Weight retained	Percentage retained
1	2360	-	-	-	-	-	-	-	-
2	1180	0.05	0.04	0.09	0.08	0.07	0.06	0.09	0.08
3	850	21.68	18.48	46.75	39.75	46.75	39.94	55.65	47.41
4	600	94.73	80.74	70.44	59.89	69.65	59.50	61.12	52.07
5	425	0.82	0.70	0.30	0.25	0.41	0.35	0.48	0.41
6	300	0.04	0.03	0.02	0.02	0.12	0.10	0.01	0.01
7	150	0.01	0.01	0.01	0.01	0.06	0.06	0.02	0.02
Pan	-		-	-	-	-	-		-
Total		117.32	100.00	117.62	100.00	117.06	100.00	117.38	100.00

Table 2 Average particle size of acha

Moisture content/% wet basis	Average particle size/mm
11.46	1.745
13.46	2.205
15.46	2.159
17.46	2.366

Values of the particle size in Table 2 show that acha grain increasingly swells as it becomes more moist. This would imply that drying of acha is expected to be accompanied with particulate shrinkage. Shrinkage during drying has been reported by many researchers (such as Akeredolu, 1987) who gave linear relationships between size and moisture content. Variation of particle size of acha with moisture content is shown in Figure 3. A linear regression analysis was performed on the data for the particle size of acha. The regression gave the following linear function (Equation (4)).

$$D = 0.0909M + 0.8051 \quad (R^2 = 0.7865) \quad (4)$$

where, D is particle size and M is moisture content (% wet basis).

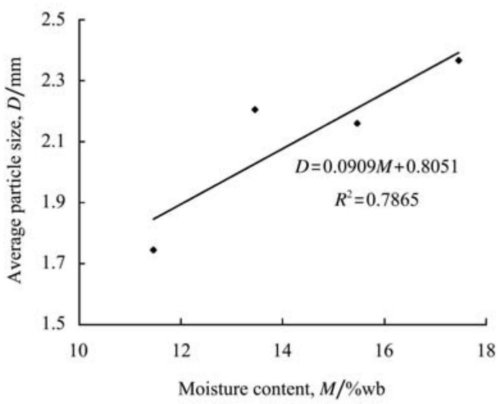


Figure 3 Plot of average particle size (D) against moisture content (M) for acha grains

3.2 Bulk Density (ρ_b)

The effect of moisture content on the bulk density of acha is presented in Figure 4. From the Figure, the bulk density of acha increased with moisture content. The additional water absorbed increased the moisture content of the grains which resulted to increase in the particle size. A regression analysis on the data for bulk density and moisture content gave a linear relationship (Equation 5).

$$\rho_b = 12M + 561.48 \quad (R^2 = 0.9931) \quad (5)$$

where, ρ_b is bulk density (kg m^{-3}) and M is moisture content (% wet basis).

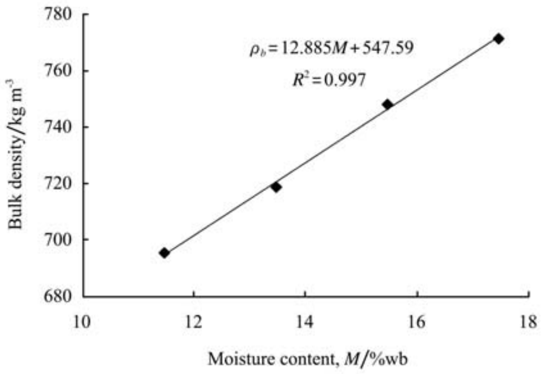


Figure 4 Plot of bulk density (ρ_b) against moisture content (M)

3.3 Porosity, ε

The summary of the porosity values for acha at various moisture contents and bulk densities are shown in Table 3. The table shows that at constant moisture content, the porosity of acha decreases with increase in bulk density. This was due to increasing compaction and reduction in void spaces within the grain mass as bulk density increased. The table also shows that porosity decreases as the moisture content increases, or put the other way round, the porosity of acha increased as it became drier. Analysis of variance (ANOVA) was performed to determine whether moisture content or bulk density had any significant effect on porosity. The ANOVA table (Table 4) shows that there was a high significant difference ($p < 0.01$) in the values of porosity at four levels of moisture content, five density levels and their interactions. This means that the increase in moisture content and bulk density individually and jointly affected the porosities of acha.

Table 3 Values of porosity for acha at various moisture contents and bulk densities

Moisture content /% wet basis	Bulk density /kg m^{-3}	Porosity /decimal fraction
17.52	627	0.629
17.52	657	0.510
17.52	680	0.457
17.52	694	0.394
17.52	705	0.362
20.52	631	0.579
20.52	665	0.483
20.52	678	0.421
20.52	699	0.371
20.52	710	0.330
23.52	628	0.506
23.52	655	0.463
23.52	678	0.397
23.52	695	0.360
23.52	712	0.327
26.52	641	0.429
26.52	675	0.389
26.52	700	0.319
26.52	717	0.290
26.52	728	0.280

Table 4 Analysis of variance for porosity

Source of variation	Degree of freedom	Sum of squares	Means squares	$F_{calculated}$	$F_{tabulated}$
Replicate	4	0.0000200	0.000005	1.25ns	3.65
Moisture content	3	0.224799	0.074933	18733.25**	4.13
Bulk density	4	0.577638	0.14441	36102.5**	3.65
Interaction	12	0.028542	0.002379	594.75**	2.5
Error	76	0.000275	0.000004		
Total	99	0.8313			

Note: **: Highly significant ($p < 0.01$); ns: not significant ($p < 0.01$)

The porosity data were plotted to reveal the trend in the relationship among porosity and bulk density and moisture content. These plots (Figure 5) show clearly that porosity decreases with increases in bulk density. This may be expected because the larger the size of an object, the more loosely packed it becomes.

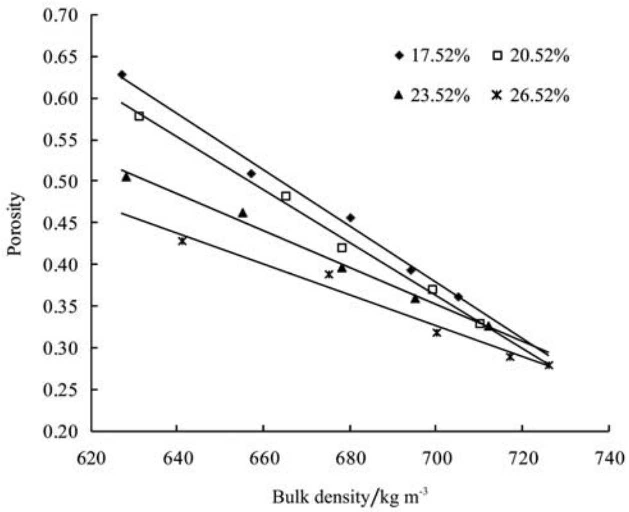


Figure 5 Porosity of acha at various moisture contents and bulk densities

A multiple linear regression was performed on porosity as a function of moisture content and bulk density, using SPSS for Windows. The results showed that porosity is linearly related to both moisture content and bulk density (Equation (6)). From the coefficients of the equation, moisture content has a more dominant influence on porosity than does bulk density.

$$\varepsilon = 4.978 - 0.006431\rho_b - 0.125M + 0.001706\rho_b M \quad (R^2 = 0.983) \qquad (6)$$

where, ρ_b and M are as defined earlier.

4 Conclusion

Particle size, particle size distribution, bulk density, and porosity of acha were determined in the laboratory at various levels of moisture content and bulk density. Particle size was determined by the method of sieve analysis. The fineness modulus obtained from the analysis was used in calculating the average particle size of acha grains. Bulk density was determined by the mass of a known volume of samples, while a porosity measuring apparatus was used for measuring the porosity of acha grains at four levels of moisture content and five levels of bulk density. The results of the tests showed that particle size and bulk density of acha grains were affected by moisture content. The grain increased in size from 1.725 mm to 2.366 mm in the moisture content range of 11.46 to 17.46% wet basis and it was positively linearly correlated with moisture content (r = 0.887). Similarly bulk density increased with moisture content and showed a positive linear dependency on moisture content (r = 0.997). Grain porosity was also affected by both moisture content and bulk density. However, a regression analysis however showed a negative multiple linear correlation of porosity with moisture content, bulk density and their interaction (r = -0.991). These results show that moisture content and bulk density of acha are factors to be considered in the design of facilities for the handling, processing and storage of the crop.

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