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COMPRESSION CHARACTERISTICS OF BAOBAB, OKRA, GINGER, AND MURUCHI POWDERS

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ABSTRACT

Powdery products of food origin have the potential to be used as ingredients and or raw materials in food industries. But powdery foods are usually compressed intentionally during densification process or unintentionally during handling and processing. Thus, this study sought to determine the compression behaviour of baobab leaf, okra fruit, ginger root, and muruchi powders with tapping and under normal low pressure < 2500 N/m^2. Compression models were also used to simulate experimental data in order to compare their performances and estimate compression parameters. All samples were subjected to tapping and normal pressure tests. Muruchi powder was compressed after 1250 taps followed by baobab and ginger powders at 1000 taps and then okra powder at 750 taps. Ginger powder had the highest volume reduction ratio (0.265) by tapping followed by muruchi powder (0.236), baobab powder (0.230) and okra powder (0.149). Ginger powder had the highest compressibility (31.6%) under normal pressure followed by baobab (16%), muruchi (15.5%), and okra (12.8%) powders. The compression models used showed good simulation of the experimental data, where Walker's model had the highest coefficient of determination (0.993-0.9998) followed by Jones' (0.9943 to 0.9997) and Barbosa-Canovas'(0.9953 to 0.9989) models. These results are very useful for solving obstacles in handling, processing and packaging of bulk powdery food materials.

KEYWORDS: *compression behaviour, baobab leaf powder, okra fruit powder, ginger powder, muruchi powder, compression models*

1. INTRODUCTION

Compression of powder refers to the increase of powder's density due to reduction of its volume by mechanical means such as vibration, impact and static load. In food powder industries food powders are usually compressed during industrial operations. Some of these operations are either intentional as in tableting and agglomerating or unintentional during handling, transportation and storage (Barbosa-Canovas *et al.*, 2005). Therefore, compression behaviour of food powders is an important phenomenon in food powder industries. Compressibility is a parameter that is used to describe the compression behaviour by quantifying the degree of compression of a powder under a specified mechanical stress. This parameter is an important input during process design in a food powder industry and the design of compaction/agglomeration equipment.

Several mathematical models have been developed and used by authors to estimate the compressibility of powders using experimental results. Sone (1969) developed a model that expressed the relationship between volume reduction ratio and number of taps. This model contains a parameter that estimates the compressibility of powder during tapping. The compressibility of chopped switchgrass, wheat straw and corn stover were investigated using Sone's model by Chevanan *et al*. (2010) and reported significant effect of biomass type on compressibility, and increase in compressibility with increase of particle length. The compressibility under the influence of static load has been estimated by researchers using several mathematical models. Emami and Tabil (2008), Skonecki *et al*. (2014), and Molenda *et al*. (2002) investigated the compression characteristics of chickpea flour and components, wheat meal and corn and soybean meal respectively. The compression characteristics of several food powdered materials have been investigated experimentally and using several compression models. However, no work has been reported on the compression characteristic of powders of ginger, baobab leaf, okra fruit and muruchi by tapping and under normal low pressure of less 5000 N/m^2. These products have become or are now becoming important industrial raw materials and ingredients in Nigeria. Thus, the objectives of this research work were to: investigate the compression behaviour with tapping and under normal light load for baobab (*Adansonia digitata* L.) leaf, okra fruit (*Abelmoschus esculentus* L.), ginger *(Zingiber officinale*), muruchi (young shoot of *Borassus aethiopum*) powders.

2. MATERIALS AND METHODS

2.1 Sample Preparation

About 10 kg each of dried ginger, dried baobab leaf, and dried okra fruit were procured from Maiduguri Monday market and 30 kg of fresh muruchi was procured from Hong Local Government Area of Adamawa State, Nigeria. After sorting out foreign and unwanted materials, samples were placed in thin layer at ambient condition for a week before grinding. For fresh muruchi after sorting out damaged ones, the remaining samples were de-fibred using knife, chopped into slices and then dried under ambient conditions for two weeks. Locally fabricated hammer mill with 2 mm screen size was used to grind the dried samples. The initial (market) moisture content of each of the materials procured was not determined however, their moisture contents after drying and grinding were determined. Three samples of 10 g each from the ground ginger, dry baobab leaf, dry okra fruits were collected and their moisture contents were determined using oven dried method (Barbosa-Canovas *et al*. 2005). The average moisture content of baobab leaves, okra fruits, ginger, and muruchi powders were calculated to be 10.7%, 11.4%, 10.3% and 9.98% (wb).

2.2 Experimental Tests and Design

Loose bulk density was measured using the USP (2012) standard method. This involved passing 100 g through a sieve of 2 mm into a dry graduated 250 ± 2 ml cylinder placed 2 cm below the sieve and carefully levelling the powder without tapping or compressing (Plate 1). The unsettled apparent volume, V_o was read to the nearest graduated unit. The tapping test was carried out by securing the filled cylinder in the holder of a tapping apparatus capable of dropping from a height of 10 mm. The tapped volumes, V_n, after 10, 250, 500, 750, 1000 and 1250 taps on the same sample were recorded.

Plate 1: Tapping apparatus

The compression test at normal pressure between 1000 and 5000 N/m^2 for each sample of the powders was performed using a compression cell fabricated at the Mechanical Engineering Workshop, University of Maiduguri. The compression cell consisted of a cylindrical die with 47 mm internal diameter and 500 mm height and a plunger with 45 mm diameter flat-end plate. A sample of 100 g was filled in the die and was allowed to be compressed with the plunger to predefined loads using a Texture press. The force-deformation data were recorded after a sample was subjected to uniaxial compression loads of 1, 2, 3, 4, 5 and 6 N.

Completely randomized design was used in all tests as the experimental design. Samples of each powder were randomly assigned to the sequence of test runs during each experiment. Each test on ground ginger, dry baobab leaf, dry okra fruits was replicated three times.

2.3 Data Analysis and Simulation

The compression behaviour of each powder with tapping was simulated using model developed by Sone (1969) (equation 1):

$$\frac{n}{\gamma_n} = \frac{1}{a \times b} + \frac{n}{a} \quad (1)$$

where, n is the number of taps, γ_n is volume reduction ratio, a and b are constants representing infinite compressibility by tapping and degree of difficulty by tapping parameters respectively. The compression characteristics with normal loads were investigated using models developed by Walker (1923), Jones (1960) and Barbosa-Canovas and co (1987) expressed as equations 2, 3, and 4 respectively:

$$\frac{V}{V_o} = m_1 \times \ln P + c_1 \quad (2)$$

$$\ln \rho_b = m_2 \times \ln P + c_2 \quad (3)$$

$$\frac{\rho(\sigma) - \rho_o}{\rho_o} = m_3 \times \log\sigma + c_3 \quad (4)$$

where *P* is applied pressure (kN/m^2), V_o and V are zero and compressed volumes in cm^3, ρ_b is bulk density in kg/m^3, ρ_σ bulk density at applied pressure in kg/m^3, ρ_o initial bulk density in kg/m^3, σ is normal stress (kN/m^2), m_1, m_2, and m_3 constant parameters related to compressibility, c_1, c_2, and c_3 are constants.

Simple descriptive statistical analysis was used to report averages and standard deviations of experimental data. Data obtained were subjected to ANOVA to determine if there were significant differences among the different powder samples. Microsoft Excel software was used to plot graphs and carryout the statistical analysis.

3. RESULTS AND DISCUSSION

3.1 Compression Characteristics during Tapping

Figure 1 presents the relationship between volume reduction ratio and the number of taps for baobab, okra, ginger and muruchi powders. Okra, baobab, ginger, and muruchi powders reached maximum volume reduction ratio at 750, 1000, 1000, and 1250 taps respectively. The highest volume reduction ratio was observed for ginger followed by muruchi, baobab and okra powder. Maximum volume reduction ratios of 0.23, 0.149, 0.265 and 0.236 were observed for baobab, okra, ginger and muruchi powders respectively. Chevanan et al. (2010) reported values of volume reduction ratio for finely chopped switchgrass, wheat straw, and corn that are similar to okra.

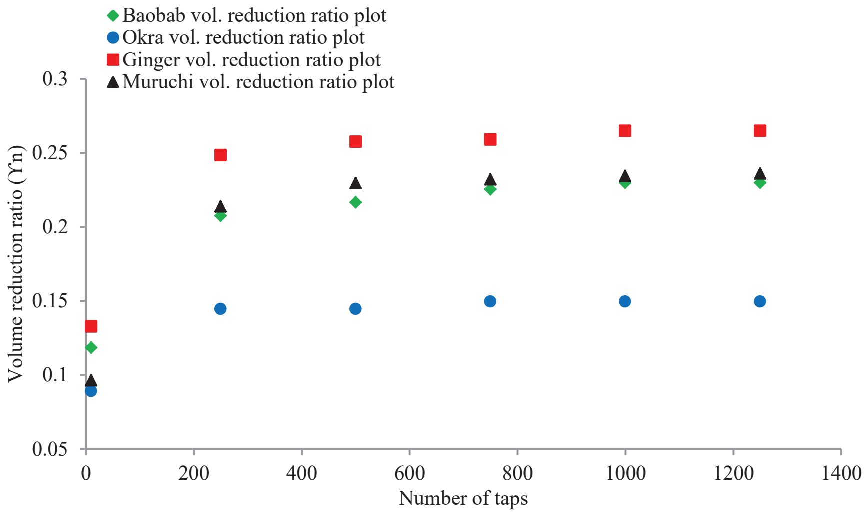

Figure 1: the plots of volume reduction ratio against number of taps for baobab, okra, ginger and muruchi powders

The experimental data and Sone's simulation plots of the linear relationship between n and n/γ_n for baobab, okra, ginger and muruchi powders are presented in Figure 2. An indication of very good Sone's simulation was observed due to the very high coefficient of determination values, R^2 that ranged between 0.9996 and 0.9999 for the powders. Infinite compressibility, a, was highest for ginger followed by muruchi, baobab, and okra powders (Table 1). The parameter for degree of difficulty of tapping, b, was the highest for baobab followed by muruchi, ginger and okra. Values of b for all the powders indicate that okra powder compressed easily by tapping followed by ginger, muruchi and baobab powders. It is worth noting here that experimental results of tapping indicated that baobab powder showed moderate difficulty of compression among the powders while Sone's model predicted highest degree of difficulty.

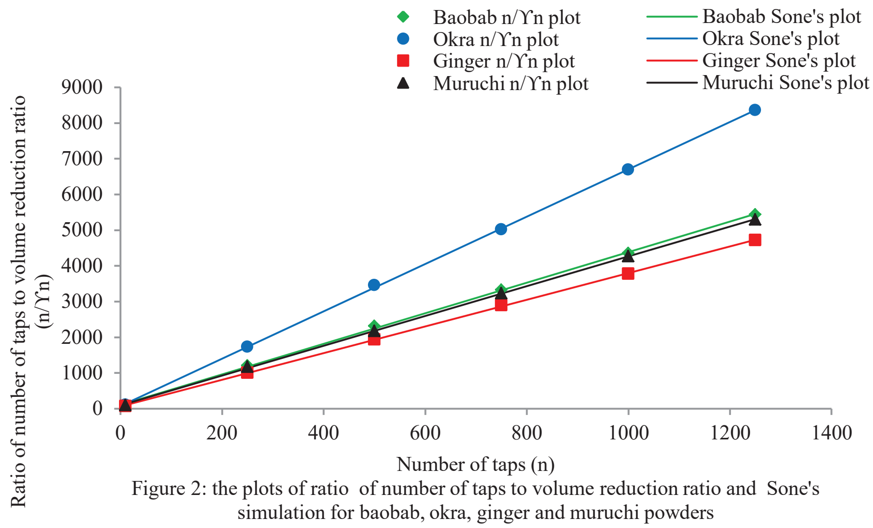

Figure 2: the plots of ratio of number of taps to volume reduction ratio and Sone's simulation for baobab, okra, ginger and muruchi powders

Table 1. Parameters of Sone's, Walker's, Jones' and Barbosa-Canovas *et al*. models for compression of baobab, okra, ginger and muruchi powders

	Models							
	Sone parameters		Walker parameters		Jones parameters		Barbosa and co parameters	
Powder	a	b	c_1	m_1	c_2	m_2	c_3	m_3
Baobab	0.2336	24.5	1.35	-0.0612	5.60	0.0682	-0.4441	0.1754
Okra	0.1508	11.2	1.34	-0.0567	5.85	0.0615	-0.2480	0.1936
Ginger	0.2678	16.8	1.12	-0.0529	5.63	0.0724	-0.3565	0.2286
Muruch	0.2396	22.2	1.27	-0.0513	5.91	0.0576	-0.1877	0.1872

3.2 Compression Characteristics during Normal Pressing

The relationship between compressibility and applied normal pressure is presented in Figure 3. The highest compressibility was observed for ginger while okra had the lowest compressibility. It can be observed that the maximum compressibility attained at 6 N for baobab, okra, ginger, and muruchi powders were 16%, 12.8%, 31.6% and 15.5% respectively. Thus, ginger had the highest compressibility followed by baobab, muruchi, and okra powder.

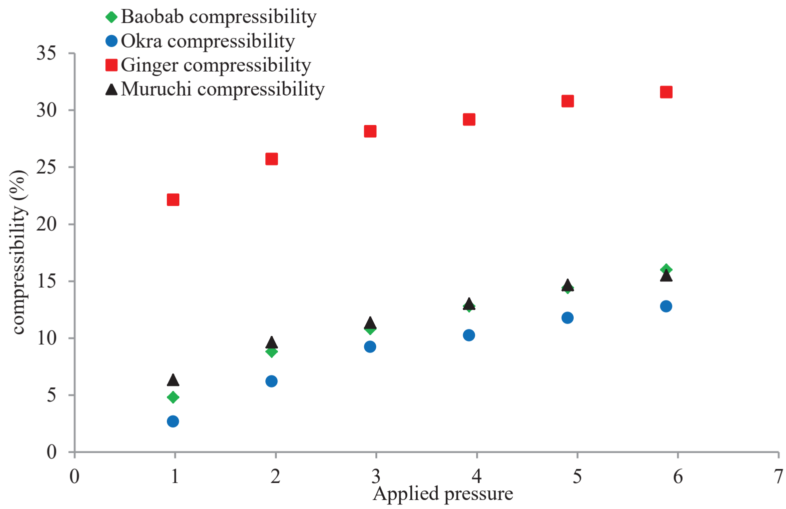

Figure 3: the plots of compressibility against applied pressure for baobab, okra, ginger, and muruchi powders

Walker's model was fitted into the pressure-volume data of baobab, okra, ginger and muruchi powders obtained during compression test (Figure 4). High R^2 values were obtained when Walker's model was fitted to the pressure-volume data. The R^2 for baobab, okra, ginger, and muruchi powders were 0.993, 0.9993, 0.9998, and 0.9997 respectively. The slope parameter, m_1 in Walker's model is proportional to density in the powder (Walker 1923). The densities of the powders increased in the following order muruchi, ginger, okra, and baobab (Table 1).

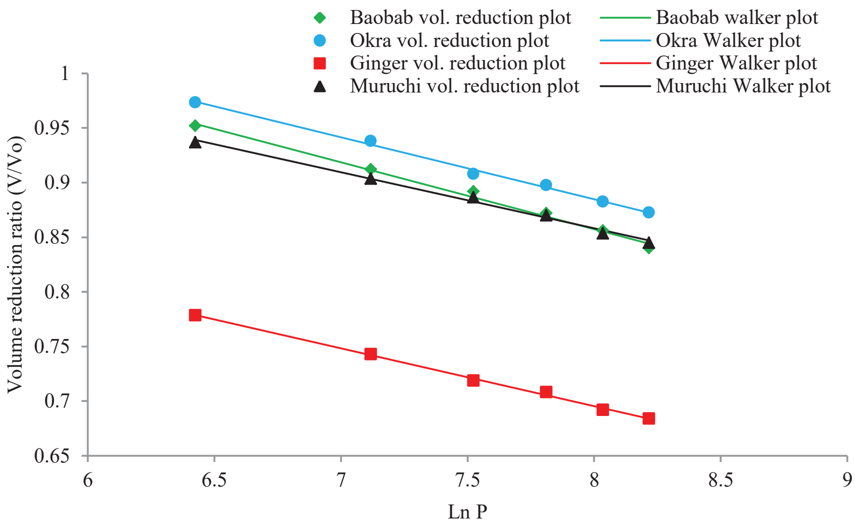

Figure 4: the plots of volume reduction ratio and Walker's simulation for baobab, okra, ginger and muruchi powders

Figures 5 and 6 present the plots of pressure data against the corresponding values of density calculated during compressibility test of baobab, okra, ginger and muruchi powders and the simulated plots of Jones, and Barbosa-Canovas *et al.* models respectively. High R^2 values for Jones' (0.9943 to 0.9997) and Barbosa-Canovas *et al.* (0.9953 to 0.9989) models indicate good fit. The slope parameter of Jones' model, m_2 provide valuable information about the onset of plastic deformation at low pressure therefore indicating that the material is more compressible. Ginger had the highest compressibility, followed by baobab, okra and muruchi respectively (Table 1). Barbosa-Canovas *et al.* model predicted compressibility, m_3 in the following decreasing order ginger, okra, muruchi, and baobab. It can be observed from the simulation results that the compressibility parameters estimated by Jones model had similar trend to the experimental data while both Jones and Barbosa-Canovas *et al.* predicted highest compressibility.

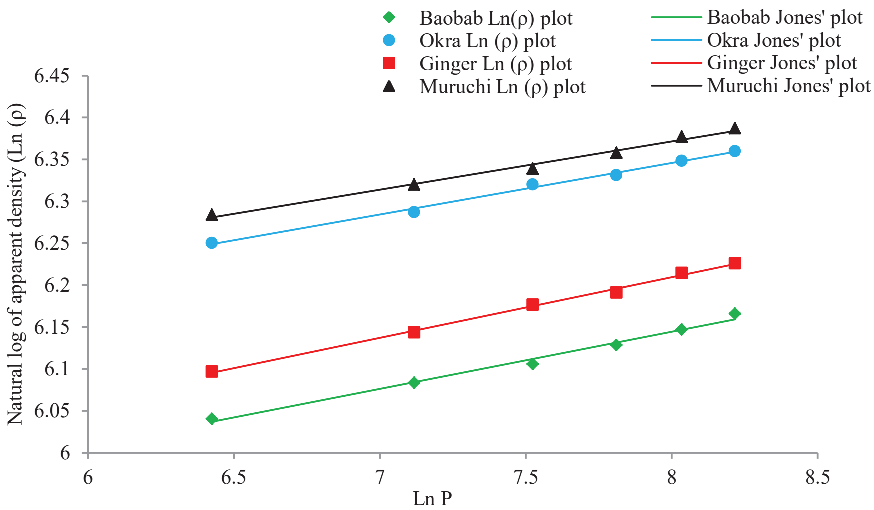

Figure 5: the plots of natural log of apparent density at applied lpressure and Jones' simulation for baobab, okra, ginger and muruchi powders

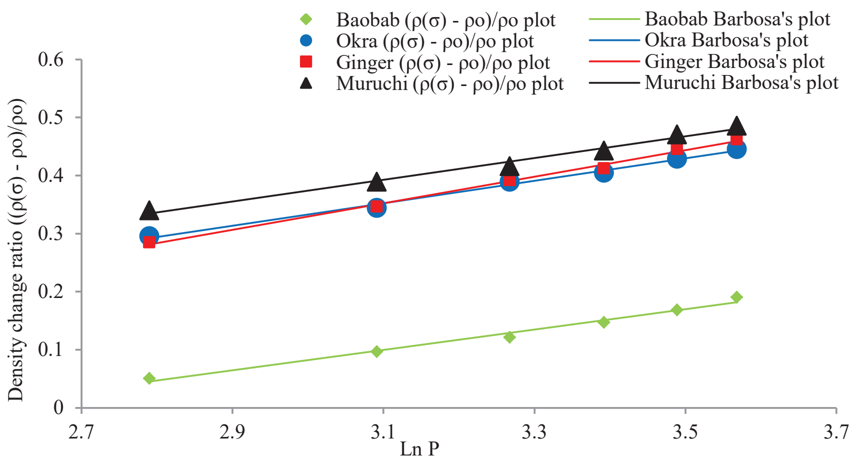

Figure 6: the plots of density change ratio and Barbosa and Co simulation for baobab, okra, ginger and muruchi powders

4. CONCLUSION

Muruchi powder was the most difficult to compress by tapping followed by baobab and ginger, and then okra which is easily compressed. Ginger had the maximum volume reduction ratio by tapping followed by muruchi, baobab, and okra. Ginger had the highest compressibility under normal pressure followed by baobab, muruchi, and okra powder. The compression models used showed good simulation of the experimental data, where Walker's model had the highest coefficient of determination followed by Jones' and Barbosa-Canovas' models.

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