Engineering and proximate properties of miracle berry fruit *(Synsepalum dulcificum* L.*)*

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Abstract: This research was carried out to determine some physical, mechanical, mineral, and proximate properties of miracle berry fruits (*Synsepalum dulcificum* L.) in the moisture range of 6.45%-9.73% (dry basis, db). Physical properties, including bulk density and terminal speed, were determined by standard procedures. Mechanical properties including stiffness and deformation were determined using quasi-static compression analysis. Proximate and mineral compositions of the fruit including crude protein and calcium contents were determined using standard analytical methods. Results showed that the terminal velocity, stiffness, mineral contents increased generally with a decrease in the moisture content ($p < 0.05$). The average values of the terminal velocity, stiffness, crude protein, calcium contents of the fruit at 6.45% (db) were 14.32 mm s^{-1}, 2.37 N mm^{-1}, 11.13% and 92.11 mg 100 g^{-1}, respectively. We recommended the values at 6.45% moisture content for minimal product damage during bulk transportation, and for the design of cutting equipment for the product.

Keywords: bulk density, crude protein, crude fibre, mechanical properties, miracle fruit

Citation: Fadeyibi, A., W. A. Lamidi, and S. M. Ademola. 2021. Engineering and proximate properties of miracle berry fruit (Synsepalum dulcificum L.) essential for its processing equipment design. Agricultural Engineering International: CIGR Journal, ? (23)4: 227-235.

1 Introduction

Miracle tree (*Synsepalum dulcificum L.*) is a tropical plant bearing berry fruit with a height between 6 to 15 feet and has dense foliage (Inglett and May, 1968; Inglett et al., 1965). Its leaf is 5−10 cm long, 2−3.7 cm wide and is glabrous below and usually clustered at the ends of the branches. The flowers are brownish-red and usually produce about 2 cm long pulp which contains fruits with single seed in each (James et al., 1993). The plant grows best in an environment free of frost with low soil pH (4.5−5.8) and in a partial shade with high humidity. It is tolerant to drought, love sunshine and very good in sloppy lands (James et al., 1993). The seeds need 14−21 days to germinate and a spacing of 4 m between plants may be suggested for planting. It starts to fruit at 3−4 years and produces two fruiting's per year, both after the end of the rainy season. The seeds are of the size of coffee beans. It is best grown in West Africa where it originated. The shelf life of the fresh fruit is only between 2−3 days. The pulp must be preserved without eating for commercial use. When freeze-dried, it may have a shelf life of 10−18 months. The fruit tests sweet like lemon when consumed due essentially to the presence of *miraculin* in its flesh

Received date: 2019-09-23 **Accepted date:** 2021-08-23

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(Madison, 2009). In the industry, the substance is often used as substitute for sugar, and can be added to processed food to enhance the protein content. The effects of the *miraculin* in the fleshy parts of the fruits bring about the sweetness when eaten. This can last in the mouth for about an hour until the protein is washed away by the saliva (Madison, 2009). In addition to the value of the fruit as a taste modifier, the skin, pulp, and seeds of miracle berries have been reported to have antioxidant properties (Roecklein and Leung, 1987).

Engineering properties of many commercial fruits and their technical applications for specific equipment design and processing have been reported. For instance, Aydın and Özcan (2007) studied the physical properties of myrtle (*Myrtus communis L.*) fruits growing wild in Turkey and reported a strong dependence of the properties with the moisture content. Jahromi et al. (2008) studied some physical properties of date fruit, and reported that the knowledge of length, width and thickness can be useful in designing screens for sorting the fruits. Omobuwajo et al. (1999) studied selected physical, mechanical, and aerodynamic properties of African bread fruit (*Treculia africana*) and reported that the properties are often required for designing of hopper, dehuller and handling machineries. Shahnawaz and Sheikh (2011) studied the physicochemical characteristics of jamun fruits, and reported the properties are essential for design equipment for their handling and processing. Owolarafe et al. (2004) studied physical and mechanical properties of two varieties of fresh oil palm fruit and reported the average cracking force and pressure requirement for oil processing of the two different varieties of the palm fruits. However, the study on the engineering properties of miracle fruits has not been reported hitherto. Hence, designing machines for processing the fruit for industrial application is often difficult. There is therefore the need to study the physical, mechanical, and mineral compositions of miracle berry fruits to provide data for its processing and mechanization. The objective of this research therefore was to determine some physical, mechanical, mineral, and proximate properties of miracle berry fruit at different levels of moisture contents.

2 Materials and methods

2.1 Materials and sample preparation

The miracle berry fruits were obtained from Masifa farm at Ejigbo in Osun State, Southwest Nigeria (Figure 1). The seed were cleaned manually and transported to the Kwara State University, Malete for experimentation. The cleaning was done to remove leaves, tree branches, stones and dust by scalping and dedusting procedure (Fadeyibi and Osunde, 2012a). Other materials use in the study include oven weighing balance, venier calipers, plywood, galvanize sheet, iron sheet, cotton wool, petri dish, distilled water, THIES anemometer.

Figure 1 Freshly harvested miracle fruits

The initiation moisture content of the berry fruit was determined according to the method described by the AOAC (2006). This was carried out by weighing 200 g of the fresh sample of the miracle berry fruit and placed in an air circulated oven dryer at 105°C±2°C and 60% RH for 24 h. The initial moisture content was therefore computed empirically at the end of drying and found to be 9.73% (db). The dried sample was then placed in a desiccator and the moisture content varied by drying to 8.86 (db) and 6.45% (db) after a further 24 h and 48 h drying time, respectively (Fadeyibi and Osunde, 2012b).

2.2 Determination of some physical properties of miracle berry fruits

The physical properties of 5 g samples of the miracle berry fruit of different moisture contents such as axial dimensions (major, minor, intermediate, and equivalent diameters), bulk density, true density, and terminal velocity were determined using standard procedures. The major, minor, intermediate, and equivalent diameters of the samples were determined as described by Fadeyibi et al. (2012). The bulk and true densities were determined using the consolidated volume pack and toluene displacement methods, respectively (Smith et al., 2016). The terminal velocity of the berry fruits was determined using a wind column experimental set (Moradi et al., 2019; Smith et al., 2016; Özcan and Hacıseferoğulları, 2007). An air stream was directed through a tube with a diameter of 71.36 mm, which had a monitoring window, by using a blower. Air flow was adjusted by changing the blower speed by an electric motor with a frequency inverter. For each test, some fruits were dropped into the tube and monitored from a suspended position in the air stream. The air velocity at that moment was measured by a THIES anemometer with 0.1 m s^{-1} accuracy. The procedures were repeated for the two samples of the miracle berry fruits and the values of the above physical parameters were measured and recorded.

2.3 Determination of some mechanical properties of miracle berry fruits

The mechanical behavior of the miracle berry fruits was determined using a Lloyd material testing machine (model LRX Plus), equipped with 5 kN load cell and a computer, in a quasi-static compression position. Since the width and thickness values were very close to each other, two loading positions, with a vertical and horizontal axis, were used in the compression tests. Each sample was placed between two plates (A and B) and compressed at 10 mm min^{-1} until the rupturing of the fruit was initiated (Figure 2). The rupture point was determined from a force-deformation curve obtained from the test (Khazaei and Rasekh et al., 2002). The mechanical properties of fruits were expressed in terms of stiffness, energy absorption, and deformation. The deformation was obtained as the change in the diameter of the fruit with reference to its original size under the 5 kN load. The stiffness is regarded as the ratio of force to deformation at the rupture point and it was computed using Equation 1. The energy absorbed was determined by calculating the area under the force-determination curves (Equation 2) (Khazaei and Rasekh et al., 2002; Khazaei and Rabani et al., 2002). Each test was repeated 30 times and the average values of the stiffness and energy absorbed during loading and unloading of the miracle berry fruit were evaluated and recorded. Analyzing the behavior of the fruit under quasi-static loading orientation from the perspective of Hertzian stress theory for contact objects showed that the strain experienced in loading was very small due to the inelastic nature of the fruit.

$$Q = \frac{F}{D} \quad (1)$$

$$E_a = ½FD \quad (2)$$

where, Q is the stiffness (N mm^{-1}), E_a is the energy absorption (mJ), F is the force (N), D is the deformation (mm) and V is the loading rate (mm min^{-1}).

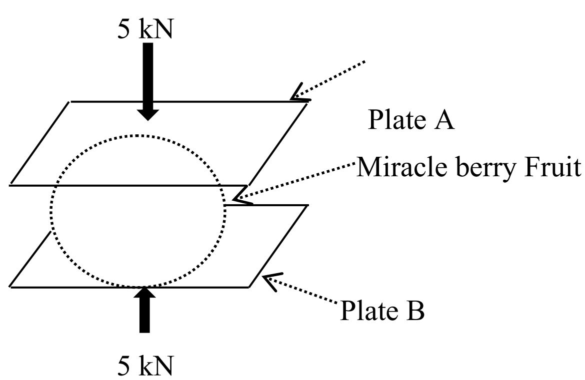

Figure 2 Schematic view of miracle berry fruit sample under compression loading

2.4 Determination of proximate and mineral compositions of the miracle berry fruits

The proximate properties of the miracle berry fruit namely crude protein, ash content, crude fibre, crude fat, and carbohydrate contents were determined for each of the three samples using the standard analytical methods reported in literature. The crude protein content was determined by Kjeldahl Method which requires titration of a mesh solution of the prepared substrate of the fruit against 0.05 N EDTA solutions and computing the nitrogen content empirically (Siegel et al., 1966). The ash content was determined using the furnaces incineration gravimetric method described as described by Demir and Ozcan (2001). The crude fibre content was determined using the weight difference of crucible method as also described by Siegel et al. (1966). The crude fat content was determined using the solvent extraction gravimetric method as described by Ayoola and Adeyeye (2010). The carbohydrate content was determined by preparing dilute solution of the sample as substrate and then measuring its absorbent using a UV spectrophotometer at 630 nm against the blank, which indicates the presence of glucose. Additionally, the mineral compositions namely, sodium, calcium, magnesium, potassium, cadmium, iron, zinc, copper, manganese, and chromium contents of the miracle berry fruits were determined using atomic absorption spectrophotometer as reported by De Souza et al. (2012). The test was repeated for the other two samples of the miracle berry fruits and the proximate and mineral values were measured and recorded.

2.5 Statistical analysis

The results obtained from the physical, mechanical, proximate, and mineral analysis of the samples of the fruit were described using tables, and the values of the standard deviation were measured empirically. The data obtained from the samples of different moisture contents were compared using the t-test at *p*< 0.05 (Fadeyibi, 2021; Fadeyibi and Adebayo, 2021).

3 Results and discussion

3.1 Effect of moisture content on physical properties of miracle berry fruit

The effects of moisture content on axial dimension, terminal velocity, sphericity, and density of the miracle berry fruit are shown in Table 1. The axial diameters and the sphericity of the fruit decreased with a decrease in the moisture content from 9.73%−6.45% (db). This implies that the size of the fruit is larger at higher moisture value, and this progressively decreases as moisture is loss from the product. It is important to note that the dimensions of the miracle berry fruit are not uniform, but scatter around its equivalent diameter. Similar results were reported by Fadeyibi et al. (2012) in their work on thermo-physical properties of rubber seed. The authors reported an increase in the axial dimensions of the rubber seed as moisture is gained by the product and vise vasa. Also, Burubai and Amber (2014) reported an increase in the axial dimension of Ngologolo fruits as moisture is gained by the product, but this progressively reduced with a decrease in the moisture.

Table 1 Some physical properties of miracle berry fruit

			Moisture content (%, db)		
S/n	Parameter	Unit	9.73	8.86	6.45
1	Major diameter	mm	17.00± 0.85	15.15± 0.78	13.24± 0.66
2	Intermediate diameter	mm	12.68± 0.63	10.00± 0.50	7.60± 0.38
3	Minor diameter	mm	11.21± 0.56	8.54± 0.43	6.23± 0.31
4	Equivalent diameter	mm	10.71± 0.54	7.14± 0.36	5.33± 0.27
5	Sphericity	%	74.61± 3.73	66.04± 3.30	57.43± 2.87
6	Terminal velocity	mm s^{-1}	10.45± 0.52	13.22± 0.66	14.32± 0.72
7	Bulk density	kg m^{-3}	630.00± 0.03	610.00± 0.03	530.00± 0.03
8	True density	kg m^{-3}	550.00± 0.03	510.00± 0.03	480.00± 0.02

Therefore, it is necessary to determine the distribution of individual sizes and the mean size based on this distribution. The quality of processing, especially in the chopping and milling operations may be characterized by the equivalent diameter of the fruit, or these data may be used to organize a technological process or in designing certain structural elements, such as the mesh dimensions of sifters for the calibration of screen holes.

The terminal velocity increases with a decrease in the moisture content of the miracle berry fruit, as was shown in Table 1. A similar finding was reported by Kural and Carman (1997). Also, Yalcın and O ̈zarslan (2004) found that the terminal velocity of vetch fruit increased with an increase in the moisture content. The increase in terminal velocity with decrease in moisture content can be attributed to the decrease in mass of the fruit per unit frontal area presented to the air stream. The terminal velocity play an important role in pneumatic or hydraulic transport of goods, in sorting foreign bodies out of the same, and in the aeration of granular piles.

The variation of the bulk density and the true density with the moisture content of the fruit was shown in Table 1. The density generally decreases with a decrease in the moisture content from 9.73%−6.45% (db). According to Goneli (2008), it is likely that the combined effect between the presence of empty space inside the fruit and contraction of its dimensions as moisture is loss from the product is responsible for the observed variation. Owolarafe and Shotonde (2004) reported a slightly higher average value of the true density and bulk density for okra fruits as 743.6 kg m^{-3} and 450.42 kg m^{-3} respectively in their work on the physical properties of fresh okra fruit. The research findings of Douglas et al. (2014) corroborate this in their work on crambe fruits. The volume and density of various agricultural products play an important role in numerous technological processes and in the evaluation of product quality. Examples can be found in the drying and storage of hays, the design of silos and other storage structures, the stability of feed pellets, the sorting of impurities and in establishing the ripeness of fruits. Additionally, the bulk density and true density are of great importance in the marketing of agricultural products; and since the transport thereof is usually accomplished by truck, therefore the miracle berry fruit products will require some enhancements to reduce the cost of transport (Zorzenoni et al., 2019).

3.2 Effect of moisture content on mechanical properties of miracle berry fruit

Effects of moisture content on deformation, stiffness and energy absorption of the miracle berry fruit are shown in Table 2. For viscoelastic materials such as the miracle berry fruit under study, there is a definite relation between deformation and moisture content. The deformation decreases with a decrease in the moisture content from 9.73%−6.45% (db). The deformation was higher at 9.73% moisture because the presence of moisture makes the fruit accumulate pressure to move the molecule under loads. Owolarafe et al. (2007) reported similar behavior for two varieties of fresh oil palm fruits. The stiffness increases with a decrease in the moisture content, whereas the energy absorbed decreases with the moisture content. The research finding of Omobuwajo et al. (1999) on African bread fruit provides credence to the findings of the current investigation. The research efforts of Aydın and Özcan (2007) and Shahnawaz and Sheikh (2011) on myrtle and jamun fruits respectively, also reported similar findings. During almost all technological processes agricultural products are exposed to mechanical effects, normally accompanied by deformation, which must be either sufficiently great or slight to avoid damage to the fruits. Consequently, the mechanical strength of fruits, here plays an important role. Most agricultural products are viscoelastic, they behave differently under static tensile, or compressive forces, and under dynamic or repeated dynamic loads. With the knowledge of the mechanical behavior fruit, it is possible to decide whether, for example, shearing or impact is best for its size reduction. The power requirements for compressing a material also vary depending on whether static or dynamic forces are applied. Fruits are sensitive to repeated loads, such as the vibration experienced during transport, as their texture becomes softer under the effect of repeated loads, and their load-carrying capacity decreases.

Table 2 Some mechanical properties of the miracle berry fruit

			Moisture content (%, db)		
S/n	Parameter	Unit	9.73	8.86	6.45
1	Deformation	mm	15.63± 0.78	13.08± 0.65	10.56± 0.53
2	Stiffness	N mm^{-1}	1.59± 0.08	1.91± 0.09	2.37± 0.12
3	Energy absorbed	mJ	95.38+ 4.77	63.50± 3.18	62.93± 3.15

3.3 Effect of moisture content on proximate composition of miracle berry fruit

Effect of moisture content on the proximate properties of the miracle berry fruits is shown in Table 3. The proximate compositions represent the macronutrient content of product as potential food and feed supplements. The samples can be considered nutritious only if they contain good amounts of food nutrients. The proximate composition of the miracle berry fruit was found to decrease generally with a decrease in the moisture content from 9.73%−6.45% (db). The higher proximate values obtained at high moisture content may be due to the low amount of the dry matter present in the fruit. In fact, this may be more pronounced especially if the fruit is well matured and ripened. Mahmood et al. (2013) in a related investigation reported a clearly distinct variation of the proximate composition of cherry fruit with respect to its maturity stage in their work on the effect of maturity on proximate composition, phenolics and antioxidant attributes of cherry fruit. This thus suggests that the fruit is a potential source of protein, hence could be used as protein supplement and food additive. Proteins perform critical roles in the biological systems; hence they are essential components of human and animal diet. They also perform structural, transport and body-building functions among others (Savello et al., 1982). The higher value of the crude fat content obtained at higher moisture content may not be unconnected with the closely packed microstructure of flesh in the fruit; and this may suggest that the fruit can contain oil. The ash and crude fibre contents were slightly higher probably because of the presence high mineral and cellulose and lignin present in the fruit at higher moisture content. This implies that the fruit contain appreciable amount of total carbohydrates and a large percentage of the carbohydrate content is digestible (Savello et al., 1982). The high carbohydrate content suggests that it could be a potential source of energy-giving food. The value of the crude fibre can therefore be used for calculating the total carbohydrate present in the miracle berry fruit.

Table 3 Proximate composition of miracle berry fruit

			Moisture content (%, db)		
S/n	Parameter	Unit	9.73	8.86	6.45
1	Carbohydrate	%	29.03± 1.45	28.64± 1.43	28.00± 1.41
2	Crude fibre	%	28.76+ 1.44	27.51+ 1.38	26.93± 1.35
3	Crude fat	%	19.24+ 0.96	18.05+ 0.91	14.18± 0.71
4	Crude protein	%	9.66+ 0.48	9.21± 0.46	8.13± 0.56
5	Ash	%	1.33+ 0.07	1.25± 0.06	1.14± 0.06

3.4 Effect of moisture content on mineral composition of miracle berry fruit

Effect of moisture content on the mineral compositions of the miracle berry fruit is shown in Table 4. The mineral composition generally increases with a decrease in the moisture content of the miracle berry fruit from 9.73%−6.45% (db). The increase in the dry matter with a decrease in the moisture can be responsible for the observed increase in the amount of the mineral elements present in the fruit. Potassium is important for the maintenance of body fluid and electrolyte balance and is involved in the proper functioning of the heart muscles. It also plays a major role in carbohydrate metabolism and protein synthesis. Rathore (1976) reported similar findings in his work on the effect of season on the growth and chemical composition of guava fruit. Torreggiani and Bertolo (2001) also corroborated our findings in their work on the effects of chemical, physical, and structural properties of fruit during osmotic pre-treatments processing. The high potassium content of these seed suggests that it could be a potential source of potassium supplements for human diets and animal feeds.

Table 4 Mineral compositions of miracle berry fruit

S/n	Mineral	Unit	Moisture content (%, db)		
			9.73	8.86	6.45
1	Potassium	mg 100 g^{-1}	569.50± 28.48	590.50± 29.53	609.50± 30.48
2	Calcium	mg 100 g^{-1}	72.17± 1.25	82.23± 4.11	92.11± 4.61
3	Sodium	mg 100 g^{-1}	25.00± 1.25	35.00± 1.75	40.00± 2.00
4	Magnesium	mg 100 g^{-1}	17.63± 0.88	18.21± 0.91	19.13± 0.96
5	Iron	mg 100 g^{-1}	3.05± 0.15	4.05± 0.20	4.95± 0.25
6	Zinc	mg 100 g^{-1}	2.71± 0.13	3.11± 0.16	3.94± 0.20
7	Copper	mg 100 g^{-1}	2.42± 0.12	3.42± 0.17	3.82± 0.19
8	Manganese	mg 100 g^{-1}	2.38± 0.12	3.48± 0.18	4.18± 0.21
9	Nickel	mg 100 g^{-1}	0.24± 0.01	1.04± 0.05	1.78± 0.09
10	Cadmium	mg 100 g^{-1}	0.01± 0.001	0.03± 0.002	0.11± 0.006
11	Chromium	mg 100 g^{-1}	0.00± 0.00	0.00± 0.00	0.00± 0.00

The high amounts of calcium, sodium and magnesium present in the miracle berry fruit may be essential in diet. Calcium is essential for the formation and maintenance of strong bones and teeth. It is also involved in regulation of nerve function, muscle contraction and blood clotting. Sodium is also an important component of human and animal diet as it helps in maintaining homeostasis within the body system and it also performs structural functions (in skeleton). Magnesium is found in every cell, and it plays a role in carbohydrate and protein metabolism, smooth muscle function and cell reproduction (Özcan and Hacıseferoğulları, 2007).

4 Conclusions

This research determines the physical, mechanical, mineral, and proximate properties of miracle berry fruits (*Synsepalum dulcificum L.*) in the direction of moisture decrease from 9.73%− 6.45% (db). There was a generally decrease in the axial dimension, density, and proximate compositions with a reduction in the moisture content ($p< 0.05$). However, the terminal velocity, stiffness and mineral composition increased with a decrease in the moisture content ($p < 0.05$). The results obtained for the major (13.24 mm), minor (6.23 mm) and intermediate (7.60 mm) diameters at the 6.45% db are recommended for use in the design of dryer for the fruit. The terminal velocity (14.32 mm s^{-1}) is required in the design of hydraulic transport and sorting equipment for the fruit. The bulk (530 kg m^{-3}) and true (480 kg m^{-3}) densities are recommended for quality evaluation of the fruit, particularly in the design of the drying and storage equipment, monitoring the level of ripeness and in evaluating the packing coefficient of the product. The fruit has antioxidant property, and its mineral and proximate properties are recommended as sweeteners in the food processing and preservation. The results of the deformation (10.56 mm), stiffness (2.37 N mm^{-1}) and energy absorbed (62.93 mJ) at 6.45% db are required in the design of equipment for transportation and packaging of the fruit. It is recommended to transport the fruit at a lower moisture content, when its texture is hard enough to withstand the damping effect of bad roads, to minimize damage on the product. The results of the deformation and stiffness are also recommended for evaluating the impact and shear resistance of the cutting component of a size reduction equipment for the product.

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