

Determination of the Engineering Properties of Aerial Yam and Water Yam

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ABSTRACT

This research presents the determination of some engineering properties (shear stress, hardness, modulus of elasticity, compressive strength, deformation at the break, bio-yield, rupture energy, gumminess, specific heat capacity, thermal diffusivity, and thermal conductivity) of water yam and aerial yam. The water yam and aerial yam were dried with the conventional hot air dryer. Using approved standard methods and instruments, experimental determination of the mechanical and thermal properties of the dried water yam (DWY), dried aerial yam (DAY), raw water yam (RWY) and raw aerial yam (RAY) were conducted and results obtained. The result showed the mechanical properties of DWY, DAY, RWY and RAY fell within the range of 1.803-6.63 N/mm² for shear strength, 15.582-31.977 N for hardness, 87.5-400N for bio-yield force, 1.256-4.699 J for rupture energy, 2.788-36.829 N/mm² for modulus of elasticity, 1.815-7.5 N for deformation at break, 0.501-2.688 N/mm² for compressive strength and 4.975-19N for gumminess. The thermal properties showed the following ranges: specific heat capacity value of 1.55-3.21 KJ/kgK, the thermal conductivity of 0.256-0.473 W/mK and the thermal diffusivity of 1.280x10⁻⁴ - 1.50x10⁻⁴ m²/s. The result provides a theoretical basis and data for the design of aerial yam and water yam processing equipment while minimizing its mechanical damage.

Key words: Aerial yam, Water yam, Bio-yield, Drying, Engineering properties.

1.0.INTRODUCTION

Aerial yam (*Dioscorea bulbifera*) which is also known as air potatoes is a member of the yam species often considered as a wild species of yam native to Africa and Asia. It is a member of the *Dioscoreaceae* family which consist several varieties found in Africa and South Asia [1]. Nigeria is a major producer of yam, but Ghana is leading in production of aerial yam. Aerial yam is among one of the most underutilized food crops in Nigeria and other parts of the world where it grows and appears in both the wild and edible forms. It has a long vine and it produces tubers (bulbis) which grow at the base of its leaves. This species of yam is not popular among farmers or consumers and does not enjoy the patronage that some of the other edible yam species enjoy. Despite its underutilization, aerial yam has been shown to possess a myriad of compounds that have also been attributed to several health benefits [2]. It is known to contain some minerals such as potassium, sodium, phosphorus, calcium, magnesium, copper, iron, manganese, zinc and sulphur [3]. It also has diosgenin, a pharmacologically active component of *Dioscorea* found in root and rhizomes which is one of the most important steroidal drugs used worldwide [4]. It can provide a widespread of health benefits including protection against development of cancer, osteoporosis, cardiovascular disease, nephritis, asthma, diabetes, and used in the preparation of contraceptives and in the treatment of various genetic disorders [5]. It is also known to possess cardio-protective activity [6], antimicrobial activity [7], analgesic and anti-inflammatory activities [8].

Water Yam (Dioscorea alata) is the most widespread yam species and more important as food in west Africa and the Caribbean than in Asia and in America where it originated and has been competing with the most important species like *Dioscorea rotundata* [9]. Water yam is popular and prevalent within Abakiliki agro ecological zone of Ebonyi state, Nigeria where it is called "Mbala or Nvula" (Native names in Igbo land) [10]. Water yam has low sugar content necessary for diabetic patients. Also, it contains

nutrient which have benefits to the body and dietary fibre and is important in the diet for the healing and health-promoting properties. It contains a lot of minerals like calcium, potassium, iron, phosphorus and copper with high presence of vitamins C and E which have antioxidant properties and lowers blood pressure levels. According to Wireko-Manu [11]), water yam contains high level of total dietary fibre (TDF) which makes it appropriate for management of pile, constipation and diabetes. It is also rich in Vitamin C, beta carotene, vitamin E, calcium, potassium, magnesium, copper and antioxidants [11]. These nutrients are identified to play vital role in general body upkeep as well as immune functioning, wound healing, suppression of blood sugar, bone growth and anti-ageing. Similarly, Agwu and Avoaja [12] reported that water yam is a good source of vitamin B6 which is needed in the body to breakdown substances called homocystein which can directly damage blood vessel walls, hence reducing the risk of heart disease. Considering the overwhelming nutritional, medicinal and economic benefits of these yams, there is still insufficient data on the engineering properties of this important food crop.

As the importance of agricultural products increases together with the complexity of modern technology for its production, processing and storage needs an enhanced knowledge of their engineering properties so that machines, processes and handling operations can be designed for maximum efficiency and the utmost quality of the final products [13]. Knowledge of the properties that have to do with the behaviour of agricultural products under applied forces such as stress, strain, hardness and compressive strength is important to engineers involve in handling agricultural products process and operation. Identifying the engineering characteristics of these yams is very important to optimize the design parameters of agricultural equipment used in their processing, handling and storage processes. Therefore, it is necessary to determine the engineering properties (thermal and mechanical) of these agricultural products because they play important role in designing and development of specific machines and their operations such as sorting, separating and cleaning, drying, milling etc.

This research seeks to determine the engineering properties of aerial yam and water yam dried with conventional hot air dryer with a view to obtaining information which could help in the design and operation of dryers for commercial preservation and production of these vital agro product.

2.0 MATERIALS AND METHODS

2.1 Collection and preparation of aerial yam and water yam sample

The aerial yam sample was sourced from Afor Opi market in Nsukka local government area of Enugu state, while the water yam was sourced from Eke Awka market, Awka Anambra state. The aerial yam and water yam were identified in crop science department of Nnamdi Azikiwe University, Awka. The yams were washed with clean water and spread in open air to avoid spoilage. The water yam was peeled and cut into desired size with a mold designed for the purpose while the aerial yam was cut without peeling since peeling tend to remove the second layer of the yam which are known to be medicinal.

2.2 Conventional hot-air drying

The method employed in conventional hot air drying was in accordance with that reported by Daniel et al.[14]. The two samples (Water yam and Aerial yam) were dried with conventional hot-air dryer at temperature of 50 °C, air speed of 2.5 m/s and sample thickness of 2.0 mm. This was done by cutting 2.0 mm of the aerial yam samples and weighing out 100g with electronic scale into the dryer tray. The temperature and air speed of the dryer were set at 50°C and 2.5 m/s, respectively. The sample was dried to a constant weight and placed in an air tight container for further use. The whole procedures were repeated for water yam sample.

2.3 Experimental procedure for determination of mechanical properties

2.3.1 Shear strength

The shear strength was determined using the Tensometer which is a universal testing machine (UTM). The shear spindle of the machine was fixed to the shear accessory of the UTM. The test sample was fixed into the shear chamber of the UTM and the revolving graph attached to the graph drum of the UTM. The working fluid (mercury) was zeroed and a continuous but gradual load was applied to the sample until the working fluid returns back to zero. The corresponding load recorded on the graph (which serves as the shear force) was recorded and the shear strength was determined using the area of the shear spindle and the shear force recorded.

2.3.2 Brinell hardness test.

The testing chamber was replaced by the brinell hardness bulb tester (indenter bulb) of 2mm diameter. A constant load for which all the samples must be subjected was chosen, and the depth of indentation produced on the sample as recorded by the machine graph was measured. The brinell hardness number (HBN) formulae (eqn 1) was then used to calculate the hardness strength.

$$HBN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})} \quad (1)$$

Where;

P = constant axial load, d = impression diameter (2mm), D = depth of indentation (5mm), HBN = Brinell hardness strength

2.3.3 Bio-yield and energy.

The sample was placed on the compressive chamber of the testing machine and the graph was fixed on the graph drum. Appropriate load spring was selected and the load applied gradually while the movement of the working fluid was carefully monitored for the point of first failure (the point the working fluid purses back and after about 30 seconds it continues to move upwards again). The force on the graph drum (this serves as the bio yield force) was recorded. The energy is a function of the maximum force the sample can withstand before failure and its average deformation at same point. This was also measured on the fixed machine graph.

2.3.4 Compressive test (Elasticity, deformation at break, compressive strength).

The sample was placed in the compressive chamber (measurement of the chamber 40*40mm was ensured). The sample to be tested was fixed into the appropriate chamber and the working fluid was returned to zero load/deformation. Gradual load was applied to the test sample, while monitoring the movement of the working fluid with the aid of an attached microscope. At a choose interval, the pin button was pushed down to the slider to make the load/deformation graph of the material. When failure occurs, the working fluid will automatically return to zero. The required parameters was then calculated from the plotted graph.

2.3.5 Gummness (separating force):

The sample was prepared into colloidal form and pasted into the separating wooden buds. The joined wooden buds were placed into the tensile chamber for bio materials on the UTM. Loads was applied to the test piece and the loads that separate the pastes on the wooden buds was recorded. The value of the corresponding force on the machine graph was also recorded.

2.4 Experimental procedure for determination of thermal properties

2.4.1 Proximate analysis

The proximate analysis of aerial yam and water yam was done after drying in a conventional hot air dryer at 70°C for 24 h [15]. The Moisture, carbohydrate, protein, fat, fibre and ash content were determined using AOAC [16] methods.

2.4.2 Specific heat capacity

The specific heat capacity of the sample were determined using equation 2 as given by Luther et al, [17].

$$C_p = 1.42X_c + 1.549X_p + 1.675X_f + 0.837X_a + 4.187X_w \quad (2)$$

where

C_p is the Specific heat capacity (KJ/kgK) and X_c, X_p, X_f, X_a and X_w are the respective mass fractions of carbohydrate, protein, fat, ash and water obtained from the proximate analysis.

2.4.3 Thermal conductivity

The thermal conductivity of the samples was determined according to Nwabanne, [15] using equation 3.

$$K = 0.25X_c + 0.155X_p + 0.16X_f + 0.135X_a + 0.58X_w \quad (3)$$

Where;

K is thermal conductivity of sample in(W/m K) and X_c, X_p, X_f, X_a and X_w are the respective mass fractions of carbohydrate, protein, fat, ash and water present in each cultivar.

2.4.4 Thermal diffusivity

The thermal diffusivity of the samples were determined according to Luther et al, [17] as given by equation 4.

$$\alpha = K/\rho C_p \quad \text{-----} \quad (4)$$

where, C_p is the Specific heat capacity, K is the thermal conductivity

3.0 RESULTS AND DISCUSSION

3.1 Engineering Properties

Knowledge of mechanical properties of food crops such as shear strength, hardness and compression tests is very important to engineers handling agricultural products. According to Anazodo [18], knowledge of mechanical properties of agricultural products (such as compressive and tensile strength) under static or dynamic loading is intended towards textural measurement of unprocessed and processed food material; the reduction of mechanical damage to agricultural products during handling, processing, and storage; and the determination of design parameters for harvest and postharvest systems. The possibility of fracture of a material under tension depends on the applied macroscopic stress and to a large extent, on the size of the particle. An engineer needs knowledge of the shear strength, hardness, compression strength etc, of aerial yam and water yam for process design and handling.

3.1.1 Shear strength

The shear strength indicates the resistance of the material to the applied load and it is an indicator of the toughness of the product when consumed in the rehydrated state [19]. The toughness indicates the energy absorbed by the material prior to rupture. Fig. 1, shows that the RWY recorded the highest shear strength (6.63 N/mm^2) followed by RAY, DAY and finally DWY with values of 4.208, 3.978 and 1.804 N/mm^2 , respectively. This is in agreement with the findings of Du & Wang, [20] who reported the values of shear strength of wheat, safflower and barley as 6.81-7.12, 2.98-6.04 and 3.9-4.49 N/mm^2 , respectively.

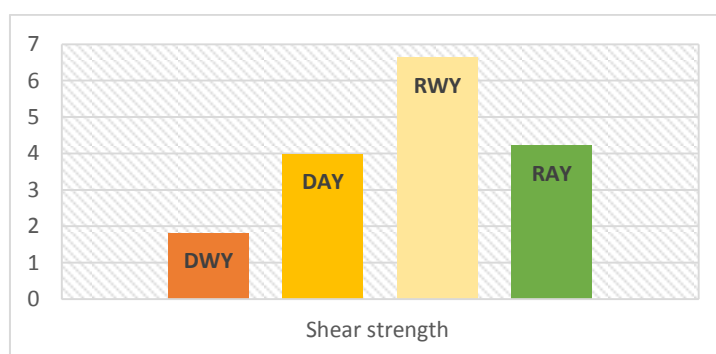


Figure 1. Shear strength for water and aerial yam

3.1.2 Hardness

Hardness is a measure of food crops ability to resist localized plastic deformation and is determined using an indentation test. It is estimated by the magnitude of the reaction force or by the depth of indentation, and can be correlated to other mechanical properties, such as ultimate strength and Young's modulus [21]. This property is required for the design of agricultural processing equipment to minimize breakage and wastage [22]. According to Fig. 2, the values of DWY, RAY, DAY and RWY ranged from 15.582 – 18.555N (Table 1). This values obtained is within the range reported by Chandio et al, [23] for wheat (12.1 -18.64 N) and rice (10.4 – 16.17 N).

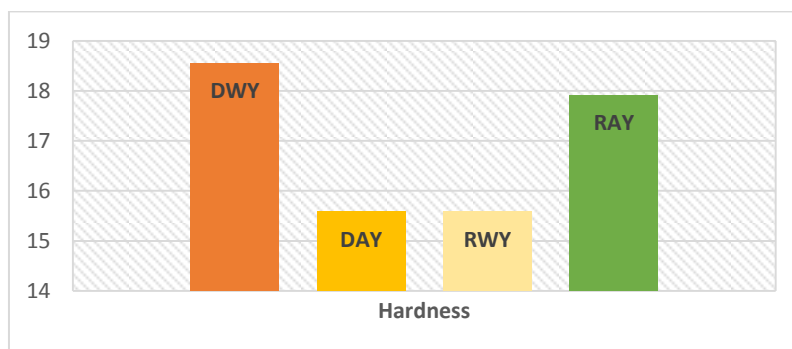


Figure 2. Hardness for water and aerial yam

3.1.3 Bio-Yield Force

The bio yield force is taken to be the maximum force at which the material fails in its internal cellular structure. The variation of bio yield force of water yam and aerial yam dried with conventional hot air dryer when subjected to compressive loading is

represented in Figure 3. The bio yield force of DAY (400N) exhibited the highest values amongst all the sample. This was followed by RWY (287.5 N), and closely followed by DWY (225.5 N) with RAY (87.5N) having the lowest values. Reza et al, [24] has reported the value of bio yield for cowpea in the range of 54.4-143.2 N, which are within the range obtained in this work.

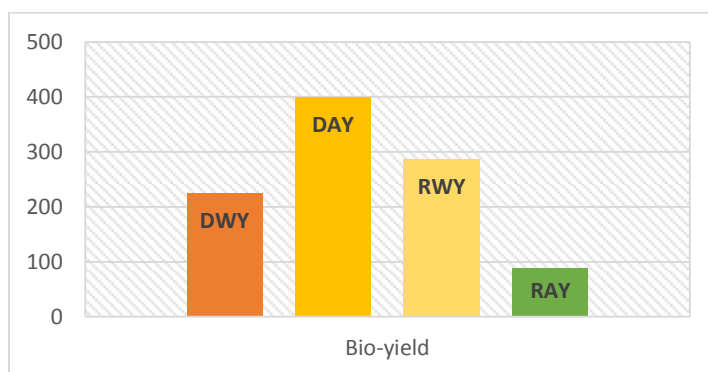


Figure 3. Bio-Yield for water and aerial yam

3.1.4 Rupture Energy

As presented in Fig. 4, the energy absorbed by DWY, DAY, RWY and RAY before initiating a rupture were 1.638, 4.699, 2.912 and 1.256 J (Table 1), respectively indicating that DAY needs more energy to get ruptured while RAY needs the least amount of energy to get ruptured. The results indicate that DAY is more flexible and is more resistant to rupturing on application of loads when compared to the other samples. The value of rupture energy of paddy grain obtained by Zareiforoush et al, [25] is in the range of 1.6-7.71 J which agrees with the result obtained in this work..

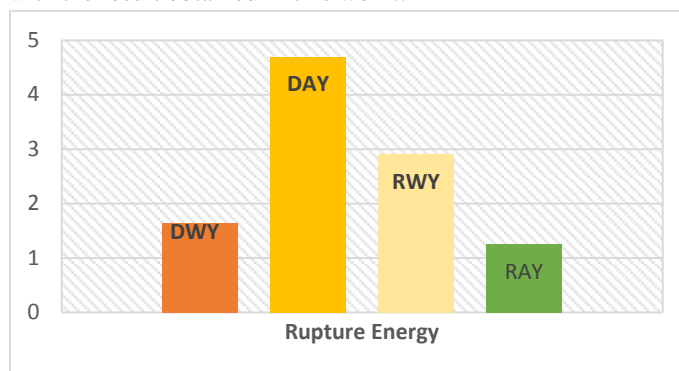


Figure 4. Rupture Energy for water and aerial yam

3.1.5 Modulus of Elasticity and Deformation at break

The modulus of elasticity is defined as a quantity that measures an object’s resistance to being deformed elastically when a stress is applied to it. Fig. 5 shows the modulus of elasticity of samples dried with conventional hot air dryer. According to Table 1, the values of the modulus of elasticity for the samples were given as 31.719, 21.686, 4.532 and 2.788 N/mm² for DWY, DAY, RWY, and RAY, respectively. It could be seen that DWY had the highest elastic modulus among other samples which showed that it is stiffer. A stiffer material will have higher elastic modulus. The results show that drying increases the stiffness of materials since the two raw samples (RWY and RAY) had the least elastic modulus. The elastic modulus obtained for wheat grain by Soliman, [26] was within the range of 20.426-46.603 N/mm² which are in the range obtained in this report. However, the value of deformation at break (Fig. 6) for the samples show that RWY exhibited a higher value (7.50 N/mm²) than the DWY, DAY and RAY with values of 2.25, 4.375 and 6.275 N/mm², respectively.

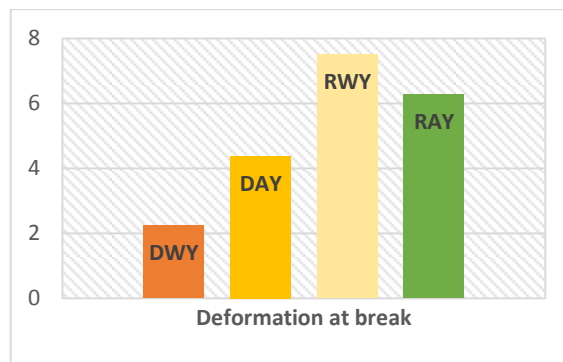
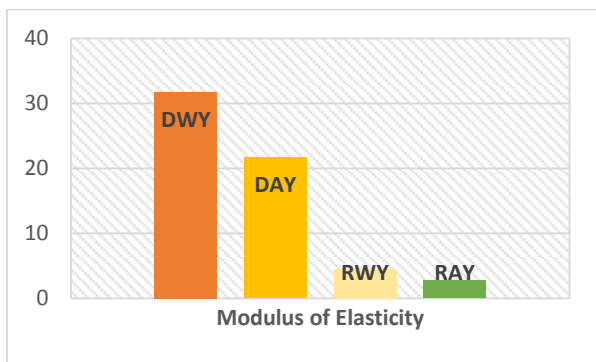


Figure 5. Modulus of elasticity for water and aerial yam Figure 6. Deformation at break for water and aerial yam

3.1.6 Compressive strength

Compressive strength shows how much the sample will deform under applied compressive loading before plastic deformation occurs. The variation of compressive strength of, DWY, DAY, RWY and RAY when subjected to compressive loading are presented in Fig. 7. According to Fig. 7, DAY had the highest compressive strength (2.688 N/mm²) followed by DWY, RWY and RAY with values of 1.813, 0.969, 0.501 N/mm², respectively. The results also show that the two raw samples (RWY, RAY) had lower value of compressive strength, which could be as a result of the presence of much moisture in the raw sample, since presence of moisture indicates low compressive strength [27]. This shows that drying increases the compressive strength of water yam and aerial yam.

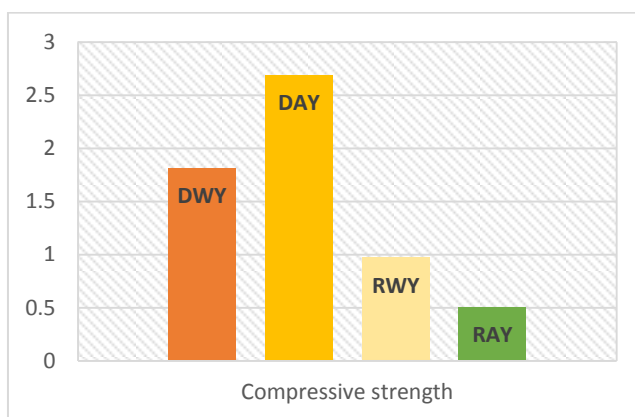


Figure 7. Compressive strength for water and aerial yam

3.1.7 Gumminess

Gumminess is a parameter derived from hardness × cohesiveness [28]; therefore, anything that affects hardness will also affect gumminess in the same way. Gumminess is a characteristic of semisolid foods with a low degree of hardness and a high degree of cohesiveness. The gumminess values obtained for DWY, DAY, RWY and RAY were 4.975, 9.85, 19.0 and 11.65 N, respectively (Figure 8). The values of RWY and RAY were higher than that of DWY and DAY. This shows that drying reduces gumminess for both water yam and aerial yam. This is because drying reduces moisture that bounds the particles together, thus reducing cohesiveness.

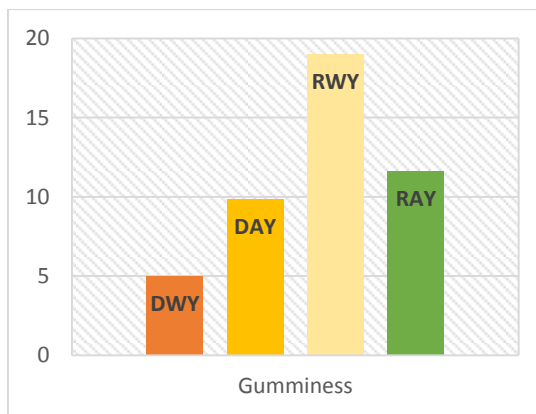


Figure 8. Gumminess for water and aerial yam

Table 1: Mechanical properties of hot air dried water yam and aerial yam

| properties | DWY | DAY | RWY | RAY |
|----------------------|----------|----------|----------|----------|
| Shear strength | 1.8035 | 3.978 | 6.63 | 4.208 |
| HBN | 18.55468 | 15.58241 | 15.58241 | 17.90803 |
| Bio-yield | 225 | 400 | 287.5 | 87.5 |
| Energy | 1.6375 | 4.6995 | 2.9125 | 1.2559 |
| Elasticity | 31.719 | 21.686 | 4.5315 | 2.7875 |
| Deformation at break | 2.25 | 4.375 | 7.5 | 6.275 |
| Compressive strength | 1.8125 | 2.6875 | 0.969 | 0.5005 |
| Gumminess | 4.975 | 9.85 | 19 | 11.65 |

3.2 Thermal Properties

Thermal properties of food products include their specific heat capacity, thermal conductivity and diffusivity. The knowledge of these thermal properties of food materials is very important in the design of industrial dryers.

3.2.1 Heat capacity

The specific heat capacities of the yam samples were calculated using the method outlined by Luther et al, [17] and shown in Fig.9. The specific heat capacity of the RWY was 3.21 KJ/kgK while that of DWY was 1.55 KJ/kgK, which represented a decrease in specific heat capacity as the water yam was dried. Also, the specific heat capacity of RAY had higher value (3.06 KJ/kgK) than DAY (1.66 KJ/kgK). The relatively high value of raw sample when compared to the dried sample is due to the fact that both water yam and aerial yam contain high moisture content since water has the greatest effect upon specific heat capacity among other constituents [17]. It was also observed that the specific heat capacity of RWY was higher than that of RAY (Table 2). This is because water yam contains higher moisture than aerial yam. Ademiliyu et al [29] reported specific heat capacity values that ranged from 1.085 to 1.284 KJ/KgK for bone dry fermented ground cassava cultivars.

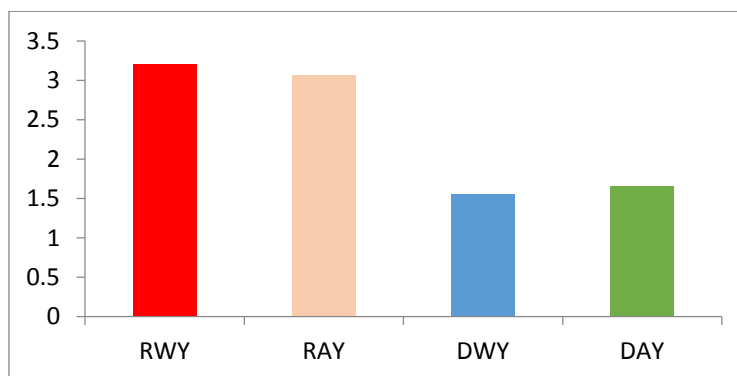


Fig. 9: Specific heat capacity of the samples

3.2.2 Thermal conductivity

Thermal conductivity deals with the ease with which heat flows through a material. The variation of the thermal conductivity on the yam samples are shown in Fig. 10. The values ranged from 0.452 for RWY to 0.256 W/mK for DWY and 0.437 for RAY to 0.271 W/mK for DAY. The thermal conductivity decreased for dried products. It is strongly influenced by a material's water content. In drying of cassava, Nwabanne [15] reported thermal conductivity values of 0.24 W/mK. It was reported by Luther et al [17] that the thermal conductivity of most food materials is in the range of 0.2 to 0.5 W/mK.

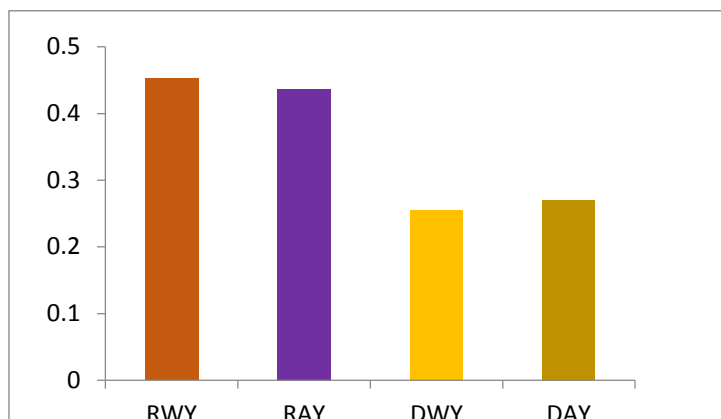


Fig. 10: Thermal conductivity of the samples

3.2.3 Thermal diffusivity

Thermal diffusivity is a measure of how fast heat propagates or diffuses through a material. Thermal diffusivity is very relevant in transient heat transfer where temperature varies with time and location and it is a combination of three basic thermal properties which are thermal conductivity, density and specific heat capacity [17]. The thermal diffusivities of the yam samples were calculated using the method of Luther et al, [17]. Fig. 11 shows the thermal diffusivities of the yam samples. The thermal diffusivity increased with drying for the products, and ranged from 1.28×10^{-4} for RWY to $1.5 \times 10^{-4} \text{ m}^2/\text{s}$ for DWY and from 1.3×10^{-4} for RAY to $1.49 \times 10^{-4} \text{ m}^2/\text{s}$ for DAY. The Thermal diffusivity of ground cassava has been reported to be between 9.0×10^{-4} to 2.0×10^{-4} [15]. Fasina et al, [30] also reported thermal diffusivity of sweet potato to be in the range of 1.98×10^{-7} - $4.25 \times 10^{-7} \text{ m}^2/\text{s}$.

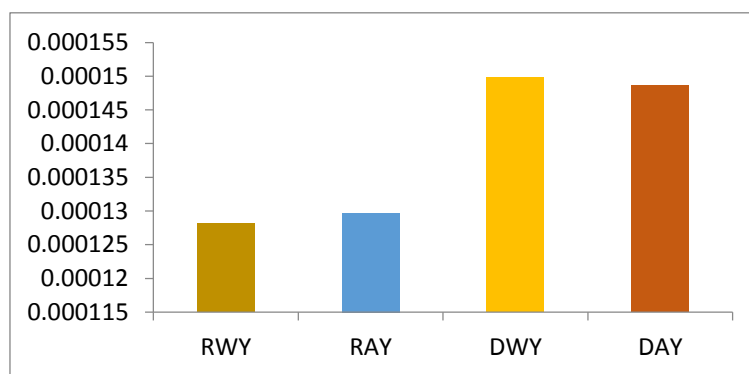


Fig. 11: Thermal diffusivity of the samples

Table 2: Thermal properties of water yam and aerial yam

| Properties | RWY | DWY | RAY | DAY |
|---|-----------------------|-----------------------|-----------------------|-----------------------|
| Specific heat (KJ/kgK) | 3.21 | 1.55 | 3.06 | 1.66 |
| Thermal conductivity (W/mK) | 0.452 | 0.256 | 0.473 | 0.271 |
| Thermal diffusivity (M ² /s) | 1.28×10^{-4} | 1.50×10^{-4} | 1.30×10^{-4} | 1.49×10^{-4} |

4.0 CONCLUSION

The information on engineering properties of water yam and aerial yam showed that the shear stress, hardness, bio-yield, rupture energy, modulus of elasticity, deformation at break, compressive strength and gumminess are all significantly influenced by drying. The thermal properties show that the specific heat capacity and thermal conductivity of the samples decreased on drying. However, the thermal diffusivity of the samples increased on drying. These parameters obtained are of importance in designing equipment for processing and handling operations of these important agro-products.

ABBREVIATIONS

AOAC: Association of analytical chemistry

DAY: Dried aerial yam

DWY: Dried water yam

HBN: Brinell hardness number

RAY: Raw aerial yam

RWY: Raw water yam

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