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Thermal, mechanical and electrical properties of selected tropical roots and tubers crops

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ABSTRACT

Roots and tubers, essential food crops with substantial industrial potential in Sub-Saharan Africa, face underutilization in Nigeria, where only approximately 5 % of the produced root and tuber crops find industrial applications. This study explores the physical, thermal, mechanical, and electrical properties of water yam (*Dioscorearotundata*), white yam (*Dioscoreaalata*), bitter yam (*Dioscoreadumetorum*), cocoyam (*Colocasia esculenta*), and sweet potato (*Ipomoeabatatas*). The weight of the roots varied widely, ranging from 41.22 g to 1169.80 g for cocoyams and white yams, while density varied from 1332.99 g/mm^3 to 1990.35 g/mm^3 for cocoyam and bitter yam, respectively. Thermal conductivity of the products ranged from 0.4042 to 0.4729 $Wm^{-1}K^{-1}$, with specific heat capacity, latent heat of fusion, and thermal diffusivity measured between 0.4042 to 0.4729 $Wm^{-1}K^{-1}$, 2.777 to 3.303 S/cm, 167.44 to 228.54 kJ $Kg^{-1}K^{-1}$, and 6.414 to 9.933 kJ K^{-1}, respectively. Compressive and tensile strengths varied from 0.609 to 2.354 kN and 0.091 to 0.822 kN, respectively, showcasing notable differences among the root and tuber crops. Furthermore, the electrical conductivity ranged from 1145 to 1701 µS/cm. This study underscores the significant variations in the physical characteristics of root and tuber crops. Notably, the thermal properties, mechanical properties, and electrical conductivity of these crops exhibit interdependence, likely influenced by moisture content.

Contribution/Originality: This study investigated the physicochemical characteristics and engineering properties of selected root and tuber crops in Nigeria. The data obtained would be valuable for equipment design and fabrication to address the problem of substantial postharvest losses of tropical root and tuber crops.

1. INTRODUCTION

Roots and tuber crops are plants that grow in warm, humid areas and produce starchy roots, tubers, rhizomes, corms, and stems (Nanbol & Namo, 2019). They include such crops as yam (*Dioscoreaspps.*), cocoyam (*Colocasia spps.*), sweet potato (*Ipomoea batatas*, Linsneus), Onions, carrots, etc. They are commonly cultivated and utilized as staple foods in many parts of Africa (Ansah, Appiah-Twumasi, & Tsiboe, 2023; Balami, Mohammed, Adebayo, Adgidzi, & Adelemi, 2012). Yam, cassava, sweet potatoes, and cocoyams account for about 95% of the total root and tuber crop production in Africa (Nayar, 2014). Roots and tubers production for Nigeria in 2019 was estimated to be 117 million tonnes, increasing from 23.8 million tonnes in 1970 to 117 million tonnes in 2019 with an average annual growth rate of 3.78% (Azeteh, Hanna, Sakwe, Njukeng, & Kumar, 2019).

In West Africa, particularly Nigeria, yams (*Dioscoreaspps.*) are significant staple food crops (Iwe, Onyeukwu, & Agiriga, 2016). Depending on the species and cultivar, they can be annual or perennial plants that yield mature tubers in 6–10 months and stay dormant for 3–6 months when stored. Just a small number of the more than 600 species of yams are grown for food and medicinal purposes. Yams' relatively high moisture content makes them a semi-perishable food (Jimoh & Olatidoye, 2009). After harvest, yam tubers are susceptible to a progressive physiological decline if proper storage facilities are not provided.

Cocoyam is a generic name for both *Xanthosoma* and *Colocasia spps.* They are the indigenous staple food of the people of the developing nations of Africa, Asia, and the Pacific. The nutritional and chemical compositions, as reported, show that cocoyam, if fully exploited, would enhance the food security of people living in the tropics. Cocoyams have the potential to be processed into several food and feed products and industrial products, similar to potatoes in the developed world. However, despite the huge nutritional benefits and economic advantages that could be derived from the industrial utilization of cocoyam, the crop has received little attention for industrial applications.

Sweet potato (*Ipomoea batatas* Linsneus) is the seventh most important food crop in the world and fourth in tropical countries after rice, corn, and cassava(FAOSTAT, 2015). It is an important alternative source of carbohydrates but is considered a low-economic crop. It is used as a staple food in many countries (Soison, Jangchud, Jangchud, Harnsilawat, & Piyachomkwan, 2015). Although sweet potato has many positive attributes, like being potentially versatile for snack food and also cheaper than other crops, this abundant resource is still poorly utilized.

Humans and livestock consume tropical root and tuber crops primarily. They are still underexploited resources for industrial applications because of the high level of mechanization required to meet the high demand for their products (Oluwamukomi & Akinsola, 2015). In Nigeria, only less than 5% of the roots and tubers crops produced are utilized industrially. Therefore, the majority of industrial products that can be obtained from the crops are still imported into the country. Current wastage for root and tuber crops in Nigeria seems to range between 15-25 per cent of production, and this represents a value of several millions of Naira (Pera, Bavagnoli, & Benni, 2019). To minimize post-harvest losses of root and tuber crops, fast, effective, and adequate food processing techniques must be employed. The shortage of automated and mechanized processing and preservation machines and equipment has been attributed to the lack or non-availability of engineering property data for most root and tuber crops (Balami et al., 2012). Engineering properties of food materials are veritable indicators of other properties and qualities(Oke, Idowu, & Omoniyi, 2007). Therefore, it is necessary to understand the physical characteristics of agricultural produce in order to design machines, processes, and handling operations, so as to obtain maximum efficiency of equipment and the highest quality of the final products(Mohsenin, 1970).

Although many research efforts have been focused on obtaining data about the engineering properties of root and tuber crops, the information available to address the problem of substantial postharvest losses of root and tuber crops is still insufficient. The physical, functional, and rheological characterization of several root and tuber crops has been studied by a number of researchers. Oriola (2014) examined the effects of ageing and moisture content on the thermal characteristics of cassava roots.Oluwamukomi and Akinsola (2015) worked on the thermal and physicochemical properties of some starchy foods, namely white yam (*Dioscorearotundata*), cocoyam (*Xanthosoma sagittifolium*), and plantain (*Musa paradisiaca*). However, there was still a need to determine the physical and engineering properties of some other important root and tuber crops. Therefore, this research aimed at determining some physicochemical characteristics and engineering properties of selected root and tuber crops.

2. MATERIALS AND METHODS

2.1. Materials

The white yams, water yams, sweet potatoes, and cocoyams were obtained at Oja-Odan Market (6° 52' 49.31"N, 2° 50' 37.03"E) in Yewa North Local Government, Ogun State, Nigeria. The chemicals and reagents utilised were of analytical grade. The study was carried out in the Food Science and Technology Department as well as the Central Teaching and Research laboratories of Bells University of Technology, Ota.

2.2. Determination of Physical Characteristics

2.2.1. Volume

The unit volume (V) of individual roots and tubers was estimated from the values of length (L), width (W), and thickness (T) using the method of Mohsenin (1970), as given in Equation 1:

$$V = \frac{\pi(LWT)}{6} \qquad (1)$$

2.2.2. Density

Rahman (2005) described a method to determine the density of 10 white yams and water yams, 20 bitter yams, and 50 sweet potatoes and cocoyams. eved by calculating the ratio of each individual's mass to the unit's volume, as shown in Equation 2. The density value was determined by calculating the average of all the distinct values.

$$\text{Density} = \frac{Mass}{Volume} \qquad (2)$$

2.2.3. Weight

The weights of the root and tuber crops were determined by weighing 10 randomly selected samples using an Ohaus analytical balance (Model: ACS-50), and average weights were calculated.

2.2.4. Proximate Analysis

The procedures outlined by AOAC (2000) were used to ascertain the samples' crude protein, crude fat, crude fiber, and total ash levels. The method outlined by AOAC (2012) was used to determine the samples' moisture content. Using the procedure outlined by Rampersad, Badrie, and Comissiong (2003), the total carbohydrate was ascertained by difference. The results for moisture, total ash, crude protein, crude fat, and crude fiber content were added together. Then the sum was deducted from 100%, as in Equation 3.

Carbohydrate= 100 - (% moisture + % ash + % protein + % crude fat +% lipids + %crude fibre). (3)

2.3. Determination of Thermal Properties

2.3.1. Thermal Conductivity

The empirical method outlined by Sweat (1986) was used to determine the thermal conductivity (K) of the food samples. Equation 4 was employed.

$$K = 0.25mc + 0.155mp + 0.16mf + 0.135ma + 0.58mm \qquad (4)$$

Where, *mc* = mass of carbohydrate; *mp* = mass of protein; *mf*= mass of fat; *ma* = mass of ash and *mm* = mass of moisture present in the food material.

2.3.2. Specific Heat Capacity

The specific heat capacity of the roots was estimated using the method of Miles, Van beek, and Veerkamp (1983), as shown in Equation 5.

$$Cp = M_w C_w + M_s C_s \qquad (KJ\ Kg^{-1}K^{-1}) \qquad (5)$$

Where, Cp = specific heat capacity; M_w = mass fraction of water, C_w = specific heat capacity of water (4.18 KJ $Kg^{-1}k^{-1}$), M= mass fraction of solids, and C_s = specific heat capacity of solids (1.46 KJ $Kg^{-1}K^{-1}$).

2.3.3. Latent Heat of Fussion

The method ofLamb (1976) was used to estimate the latent heat of fusion as

$$L = 335\ M_w\ (KJ\ Kg^{-1})$$

Where, M_w = Mass fraction of water.

2.3.4. Thermal Diffusivity

The thermal diffusivity was estimated as described byLewis (1987) as

$$\alpha = \frac{K}{\rho Cp}$$

Where:

A= thermal diffusivity, K = thermal conductivity, ρ - density, cp = specific heat capacity.

2.4. Determination of Electrical Properties

2.4.1. Electrical Conductivity

Slices of root and tuber crops (1:5, slice: water) were macerated with distilled water (having an electrical conductivity of <1 μS/cm and CO_2 concentration no higher than atmospheric equilibrium) at low speed (1200 rpm) in a Scanfrost blender for 20 minutes.

Using a 0.01M KCl reference solution (made by dissolving 0.746 g KCl, which had been dried at 105 °C for two hours, and volume adjusted to 1 L with CO2-free distilled water), the conductivity meter was calibrated in accordance with the manufacturer's instructions. At 25°C, the electrical conductivity of this solution is 1.413 dS/m.

The electrical conductivity meter cell was carefully cleaned. The root and tuber crop suspensions were tested at the same temperature as the electrical conductivity of the 0.01M KCl.After flushing the conductivity cell with the root and tuber crop suspension and refilling it without disturbing the settled suspension, we recorded the value using the conductivity meter. We periodically cleaned the cell with distilled water between samples.

2.5. Determination of Mechanical Properties

2.5.1. Compressive Strength and Tensile Strength

These were determined by stress/strain relationship using Universal Testing Machine (UTM) Okhard Machine Tools Ltd Serial no. 1910E11.

2.5.2. Statistical Analysis

The data obtained were subjected to a one-way analysis of variance (ANOVA) at a 95% probability interval.Means were subjected toa Duncan multiple range test (DMRT) usingthe statistical package for social sciences (SPSS) version 20.0 software for window (SPSS Inc., Chicago, U.S.A).

3. RESULTS AND DISCUSSION

3.1. Physical Characteristics of the Selected Roots and Tubers Crops

Food materials' physical characteristics significantly influence their processing and handling behaviour. Table 1 presents the weight, length, width, area, density, and volume of selected root and tuber crops. White yams recorded the highest values in weight and height, while water yams surpassed others in width, density, and volume. These findings align with the data reported by Kolawole and Chidinma (2015). The weights of roots and tubers ranged from 41.22 to 1169.80 g, with white yam showing the highest value, followed by water yam and sweet potato. Significant differences ($P \leq 0.05$) exist between the white yam, water yam, and sweet potato weights. At 41.22 g, Cocoyam had the lowest weight, consistent with the range of 27.0 to 108.03g reported by Balami et al. (2012). The weight of sweet potatoes (456.21 g) aligns with the range of 449.42 to 531.40 g reported by Obomeghei and Ebabhamiegbebho (2020).

Understanding the weights of agricultural materials is crucial for designing equipment and practical applications, such as mechanical separators and conveyors. The average length of selected roots and tubers ranged from 48.37 to 338.71 mm, with trifoliate yam (bitter yam) and white yam having the highest and lowest lengths, respectively. Cocoyam's length mean value (60.53 mm) aligns with the 55.0–112.3 mm range reported by Balami et al. (2012). The width mean values ranged from 29.82 to 75.68 mm, with water yam having the highest and Cocoyam the lowest. Significant differences were observed among all samples for width, comparable to the diameters of cocoyam corms reported by Balami et al. (2012). Density results indicated that bitter yam had the highest density, though its mass was lower than that of water yam. Density values ranged from 1462.01 to 1990.35 kg/mm^3, with white yam having the lowest value. In this study, Cocoyam's density (1462.01 kg/mm^3) exceeded what Balami et al. (2012) reported. Sweet potato density (1946.81 kg/mm^3) was higher than the range reported by Obomeghei and Ebabhamiegbebho (2020).Varietal differences, maturity levels, and storage durations affecting respiration and transpiration losses may be the cause of these variations. Volumes recorded ranged from 28194.17 to 430644.24 mm^3, with white yam having the highest value, followed by water yam and sweet potato. Cocoyam had the lowest volume, not significantly differing ($P \leq 0.05$) from bitter yam. Cocoyam's values in the experiment align with the data reported by Balami et al. (2012).

Table 1. Physical characteristics of the selected roots and tubers crops.

Samples	Weight (g)	Length (mm)	Width (mm)	Area (mm^2)	Volume (mm^3)	Density (g/mm^3)
RWA	697.54± 4.55^b	143.55±1.51^b	75.68±0.52^a	430644.24±21.3^b	398.38±2.43^b	1619.76± 9.92^c
RWY	1169.80±24.94^a	338.71±1.48^a	70.33±0.83^b	877571.73±16.7^a	804.97±1.84^a	1332.99±18.24^e
RBY	57.47 ± 0.83^d	48.37 ± 1.18^e	33.77±1.03^d	28894.26±8.34^c	28.46± 0.89^d	1990.35 ± 7.78^b
RCC	41.22 ± 0.95^d	60.53± 1.54^d	29.82±0.38^e	28194.17±8.9^c	25.82± 0.51^d	1462.01±24.17^d
RSP	456.21±0.15^c	127.24±1.00^c	57.97±0.90^c	233977.11±10.2^d	206.52±2.83^c	1949.81±14.14^a

Note: Means with the same (a, b, c, d, e) superscript in the same column are not significantly different at $p \leq 0.05$.
RWA: Raw Water Yam, RWY: Raw White Yam, RBY: Raw Bitter Yam, RCC: Raw Cocoyam Corm, RSP: Raw Sweet Potato.

3.2. Mechanical Properties of the Selected Roots and Tubers Crop

The results of some mechanical properties of the selected roots and tubers crops are presented in Table 2. The compressive strengths of the samples varied between 0.609 and 2.354 KN, respectively, for raw water yam and sweet potatoes. It was noted that there was no significant difference ($p \leq 0.05$) between the compressive strengths of white yam, bitter yam, and cocoyam. This may have been due to the closeness of their moisture contents. The compressive load break reported by Balami et al. (2012) for cocoyam ranged between 0.56 and 1.84 kN and was similar to that (1.466 kN) obtained in this study. The sweet potato required greater force to break or crack, being the one with the highest compressive load strength compared to the other roots and tubers. This is in line with what is experienced even in the peeling and cutting of sweet potatoes at home during food preparations. The knowledge of the compressive load forces required for various roots and tubers could be applied to the design of harvesting, processing, and handling equipment.

Table 2. Mechanical properties of the selected roots and tubers crop.

Samples	Compressive strength	Tensile strength
RWA	0.609± 0.09^c	0.091± 0.01^e
RWY	1.307± 0.07^b	0.275± 0.03^d
RBY	1.609± 0.14^b	0.562± 0.07^b
RCC	1.466± 0.20^b	0.480± 0.03^c
RSP	2.354± 0.33^a	0.822± 0.04^a

Note: Means with the same (a, b, c, d, e) superscript in the same column are not significantly different at $p \leq 0.05$.
RWA: Raw Water Yam, RWY: Raw White Yam, RBY: Raw Bitter Yam, RCC: Raw Cocoyam Corm, RSP: Raw Sweet Potato.

The tensile strength of the roots and tubers crops ranged from 0.091 to 0.822 KN and varied just like the compressive strength. Results showed that sweet potatoes had the highest tensile strength value when compared to those of Kolawole and Agbetoye (2007). There were significant variations between the tensile strengths of the samples ($p \leq 0.05$).The tensile strength of any material gives an idea of the amount of mechanical force required to perfectly cut it into two. Mechanical properties provide useful data that could be applied to process and equipment designs. Information like this was utilized by Fadeyibi and Ajao (2020) to design a multi-tuber peeling machine.

3.3. Proximate Analysis of the Selected Roots and Tubers

The results of the proximate composition of fresh roots and tubers crops are presented in Table 3. The moisture content varied between 50.27% and 68.22%. Water yam had the highest moisture content, followed by white and bitter yam, while cocoyam had the lowest. The moisture content of sweet potato and cocoyam does not differ significantly at the $P \leq 0.05$ level. The elevated moisture levels align with the findings of Shajeela, Mohan, Louis Jesudas, and Tresina Soris (2011) on some types of roots and tubers. In this study, the moisture content of sweet potatoes was lower than the mean moisture value (64.47%) reported by Obomeghei and Ebabhamiegbebho (2020) for yellow-fleshed sweet potatoes. Shajeela et al. (2011) also reported greater values for freshly harvested varieties of *Dioscoreaspp.* Compared to those mentioned in the study. The marginal reduction in the moisture content of the selected roots and tubers can be attributed to the loss of water due to transpiration and respiratory losses during storage. The moisture content of food is an indicator of water activity, which determines, to a more significant extent, the quality and preservative potential of any food. The results show that roots and tubers crops must be processed to low moisture content to inhibit microbial growth (Alegbeleye, Odeyemi, Strateva, & Stratev, 2022) and enhance their shelf stability (Akpapunam & Sefa-Dedeh, 1995).

The mean protein of the roots and tubers evaluated ranged between 1.84 and 3.34 %. Cocoyam had the highest value, and water yam had the lowest value. The protein content of cocoyam was significantly higher than that of other roots and tubers. This can be partly due to the low moisture content of cocoyam. Shajeela et al. (2011) reported significantly high values ranging between 6.48 and 13.42 % (on a dry-basis analysis) for some freshly harvested *Dioscoreaspp.* Ezeocha and Ojimelukwe (2012) reported a 10.27 % protein content for water yam. Alaise and Linden (1999) also reported 3.64 % for sweet potatoes. However, the protein mean values of this study agree with the range of 1.83 and 2.00 % reported by Obomeghei and Ebabhamiegbebho (2020) for sweet potato roots. The variations in protein content may be due to various levels of fertilization and agronomical practices.

The mean values of crude ash ranged between 1.09 and 2.28%. Cocoyam had the highest value, and water yam had the lowest value. There was no significant difference between the values for cocoyam and white yam, and no significant difference exists between bitter yam and sweet potato. The crude ash content reported in this study was lower than the range of 0.78 to 1.00 % obtained by Obomeghei and Ebabhamiegbebho (2020) for sweet potato roots. Wild water yam analyzed by Shajeela et al. (2011) had a significantly higher value of 3.56 % than the 1.09 % obtained for water yam in this study. As crude ash content indicates the mineral composition of food materials, the roots and tubers evaluated can be inferred to contain low mineral nutrients.

The lipid contents of this study ranged between 0.69 and 1.68%. Sweet potato had the highest value, followed by bitter yam and cocoyam. The most negligible value was for white yam, but there was no significant difference between water yam and white yam values. The fat contents in the experiment were comparably higher than those of sweet potatoes (0.95%) and white yam (0.56 %) as Alaise and Linden (1999) reported. The crude fat contents are reasonable, as all roots generally contain little fat.

The crude fibre ranged from 0.96 to 2.77 %, with bitter yam having the highest value, followed by sweet potato, while water yam had the lowest value. The crude fibre contents obtained for *Dioscorea* spp. in this study were comparably lower than the 3.48 to 7.69% range reported by Shajeela et al. (2011) for wild yam varieties. The crude fibre contents reported by Obomeghei and Ebabhamiegbebho (2020) for sweet potato root varieties agreed with the report's values. The carbohydrate contents were determined by difference and ranged between 27.13 and 41.82 %. Cocoyam had the highest value, but there was no significant difference between its value and sweet potato roots.

Water yam had the lowest value; next was the value of bitter yam. The carbohydrate values were comparably lower than those obtained by Longe (1986) for white yam (78 %), water yam (75.65 %), and sweet potato (82.55 %). However, the carbohydrate contents reported in this work align with the values obtained by Obomeghei and Ebabhamiegbebho (2020) for various varieties of sweet potato roots.

Table 3. Proximate composition of the selected roots and tubers crops.

Samples	Moisture content(%)	Crude protein(%)	Ash(%)	Crude fat(%)	Crude fibre(%)	Carbohydrates (%)
RWA	68.22 ± 0.45^{a}	1.84 ± 0.07^{d}	1.09 ± 0.06^{c}	0.74 ± 0.06^{d}	0.96 ± 0.07^{d}	27.13 ± 0.44^{c}
RWY	54.57 ± 1.18^{b}	2.21 ± 0.05^{c}	2.09 ± 0.10^{a}	0.69 ± 0.03^{d}	1.03 ± 0.04^{d}	39.42 ± 1.17^{b}
RBY	52.78 ± 0.29^{c}	2.95 ± 0.07^{b}	1.75 ± 0.03^{b}	1.05 ± 0.03^{b}	2.77 ± 0.17^{a}	37.69 ± 1.86^{b}
RCC	49.98 ± 0.44^{d}	3.34 ± 0.17^{a}	2.28 ± 0.38^{a}	0.84 ± 0.04^{c}	1.68 ± 0.03^{c}	41.82 ± 0.84^{a}
RSP	50.57 ± 0.14^{d}	2.52 ± 0.35^{c}	1.51 ± 0.02^{b}	1.68 ± 0.03^{a}	2.29 ± 0.27^{b}	41.43 ± 0.49^{a}

Note: Means with the same superscript in the same column are not significantly different at $P\leq 0.05$.
RWA: Raw Water Yam, RWY: Raw White Yam, RBY: Raw Bitter Yam, RCC: Raw Cocoyam Corm, RSP: Raw Sweet Potato.

3.4. Thermal Properties of the Selected Roots and Tubers Crops

Table 4 presents the thermal properties of the selected roots and tubers. The thermal conductivity, specific heat, and latent heat were observed to vary in a manner consistent with the moisture content of the roots and tubers, both in order and magnitude. However, thermal diffusivity showed no such trend.

Thermal conductivity ranged between 0.40 and 0.47 $Wm^{-1}K^{-1}$, specific heat between 2.78 and 3.30 $Wm^{-1}K^{-1}$, and latent heat between 167.44 and 228.54 kJ Kg^{-1}. Water yam exhibited the highest values for all parameters, while cocoyam had the lowest. Thermal diffusivity ranged between 0.64×10-6 and 0.99×10-6 m^2s^{-1}, with white yam having the highest value and sweet potato the lowest. It is very important to understand the engineering properties of food materials, like their specific heat capacity, thermal conductivity, and thermal diffusivity, because they are often signs of other properties and qualities (Oke et al., 2007).

The thermal conductivity of water yam is significantly higher than the values of the other roots and tubers, followed by white yam. This can be attributed to the high moisture content of water yams compared to the others. The values of cocoyam and sweet potato were not significantly different at the $P\leq 0.05$ level. The values reported in this study are similar to the range of 0.44 to 0.55 $Wm^{-1}K^{-1}$ reported by Obomeghei and Ebabhamiegbebho (2020) for some Nigerian varieties of sweet potatoes and also within the range of 0.4770 to 0.6102 $Wm^{-1}K^{-1}$ reported for cassava by Oriola (2014). However, the values reported in this study are higher than the range of 0.107 to 0.217 $Wm^{-1}K^{-1}$ for an unspecified sweet potato variety by Oke et al. (2007). The high thermal conductivity suggests that the roots and tubers under study are superior heat conductors, leading to a faster rate of heat energy transfer during drying, cooling, and similar operations compared to Oke et al. (2007) and Brinley, Truong, Coronel, Simunovic, and Sandeep (2008).

Water yam has a considerably higher thermal conductivity than the other tubers and roots, with white yam coming in second. This is explained by the water yam's higher moisture content than the others. There was no significant difference found between the cocoyam and sweet potato values at the $P\leq 0.05$ level. The results of this study are comparable to the range of 0.44 to 0.55 $Wm^{-1}K^{-1}$ presented by Obomeghei and Ebabhamiegbebho (2020) for certain sweet potato cultivars from Nigeria, as well as the range of 0.4770 to 0.6102 Wm-1K-1 reported by Oriola (2014) for cassava. The results of this investigation, however, exceed the range of 0.107 to 0.217 Wm-1K-1 for an unspecified sweet potato cultivar reported by Oke et al. (2007). Owing to their high thermal conductivity, the roots and tubers under investigation were probably better heat conductors than those of Oke et al. (2007) and Brinley et al. (2008). As a result, the rate of heat energy transfer during drying, cooling, and other related operations would be faster. The specific heat capacity ranged from 2.78 to 3.30 kJ $Kg^{-1}K^{-1}$. The specific heat for water yam was significantly higher than the values for all other roots and tubers crops, followed by the value for white yam. There is no significant difference between the white and bitter yam values. Cocoyam had the lowest value. The specific heat reported in this research was lower than 3.33, 3.53, and 3.70 kJ $Kg^{-1}K^{-1}$ reported for cocoyam, yam, and cassava, respectively, by

Nwanekezi and Ukagu (1999). However, it falls within the range of 2.3626 to 3.1495 KJ $Kg^{-1}K^{-1}$ reported by Oriola (2014)for cassava. The values for specific heat obtained in this study were higher than 1.25 to 2.76 kJ $kg^{-1o}C^{-1}$ reported by Oke et al. (2007) for sweet potatoes. The thermal energy required to raise or lower the temperature of produce is directly proportional to the specific heat value of the produce, hence the need to evaluate the specific heat capacity of produce. Specific heat capacity values are also required in estimating the sensible heat or heat of respiration in the cold storage of fresh horticultural produce.

The latent heat of fusion values ranged from 167.44 to 228.54 kJ Kg^{-1}, with water yam having the highest value and white yam and cocoyam having the lowest value. A significant difference exists at the $P \leq 0.05$ level among values for water yam, white yam, and bitter yam, but no significant difference exits between the values for cocoyam and sweet potato. The latent heat of fusion reported in this study for sweet potatoes is lower than the values (range of 198.08 to 272.1 $kJKg^{-1}$) reported by Obomeghei and Ebabhamiegbebho (2020) for some common varieties of sweet potatoes in Nigeria. Also, the latent heat obtained for cocoyam and white yam in this study is lower than 221.40 and 248.90 obtained for cocoyam and yam, respectively, by Nwanekezi and Ukagu (1999). Low latent heat produces high heat energy to heat or freeze food (Nwanekezi & Ukagu, 1999). The thermal diffusivity values of white yam and sweet potato were found to be highest and lowest, respectively, within the range of 0.71×10^{-6} to 0.99×10^{-6} m^2s^{-1}. Compared to all other crops with roots and tubers, white yam has a considerably ($P \leq 0.05$) higher thermal diffusivity. This study's data exceed those reported by Obomeghei and Ebabhamiegbebho (2020) for 1.22×10^{-7} m^2s^{-1} to $1.51\times10^{-7} m^2s^{-1}$ for some sweet potato varieties, Farinu and Baik (2007) for an unidentified sweet potato variety that ranged from 6.688×10^{-8} to 8.823×10^{-8} m^2s^{-1}, and Oke et al. (2009) for yam with values of 2.365×10^{-8} to 11.86×10^{-8} m^2s^{-1}. Moreover, the thermal diffusivity values from this experiment are greater than those reported by Oriola (2014) for cassava, which range from 1.432×10^{-7} to 2.426×10^{-7} m^2s^{-1}. When calculating thermal diffusivity, it was found that there was an inverse relationship between food moisture content and thermal conductivity. It takes longer for food to lose or conserve heat when its thermal conductivity drops. Thermal diffusivity has a relationship with heat storage capacity. According to Nwabanne (2009), there is a negative correlation between thermal diffusivity and moisture levels in food products. Specifically, thermal diffusivity decreased as moisture content increased.

Table 4. Thermal properties of the selected roots and tubers crops.

Samples	Thermal conductivity ($Wm^{-1}K^{-1}$)	Specific heat capacity (KJ $Kg^{-1}K^{-1}$)	Latent heat of fussion (KJ Kg^{-1})	Thermal diffussivity ($\times10^{-6}m^2s^{-1}$)
RWA	0.47 ± 0.59^a	3.30 ± 0.007^a	228.54 ± 1.50^a	0.79 ± 0.115^c
RWY	0.42 ± 0.38^b	2.94 ± 0.031^b	182.80 ± 3.84^b	0.99 ± 0.018^a
RBY	0.41 ± 0.11^c	2.90 ± 0.008^b	176.82 ± 0.95^c	0.71 ± 0.007^d
RCC	0.40 ± 0.10^d	2.78 ± 0.065^c	167.44 ± 1.46^d	0.93 ± 0.233^b
RSP	0.40 ± 0.07^d	2.84 ± 0.004^c	169.42 ± 0.45^d	0.64 ± 0.018^e

Note: Means with the same (a, b, c, d, e) superscript in the same column are not significantly different at $p \leq 0.05$.
RWA: Raw Water Yam, RWY: Raw White Yam, RBY: Raw Bitter Yam, RCC: Raw Cocoyam Corm, RSP: Raw Sweet Potato.

3.5. Electrical Conductivity of the Selected Root and Tuber Crop

Table 5 provides the electrical conductivities of the root and tuber crops mentioned, with average values ranging from 1145 to 1701 S/cm. The water yam demonstrated the maximum conductivity, whereas the sweet potato exhibited the lowest conductivity. A comparative analysis found no statistically significant distinction between sweet potato, electrical conductivity, and cocoyam. Likewise, there was no significant differentiation in terms of electrical conductivity between white yam and bitter yam. This observation highlights the relationship between electrical conductivity and the moisture level of the roots and tubers.

Table 5. Electrical conductivity of selected roots and tubers crop.

Samples	Electrical conductivity(µS/cm)
RWA	1701± 16.25^{a}
RWY	1291± 33.40^{b}
RBY	1263± 13.17^{b}
RCC	1160± 9.24^{c}
RSP	1145± 23.12^{c}

Note: Means with the same (a, b, c) superscript in the same column are not significantly different at $p \leq 0.05$. RWA: Raw Water Yam, RWY: Raw White Yam, RBY: Raw Bitter Yam, RCC: Raw Cocoyam Corm, RSP: Raw Sweet Potato.

Upon comparing our findings with prior research on roots and tuber crops, it is apparent that the variation in electrical conductivity corresponds to the patterns of moisture content shown in the studies conducted by Oriola and Raji (2013) andAdetan, Adekoya, and Aluko (2003). The increased conductivity in water yam aligns with the results reported by Yeh, Chan, and Chuang (2009), who observed comparable findings in their investigation of water yam. On the other hand, the decreased electrical conductivity in sweet potatoes aligns with the findings of Brinley et al. (2008), which highlight the impact of moisture content on this characteristic in various types of roots and tubers.

4. CONCLUSION

The study has identified notable disparities in the physical attributes of the analyzed root and tuber crops. Significantly, these crops' thermal characteristics, mechanical properties, and electrical conductivity have a noticeable association with their moisture level. The correlation between these features and moisture content emphasizes the significant impact of moisture on the overall characteristics of roots and tubers.

Notably, the different crops displayed significant variations in weight, length, densities, thermal conductivities, specific heat, and latent heat. The diversity of root and tuber varieties is evident in their distinct composition and structural characteristics. Additionally, the fact that these qualities are linked to moisture content shows how important it is to study and understand how moisture affects the physical, thermal, and mechanical properties of different agricultural goods.

Abbreviation	**Full name**
AOAC	Association of official agricultural chemists
RCC	Raw cocoyam corm
RBY	Raw bitter yam
RSP:	Raw sweet potato
RWA	Raw water yam
RWY	Raw white yam
SPSS	Statistical package for the social sciences

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