

PHYSICOCHEMICAL, THERMAL AND PASTING PROPERTIES OF FLOURS FROM SELECTED NEW YAM CULTIVARS

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Abstract

We investigated the physicochemical, thermal, and pasting characteristics of selected new yam cultivars - REP1BED8, TDR1100585, MECC9RU59, REP1BED4, TDR00396, TDR1100492, TDR0500491, REP1BED19, TDR0900082 and TDR0900002, at Ebonyi State University, Abakaliki. Our results showed significant variations in these cultivars' physicochemical, thermal, and pasting properties. The bulk densities of new yam cultivars varied between 680.45 to 780.34 kg/m³, actual density 1125.24 to 1225.35 kg/m³, wettability 1.14 to 3.24 seconds, water absorption capacity 198 to 375%, dispersibility 54.70 to 63.80%, oil absorption capacity 85.00 to 227.50 g/ml. The MECC9RU59 flour sample had a better swelling index of 98.50 to 215.00v/v. The results showed significant ($P \leq 0.05$) variations in the flour samples' thermal properties. The TDR0900002 new yam cultivar exhibited improved thermal conductivity 0.04 to 0.07 W/m²°C, specific heat capacity 1.18 to 1.63 KJ/Kg°C, thermal diffusivity 6.45 to 7.36 W/m²°C compared with the other new yam cultivars. The TDR00396 flour sample had the highest peak viscosity, 249.11 N/m², highest trough viscosity, 218.20 N/m², highest final viscosity, 368.37 N/m², and lower breakdown viscosity, 30.89 N/m². The REP1BED4 flour sample had the highest pasting temperature, 93.89°C, and a higher paste time, 6.86 min, to form a viscous paste than other flour samples.

Keywords: Physicochemical Properties; Thermal Properties; Yam Cultivars; Pasting Properties

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Introduction

Studies have shown that most people in Africa depend on yam tubers for their nutritional needs and income (Iwe *et al.*, 2017). The perennial nature of the yam tubers makes them abundant during the harvesting season. However, yam tubers become limited in supply and costly during the sowing and sprouting season. (Linus-Chibuezeh *et al.*, 2017). Yam preservation is, however, restricted to inactivity, after which they germinate and give up their nutritive quality. Yams contain nutrients such as vitamins A, E, and C. They also contain minute amounts of other minerals, including manganese, zinc, phosphorus, iron, and calcium. These nutrients are suitable for the human body as they improve good health (Iwe *et al.*, 2017).

Nigeria is the world's highest producer of yams, constituting over 70-80% of the world's production. Based on the Food and Agriculture Organization record in 1985, Nigeria cultivated 18.3 million tonnes of yam from 1.5 million hectares, showing 73.8 % of entire yam cultivation in Africa (Agunbiade and Ighodaro, 2010). According to 2008 figures, yam cultivation in Nigeria has nearly doubled since 1985, with Nigeria cultivating 35.017 million metric tonnes with a value equivalent of US\$5.654 billion (Adebowale *et al.*, 2008). People consume yam in various forms, including steamed, baked, crisped, and yam fufu. Yam is in the category of roots and tubers, which are staples of the Nigerian and West African diets and furnish a few 200 calories of energy per capita daily (Abioye *et al.*, 2008). To make fufu, people mix yam flour with hot water and stir it until it forms a solid mass. Consumers typically eat fufu with various soups (Akissoe *et al.*, 2001; Babajide *et al.*, 2006). The yam species commonly utilized is pallid; the hue of the prepared powder changes from gel-pallid to gloomy chocolate. However, yam cultivation in Nigeria is markedly inadequate and cannot accommodate the expanding request at its current consumption volume. Community members also attribute significant social reputation to individuals during assemblies and denominational activities based on the magnitude of yam barns they acquire (Sanni *et al.*, 2006). The inadequate yam production in Africa and the resultant malnutrition challenges (Musieba *et al.*, 2013) have prompted investigations into diversifying the yam cultivars (Enujiugha and Ayodele-Oni, 2003).

The functional properties are dependent on the composition and structures of the flours or starches in the roots, which include amylose/amylopectin ratio, granular size and molecular weight of the

flour, and chain length distribution of amylopectin (Nuwamanya *et al.*, 2010). Heat methods, for example, purification, dehydrating, warming, chilling disinfection, melting, catering, cooling, and vaporization, are regularly employed in the commercial approach, transportation, and preservation processes. For the design of equipment such as heat exchangers, chillers, and evaporators, as well as for the prediction and control of various changes occurring in foods during heat transfer processes associated with storage and processing, knowledge of thermal properties such as thermal conductivity, thermal diffusivity, and specific heat capacity of foods is essential (Oke *et al.*, 2008). Therefore, a deeper understanding of their unique physicochemical, functional, and sensory evaluation is necessary to unlock the potential of the flour's or stodge's thermal properties for application in the fabrication of viands and non-viands. The present study investigated flours' physicochemical, thermal, and pasting properties from selected new yam cultivars.

Materials and Methods

Materials

Some selected new yam cultivars include REP1BED8, TDR1100585, MECC9RU59, REP1BED4, TDR00396, TDR1100492, TDR0500491, REP1BED19, TDR0900082, and TDR0900002, which were sourced from the International Institute of Tropical Agriculture (IITA)-African Yam Barn Research Centre, Faculty of Agriculture and Environmental Science, Ebonyi State University, Abakaliki, Nigeria.

Sample Preparation

Researchers sorted new yam rootstocks, cleaned them using tap water, removed the outer covering, and sliced them into smaller pieces of 1 mm thickness using a stainless-steel knife (Oluwamukomi *et al.*, 2011). The smaller pieces were immersed in sodium metabisulphite solution (200 parts per million) for 10 minutes, decanted, and then dried in an oven at 60°C for 48 h. We pulverized the sample to obtain a powdery mass using the Marlex Blender (Electro Line Model IS 4780, CM/L 7902804). The powdered flour was packed in polythene bags, sealed to prevent moisture absorption, and kept at room temperature before additional examination. Figure 1 shows the peeled yam tubers and powdered yam flour.

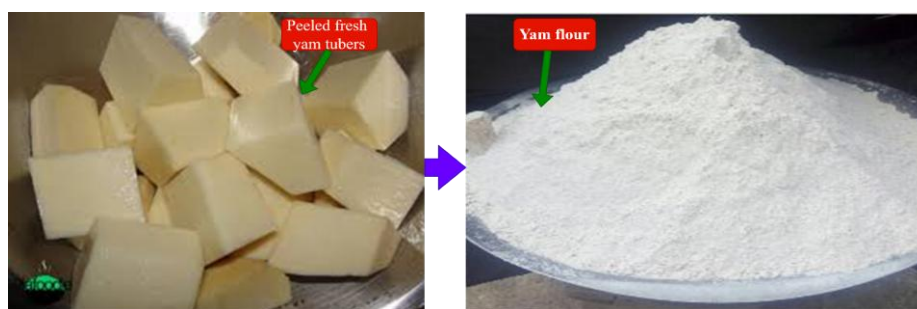


Figure 1. Shows peeled fresh yam tubers and yam flour

Determination of Physicochemical Characteristics of the Samples

Bulk Density

We determined the bulk density of the flour sample using the gravimetric technique described by Olubukola *et al.* (2017). We filled a calibrated 25 ml measuring cylinder with a 10 g weighed sample and recorded the volume as the loose volume. We gently tapped the bottom of the cylinder on a hard pad on the lab bench until we observed steady volume, then recorded the packed volume. The weight of the sample divided by the volume it occupied before and after tapping was used to compute the loose bulk density (LBD) and packed bulk density (PBD). We calculated bulk density using Equation 1.

$$\text{Bulk density (g/cm}^3\text{)} = \text{weight of sample/volume of sample after tapping} \quad (1)$$

Swelling Measurement

The swelling index was determined using the technique explained by Linus-Chibuezeh *et al.* (2017). A 15 ml centrifuge tube containing 1 g of sample was filled with 10 ml of distilled water and gently stirred. The slurry was cooked for fifteen minutes at 100°C in a water bath. The slurry was carefully swirled to keep the flour from clumping as it heated. The paste tube was centrifuged for 10 minutes at 3000 revolutions per minute after 15 minutes. Immediately following centrifugation, the supernatant was poured out, and the sediment's weight was noted. The sediment was placed in crucibles and dried in an oven (Gallenkamp Co. Ltd. London, England) at 105°C. The swelling index was calculated using Equation 2:

$$\text{Swelling index (\%)} = \text{weight of wet mass sediment (g)/weight of dry matter in sediment} \times 100 \quad (2)$$

Dispersibility

Dispersibility was determined using the procedure outlined by Ugwuanyi *et al.* (2020). Yam

flour weighing 10g was prepared to a capacity of 100 ml in a measuring cylinder graduated by pouring distilled water, stirred, and permitted to simmer for three hours. The quantity of the yam flour was deducted from 100. Using equation 3, the % dispersibility was determined:

$$\text{Dispersibility (\%)} = 100 - \text{volume of settled particle} \quad (3)$$

Water Absorption Capacity

The water absorption capacity of the flour samples was determined using the procedure reported by Awoyale *et al.* (2011). A 1 g sample was combined with 10 ml of distilled water and blended for 30 seconds. After letting it stand for half an hour, it was centrifuged for half an hour at room temperature at 3,500 rpm. After the supernatant was decanted, the flour's water absorption weight was computed. The water absorption index was calculated using Equation 4:

$$\text{WAC (\%)} = \frac{W_3 - W_2}{W_1} \times 100 \quad (4)$$

Meanwhile, W_3 = mass of tube (g) + residue after centrifuge (g), W_2 = mass of empty tube (g), and W_1 = mass of sample (g).

Wettability

The procedure outlined by Onwuka (2018) was applied. 1g of sample was added to a graduated 25-milliliter cylinder measuring 1cm. One finger was thumbed across the cylinder's open end, lying upside down. The cylinder was suspended at a height of 10 cm above a 600 ml beaker filled with 500 ml of pure water. On removal of the index finger, the resultant mixture flowed into a beaker containing water.

Oil Absorption Capacity

The method described by Iwe *et al.* (2017) was used to calculate the capacity of oil absorption. 1 g of yam-weighed flour was added to a sterilized centrifuge of predetermined weight. The flour was combined with groundnut oil to produce a 10-millilitre solution. Then, it was centrifuged at 3500 revolutions/min for 15 min. The buoyant was discharged, and the conduit was re-weighed. The oil absorption capacity was calculated as a gain in weight.

Thermal Properties

Measuring specific heat (Cp) Capacity

The precise temperature of yam flour was calculated using a DSC, or differential scanning calorimeter, as detailed by Wahab *et al.* (2018). The sample was broken up, and about 5 mg of the powdered sample acquired was put inside the aluminum crucible 6 mm in diameter and 1.5 mm in depth, with an aluminum lid. The representative sample was ramped to an onset temperature using liquid nitrogen cooling. The sample was equilibrated both in an isothermal manner and dynamically scanned at the speed of 50°C/min at a range of temperatures of 10-50°C. Finally, a 5 mg yam flour sample was used to activate the nitrogen and oxygen gases in the apparatus and conduct the experiment for specific heat. Thermograms resulting from the specific heat of the sample were assessed using the DSC.

Thermal conductivity (K)

The sample thermal conductivities were measured employing the equation 5, (Atobatele and Afolabi, 2016).

$$Q=KA (\theta_2 - \theta_1)/L \quad (5)$$

A is the specific surface area (m²),
K is for thermal conductivity (w/m²°C),
 θ_1 = Initial temperature of the cold sample (°C),
 θ_2 = The hot sample's final temperature (°C),
Q represents the thermal energy (J), and L stands for length (meters).

The Thermal Diffusivity (α)

The diffusivity of heat was determined using the equation 6, Sopha *et al.*, (2008).

$$\alpha = k/\rho C \quad (6)$$

in which thermal diffusivity, α , is (m²/s),
K is the heat conductivity (W/m²°C),
C is the specific heat capacity (J/kg°C), and ρ is the bulk density (g/cm³).

Pasting Properties

The pasting properties of the flour formulation were determined using the rapid visco analyzer (RVA) Tecmaster, Perten instrumented as described by Newport Scientific (1998) as reported by Ehimen *et al.* (2016). The samples were turned into slurry by mixing 3g of the flour formulation with 25 ml of water inside the RVA can. The can was inserted into the tower, which was lowered into the system. The slurry was heated to 50°C within 12-14 minutes; the peak time, peak viscosity, holding strength, setbacks, and final viscosity were estimated.

Results and Discussion

The Functional Properties of Selected New Yam Cultivars

Oil Absorption Capacity (O.A.C)

The oil absorption capacity (OAC) ranges from 85.00g/ml to 227g/ml (Table 1). Sample TDR0900082 gave a minimal value of 85.00g/ml, while sample TDR 1100585 had the highest value of 227g/ml. Significant differences ($P \leq 0.05$) exist amongst flour samples for oil absorption capacity. The OAC values 85.00g/ml to 227g/ml are within the values obtained for yam (*D. Dumetorum*) flour 72.3 to 94.8 % reported by Medoua *et al.* (2005) and higher than the values (220 and 230%) reported by Princewill-Ogbonna and Ezembaukwu (2015) for green and red aerial yam cultivars which is an indication of the intact starch granules in the raw flour of the sample. The OAC in this study was similar to the value of (103.67-220.60%) Eke-Ejiofor and Oparandu (2019) reported for pearl millet, finger millet, and fonio flour blend. OAC is a crucial component of food composition since fats enhance the flavor and texture of meals (Ikegwu *et al.*, 2009). The difference in the OAC is a function of no permanent dipole oil side chains. The process of oil absorption capacity can be described as a physical capture of oil similar to the non-polar pendant protein chain. The type and quantity of protein influence food materials' ability to hold the oil they contain (Falade *et al.*, 2014).

Water Absorption Capacity (W.A.C)

Table 1 presents the water absorption capacity (WAC). Results showed that the values of flour samples varied from 198.50 to 375.00 g/ml. Sample TDR0500491 exhibited a higher value of 375.00 g/ml than the REP1 BED8 of 198.50 g/ml. It was found that there is a substantial variation ($P \geq 0.05$) in all the flour samples TDR1100585, MECC9RU59, REP1 BED4, and TDR 1100492. Also, flour samples REP1 BED8 and TDR00396,

TDR0900082, and TDR0900002 did not show significant variation ($P \geq 0.05$) in their water absorption capacity. The WAC is an indication of the volume of water needed for gelatinization. It measures the extent of water retention of flour as it affects its ability to form a paste. Another way to think about it is a product's affinity for water under a condition where water is limiting, for example, dough and paste (Otegbayo *et al.*, 2006). According to Diallo *et al.* (2015), flour with high WAC will require more water during dough formation, which improves maneuverability. The value 198.50-375.00g/ml obtained for the flour samples analyzed is within the values (182.30 to 390.70 %) reported by Kouadio *et al.* (2017) for yam flours (*discorea dumetorum*) and higher than the value 202.55 % reported by Igboke *et al.*, (2016) for yellow-fleshed aerial yam, this could describe the reduction of nutrients loss during cooking. Higher WAC increases viscosity, faster pasting time, and potentially altered thermal behavior. This is because water absorption influences factors like swelling capacity and starch granule structure, affecting pasting and thermal properties.

Wettability

Results from Table 1 reveal that wettability ranged from 1.14 to 3.24 seconds. Significant differences ($P \leq 0.05$) exist amongst the flour samples. Sample TDR0900002 had the highest value, 3.24 sec, lower than the 27 to 35 seconds recorded for various *D. alata* flour types by Udensi *et al.* (2008). The result for wettability was considerably lower than the 52.00 seconds reported by Nwosu *et al.* (2014) for wheat flour, 37.00 seconds for cassava flour, and 31.00 seconds for malted soybean flour, respectively. This could be due to increased surface area. Sample MECC9RU59 and TDR1100585 showed similar values of 2.41 and 2.44 in this study, which suggests to what degree the dry flour samples will likely possess instant characteristics. Wettability indicates the time taken to dissolve flour in water completely. The wettability of flour samples was affected by surface polarity, topography, texture, area, size, and microstructure of the particles but not necessarily by the amount of native structure (Ikegwu *et al.*, 2009). Studies have shown that wettability is influenced by the physical attributes of flour, including density, shape, porosity, and particle size. The flour's increased density tends to sink rapidly, while larger particle sizes generally have superior wetting behavior (Fitzpatrick *et al.*, 2017). This could be seen in sample TDR0900002 with low bulk density and high wettability.

Swelling Index

The swelling index (SI) results ranged from 98.50 to 215.00%. Samples MEEC9 RU59 showed a higher value of 215.00%, while sample TDR0500491 had the lowest value of 98.50%. Samples with low peak viscosity give more resistance to swelling; samples TDR0500491 and REP1BED8 revealed it. Significant differences ($P \leq 0.05$) exist for all the samples for SI. Results for Samples TDR1100585 (205.500%), MECC9RU59 (215.00%), and TDR0900002 (212.00%) had similar values with lesser differences, which suggests that Differences between the flour samples' SI could be due to differences in starch composition and granules organization in the different cultivars (Singh *et al.*, 2003). The results obtained for the new yam cultivars are lower than the values 268 to 269, 104 to 133 reported by Abiodun and Akinosa (2014) and Tortoe *et al.* (2017) for oven-dried in the sun *D. alata* and *D. rotundata* yam flour. The swelling index (SI) is a significant functional characteristic of the food. It is the gauge of the aptitude of flour or starch to absorb moisture and expand (Ogunlakin *et al.*, 2022). Superior flour quality can expand to at least three times its initial volume or a 5.00 volume increase (Sanni *et al.*, 2008; Baafi *et al.*, 2015; Adebayo-Oyetoro *et al.*, 2017). Bibiana *et al.* (2014) showed that the swelling power of flours indicates the amount of associative forces within the granules. Fasogbon *et al.* (2017) claimed that the correlated force increased with the swelling power. According to earlier studies, granules will swell more quickly and have a higher viscosity when the particle size is larger. (Lindeboom *et al.*, 2004). Like the water absorption capacity, the swelling index has a linear relationship to the flour samples, which alters starch granules and thermal behavior. It also increases viscosity and pasting time. The swelling index is a function of process conditions, the material's nature, and the treatment type (Olubukola *et al.*, 2017).

Dispersibility

The values obtained for dispersibility ranged from 54.70 to 63.80 %. Significant ($P \leq 0.05$) variations exist amongst flour samples for dispersibility except for flour samples REP1BED8 and TDR00396, MECC9RU59, and TDR1100492, REP1BED4, and TDR500491, which are not significantly different ($P \geq 0.05$) from one another. The dispersibility results obtained were lower than the value of 3.25-4.91g/cm³ recorded by Ayo *et al.* (2018) for aerial yam flour and similar to the range of 51.83 to 61.00% reported by Wahab

et al. (2018) for yam (*D. Rotundata*) flour. Ikujenlola *et al.* (2008) stated that dispersibility is a measure connected with the process of reconstituted flour in water. How well a mixture dissolves in water indicates reconstitution ability and higher dispersibility, which is preferable. It is anticipated that the samples of instant yam flour will readily reconstitute to produce a uniform dough when combined. (Nwokocha *et al.*, 2009). Improved dispersibility can lead to better pasting properties and affect thermal conductivity and heat transfer rates (Cheng *et al.*, 2020).

Bulk Density

Bulk density values varied from 680.45-780.34 kg m⁻³. Notable variations ($P \leq 0.05$) exist for flour samples, as shown in Table 1. Different values of bulk densities have been reported for yam flour products. Udensi *et al.* (2008) reported a range between 0.64 and 0.76 g./cm³, Kouadio *et al.* (2017) revealed a variety from 1.14 to 0.76 g/cm³ for yam flour 'Azaguie'. The values acquired exceeded those obtained by Udensi *et al.*, (2008) 0.64 to 0.76 g/cm³ and Kouadio *et al.*, (2017) 1.14 to 0.76 g/cm³, indicating higher levels of packing or compactness of the flour particles, which could influence other functional properties like WAC, swelling index and the flours potential for use in various food preparation and development. As the high bulk density increases the rate of dispersion (Nwokocha *et al.*, 2009), It is crucial to reconstitute yam flour in hot water to make dough for yam fufu. Nwokocha *et al.* (2009) revealed that the structure of starch polymers affected bulk densities, with loose starch polymer structures leading to low bulk densities. Agunbiade and Ighodaro (2010) assert that a good material's bulk density impacts its packaging.

Thermal Properties of Selected New Yam Cultivars

Specific Heat

Table 2 shows the capacity to hold specific heat of flour samples from new yam cultivars.

Specific heat capacity varied from 1.18 to 1.63 KJ/Kg°C. The TDR0900002 flour samples gave a higher value of 1.63 KJ/Kg°C, while flour samples from REP1BED4 had the lowest value of 1.18 KJ/Kg°C. Flour samples TDR0900082, TDR1100585, REP1BED19, and TDR1100492 revealed no statistically significant ($P \geq 0.05$) variance from one other. Significant ($P \leq 0.05$) differences exist among the flour samples for specific heat capacity. Ademiliyu and Fubara, (2005) found that bone-dry fermented ground cultivars range from 1.085 to 1.284 KJ/KgK. Adebowale *et al.* (2008) obtained 1.205KJ/KgK measuring native cassava that is bone dry with a scanning calorimeter. This value of specific heat 1.18 to 1.63 KJ/Kg°C.) are within the range of 1.205 KJ/Kgk recorded by Adebowale *et al.* (2008); Okafor (2011) for potatoes, and Sanni *et al.* (2006). The discrepancy is attributable to variations in starch contents in the cultivars. Specific heat is the energy required to alter a material's temperature. It depends on the heating method, which may be at constant pressure or volume. This indicates the ability of the material to conserve warmth upon processing and is independent of mass density.

Thermal Conductivity

The thermal conductivity of the new yam cultivars is shown in Table 2. The values varied from 0.03 to 0.07w/m²°C. Significant ($P \leq 0.05$) variations exist for all flour samples for thermal conductivity, except for flour samples from REP1BED8, TDR1100585, and TDR0900082 without significant ($P \geq 0.05$) variation from one another. Oke *et al.* (2008) reported the values of thermal conductivity of *amula* to be 0.2258 and 0.3485 W/m C for *Hemba kwase* flour, which was higher than the values reported in this study. He further noted that the values for *agbo-pan ave* 0.2662 W/mC and *Agbo-kor* 0.3230 W/mC. Ademiliyu and Fubara (2005) obtained 0.24 W/mK for born dry air flour. The low thermal conductivity of the flour samples in this study indicates that it is

Table 1. Shows functional properties of selected new yam cultivars

Sample	Oil absorption capacity (g/ml)	Dispersibility (%)	Water absorption capacity (g/ml)	Swelling index (%)	Wettability (sec)	Bulk density (kg/m3)
REP1BED8	221.00 ^a ±1.41	61.75 ^c ±0.35	198.50 ^a ±0.71	120.50 ^a ±0.71	2.23 ^d ±0.01	755.26 ^b ±0.01
TDR1100585	227.50 ^a ±0.71	55.75 ^c ±0.35	238.50 ^d ±0.71	205.50 ^b ±0.71	2.44 ^b ±0.01	745.63 ^c ±0.01
MECC9RU59	206.00 ^a ±1.41	56.40 ^a ±0.14	234.50 ^d ±0.71	215.00 ^a ±5.67	2.41 ^c ±0.01	780.34 ^a ±0.01
REP1BED4	201.50 ^a ±0.71	57.40 ^d ±0.14	239.00 ^d ±1.41	191.50 ^d ±0.71	1.56 ^e ±0.01	698.58 ^a ±0.01
TDR00396	200.50 ^a ±0.71	61.80 ^c ±0.14	200.50 ^a ±0.71	144.00 ^f ±1.41	2.11 ^c ±0.01	730.26 ^d ±0.01
TDR1100492	217.00 ^b ±1.41	56.80 ^a ±0.14	237.50 ^d ±0.71	141.50 ^f ±2.12	1.14 ^d ±0.00	699.36 ^f ±0.01
TDR0500491	90.00 ^a ±14.14	57.80 ^d ±0.14	375.00 ^b ±7.10	98.50 ^b ±0.71	1.33 ^b ±0.01	680.45 ^d ±0.01
REP1BED19	95.00 ^a ±7.07	63.80 ^a ±0.14	355.00 ^b ±7.10	196.50 ^c ±0.71	2.11 ^c ±0.01	720.16 ^e ±0.01
TDR0900082	85.00 ^a ±7.10	62.30 ^b ±0.14	315.00 ^c ±7.10	152.50 ^c ±0.71	1.49 ^a ±0.00	695.36 ^f ±0.01
TDR0900002	126.5 ^d ±7.01	54.70 ^a ±0.14	315.00 ^c ±7.10	212.00 ^a ±1.41	3.24 ^a ±0.01	688.59 ^a ±0.01

Values are three replicates determination, means with different letters varied significantly ($P < 0.05$)

a poor conductor of heat. This implies that heat transfer through flour (*Dioscorea spp.*) samples will be slow, influencing other thermal properties like thermal diffusivity and specific heat capacity. A low thermal conductivity could also affect how quickly the flour sample could be heated or cooled during processing or cooking. The ability of a substance to conduct heat is known as its thermal conductivity, which depends not only on the chemical composition but also on a variety of other elements that influence the routes by which heat flows through the material, including homogeneity, void fraction, and void space size, form, and arrangement, and the fluid inside the pores (Agunbiade and Ighodaro, 2010). The characteristics of materials indicate the amount of heat flux that will pass through them in the event of a temperature difference.

Thermal Diffusivity

The thermal diffusivity of the new yam cultivars is shown in Table 2, ranging from 6.45 to 7.36 $\text{w/m}^2\text{°C}$. Significant variations ($P \leq 0.05$) exist for all flour samples for thermal diffusivity, except for flour samples from TDR1100585, MECC9 RU59, and REP1 BED8, which are not significantly different ($P \geq 0.05$) from each other. This means that heat energy in yam tubers spreads at different rates, and some can be as much as over twice the value of others. Thermal diffusivity measures the rate of heat propagation or diffusion through a body. It is a physical property connected with heat flow and measures a substance's capacity to transfer warmth in relation to the thermal energy storage capacity. Nwabanne (2009) reported that thermal diffusivity of food materials is related to moisture content, which causes thermal diffusivity to decrease as moisture content rises. That means yam tubers with high moisture content should have lower thermal diffusivity values. It can be suggested that these

properties may correlate with the chemical composition of the tubers, like carbohydrates, as Nwokocha *et al.* (2009) proposed. The differences in the thermal diffusivity values may be due to differences in the moisture and chemical composition of the yam cultivars.

Pasting Properties of Flours from Selected New Yam Cultivar

Peak Viscosity

Peak viscosity measures starch's ability to create a paste. Table 3 shows the peak viscosity of the new yam cultivars. The maximum viscosity values varied from 60.89 to 249.11 RVU. Flour sample TDR00396 gave the highest value, 249.11 RVU, whereas flour sample TDR0900002 gave the lowest value of 60.89 RVU. Significant variations ($P \leq 0.05$) existed for peak viscosity in all the flour samples. Abiodun and Akinoso (2014) reported that the maximum viscosity of trifoliate yam flour varied from 84.09 to 213.33 RVU. The values 60.89 to 249.11 RVU obtained in this study are close to those reported by Abiodun and Akinoso (2014), 84.09 to 213.33 RVU for trifoliate yam. At the same time, Agunbiade and Ighodaro (2010) reported that the amount of starch in the product has a greater influence on the viscosity rise of gelatinized foods. This could be ascribed to the morphological and biochemical characteristics of the flour samples, which may have been impacted by some flour starch granules' decreased stiffness. It ultimately led to instability and, as a result, disturbance during the heating and stirring processes. (Leon *et al.*, 2006). On the other hand, the highest peak viscosity of the sample TDR00396 (Table 3) compared to other flour samples could be due to the small granules size of the flour samples, which contributes to the good texture of pounded yam and a gel strength that is moderately high (Otegbayo *et al.*, 2006).

Table 2. Shows thermal properties of selected new yam cultivars

Sample	Specific heat (KJ/Kg°C)	Thermal conductivity ($\text{w/m}^2\text{°C}$)	Thermal diffusivity ($\text{w/m}^2\text{°C}$)
REP1BED8	1.43 ^d ±0.01	0.04 ^d ±0.00	6.69 ^e ±0.01
TDR1100585	1.39 ^c ±0.01	0.04 ^d ±0.00	6.74 ^c ±0.01
MECC9RU59	1.28 ^a ±0.01	0.04 ^d ±0.00	6.73 ^c ±0.01
REP1BED4	1.18 ^b ±0.01	0.03 ^c ±0.00	6.45 ^b ±0.01
TDR00396	1.36 ^b ±0.01	0.03 ^c ±0.00	6.68 ^e ±0.01
TDR1100492	1.48 ^c ±0.01	0.06 ^b ±0.00	6.83 ^d ±0.01
TDR0500491	1.56 ^b ±0.01	0.06 ^b ±0.00	7.26 ^b ±0.01
REP1BED19	1.48 ^c ±0.01	0.05 ^c ±0.00	6.94 ^c ±0.01
TDR0900082	1.38 ^c ±0.01	0.04 ^d ±0.00	6.66 ^e ±0.01
TDR0900002	1.63 ^a ±0.01	0.07 ^a ±0.00	7.36 ^a ±0.01

Values are three replicates determination, means with different letters varied significantly ($P < 0.05$)

Trough Viscosity

Trough viscosity could be referred to as retaining power, which evaluates the starch's strength in staying unperturbed during the steaming process when yam paste is exposed to a prolonged, high, steady temperature. Trough viscosity among the new yam cultivars in Table 3 ranged from 58.30 to 218.20 RVU. Flour sample TDR 0900002 had the lowest value, whereas flour sample TDR00396 was the most valuable. Considerable ($P \leq 0.05$) differences exist amongst every flour sample for trough viscosity. The range of value 58.30 to 218.20 RVU recorded in this study was higher than the value 81.25 to 157.00 RVU reported by Abiodun and Akinoso (2014) for trifoliate yams. The value of higher trough viscosities impacts the texture and stability of the gel. It further suggests a more potent, stable gel with less tendency to break down or become watery. This indicates that a high holding strength typically translates into excellent eating quality and less cooking loss (Ugwuanyi *et al.*, 2020). Strong associative forces between the dried yam slices' starch granules may cause higher holding strength (Ugwuanyi *et al.*, 2020). The reported value for trough viscosity of the yam flour is directly related to its thermal and functional properties, particularly its ability to form a stable thickened paste or gel during cooking and processing. Higher trough viscosity values indicate a more viscous, thicker paste, influencing thermal behavior and functional characteristics like water absorption and stability. This could be related to sample TDR0500491 in this study, which has a high viscosity and an excellent capacity for water absorption. In essence, the trough viscosity value of 58.30 to 218.20 RVU is an important indicator of the pasting characteristics of yam flour, which can directly impact its behavior during heating and its ability to perform various functional roles in food products.

Breakdown Viscosity

The breakdown viscosity measures the capacity of starch to resist deformation upon cooling. Table 3 shows that the breakdown viscosity varied from 26.0 to 74.60 RVU. Flour sample TDR0900002 had the lowest value, 26.0 RVU, for breakdown viscosity, implying it's less stable under heat, leading to a more rapid breakdown of starch granules. Sample TDR0900082 had the highest value, 74.60 RVU, for breakdown viscosity compared to the other flour samples. This suggests a greater exhibition of thermal stability and more resistance to break down under heat, allowing them to retain viscosity and structure even at higher temperatures like pounded yam. Significant variations ($P \leq 0.05$) exist for all

flour samples for breakdown viscosity. Wahab *et al.* (2018) found that extremely weak cross-linking occurs within the granules of starches with low breakdown viscosity or paste stability. Consequently, it suggests that the flour samples' granules had higher cross-linking. According to Adebowale *et al.* (2005), a sample's capacity to tolerate heat and shear stress during cooking decreases with increasing breakdown viscosity.

Final Viscosity

The final viscosity indicates whether the starch materials from the flour samples form a gel or paste on cooling. It also means the strength of the cooked flour paste when cooling. Table 3 shows final viscosity values for new yam cultivars, ranging from 70.10 to 368.37 RVU. Flour sample TDR00396 had the highest value of 368.37 RVU compared to other cultivars, indicating that the flour is more resistant to breakdown under heat and shear stress during cooking. This also means the paste will maintain its consistency and structure when heated. Higher final viscosity correlates with higher pasting temperature and longer pasting times, as seen in Table 3 for all the new yam cultivars. Flour sample REPIBED19 had the lowest value, 70.10 RVU. The results for final viscosity in this study are higher than the value of 75.83-169.42 reported by Rosida *et al.* (2017) for modified water yam. The higher values obtained for final viscosities compared to the peak viscosities (Table 3) are due to the high association between starch-water and their high recrystallization ability (Bhattacharya *et al.* 1999). Significant ($P \leq 0.05$) differences exist for every sample of flour. The final viscosity of flour samples increased gradually with time, while as the paste cooled, its temperature dropped. The increase in the final viscosity of TDR00396 paste indicates the development of a solid gel during cooking and cooling, as opposed to other flour samples' fluid paste. According to Afoakwa and Sefa-Dedeh (2001), the high retrogradation property of yam starch during cooling may have caused a sharp rise in the viscosity of yam paste.

Setback Viscosity

Setback viscosity evaluates the starch's re-association, which is connected to the coherence of the dough after processing (Baafi *et al.*, 2015). The setback viscosity values varied from 32.70 to 163.91 RVU. Significant ($P \leq 0.05$) variations exist in each flour sample for setback viscosity. Flour sample TDR0900002 possessed the most essential value of 163.91 RVU, and flour sample REPI BED8 had the lowest value of 32.70 RVU. Baafi *et al.* (2015) had previously stated that a high

setback value characterizes a cohesive paste, whereas a low value indicates a no coherent paste. Therefore, the paste from flour sample REP1BED8 is not cohesive, but the paste from flour sample TDR0900002 is the most cohesive. Sample TDR0900002 flour will be suitable for restructured foods and extruded products where a cohesive or gelled structure is desired.

Peak time

The peak period indicates the lowest cooking time needed (Tunde-Akintunde and Toyosi, 2010). In Table 3, the peak time for the new yam cultivars varied from 6.28 to 6.98 minutes. Flour sample TDR0500491 had the highest value of peak time (6.98 minutes), which may indicate a greater structural rigidity in comparison to other flour samples (Leon *et al.*, 2006), while flour sample TDR1100585 had the lowest value of peak time (6.28 minutes). Significant ($P \leq 0.05$) variations exist for every sample of flour except MECC9RU59, TDR00396, and TDR0900082 flour samples without significant ($P \geq 0.05$) variation from one another. The higher the peak time, the higher the energy needed for the food sample to form a gel and, hence, the high cost of production.

Pasting Temperature

According to Linus-Chibuezeh (2017), the pasting temperature of starches has been linked to the texture and cooking quality of various food products. It also indicates the lowest temperature required to cook a sample. Pasting Temperature values ranged from 93.08 to 93.89°C. Flour sample REP1 BED4 had the highest value of 93.89°C, while sample MECC9 RU59 had the least (93.08°C), as shown in Table 3. Significant ($P \leq 0.05$) variations exist in all flour samples for pasting temperature except for flour samples

TDR1100492 and REP1 BED19 without significant ($P \geq 0.05$) variation from one another. The pasting temperature range of 93.08 to 93.89°C in this study is the temperature at which the flour samples granules begin to gelatinize, absorbing water and swelling, increasing the viscosity of the resulting slurry. Different pasting temperatures have been variously reported. Okoro (2004) reported 76.80°C for fufu; according to Sanni *et al.* (2008), the pasting temperature was 64°C for garri, and Ekwu *et al.* (2005) reported that high amylose content in Starchy foods altered their natural cooking qualities and delay the gelatinization of starch, which were lower than the value reported for this study. The higher pasting temperature of the samples may be attributed to their high water absorption capacity, as shown in Table 1.

Conclusions

The findings in this study have shown that the new yam varieties demonstrate good thermal stability suitable for restructuring foods where the cohesive gelling structure is desired, indicating their pasting characteristics, which reveal the existence of strong interfacial interactions within the granules of starch behavior during heating. This study revealed their ability to perform various functional roles in food product development by flour samples TDR0900002 and REP1BED8. It shows that highly nutritious and functional flours can be produced from the new yam varieties, increasing raw materials and their economic value by improving utilization and providing cheaper alternatives to other yam species. This research provides additional data on engineering properties and choices of yam flour varieties for utilization in food technology.

Table 3. Shows pasting properties of selected new yam cultivars

Sample	Peak 1 Viscosity (RVU)	Trough 1 Viscosity (RVU)	Breakdown Viscosity (RVU)	Final Viscosity (RVU)	Setback Viscosity (RVU)	Peak time (min)	Past temp (°C)
REP1BED8	98.55 $\pm$ 0.07	98.89 $\pm$ 0.08	6.72 $\pm$ 0.06	131.73 $\pm$ 0.02	32.70 $\pm$ 0.04	6.42 $\pm$ 0.03	93.29 $\pm$ 0.01
TDR1100585	161.05 $\pm$ 0.07	100.39 $\pm$ 0.08	60.71 $\pm$ 0.06	227.37 $\pm$ 0.06	66.39 $\pm$ 0.08	6.28 $\pm$ 0.04	93.38 $\pm$ 0.04
MECC9RU59	169.48 $\pm$ 0.90	109.15 $\pm$ 0.09	60.37 $\pm$ 0.06	230.73 $\pm$ 0.09	61.30 $\pm$ 0.06	6.39 $\pm$ 0.01	93.08 $\pm$ 0.04
REP1BED4	161.98 $\pm$ 0.08	100.73 $\pm$ 0.09	61.23 $\pm$ 0.10	232.93 $\pm$ 0.01	71.07 $\pm$ 0.10	6.86 $\pm$ 0.01	93.89 $\pm$ 0.02
TDR00396	249.11 $\pm$ 0.15	218.20 $\pm$ 0.04	30.89 $\pm$ 0.8	368.37 $\pm$ 0.05	150.20 $\pm$ 0.04	6.39 $\pm$ 0.01	93.21 $\pm$ 0.01
TDR1100492	210.73 $\pm$ 0.01	144.38 $\pm$ 0.06	66.39 $\pm$ 0.06	231.41 $\pm$ 0.01	87.10 $\pm$ 0.01	6.45 $\pm$ 0.01	93.50 $\pm$ 0.01
TDR0500491	221.48 $\pm$ 0.08	157.07 $\pm$ 0.09	64.41 $\pm$ 0.02	237.12 $\pm$ 0.06	80.10 $\pm$ 0.03	6.98 $\pm$ 0.04	93.66 $\pm$ 0.01
REP1BED19	108.63 $\pm$ 0.06	67.73 $\pm$ 0.08	40.92 $\pm$ 0.01	70.10 $\pm$ 0.03	38.52 $\pm$ 0.02	6.67 $\pm$ 0.01	93.46 $\pm$ 0.01
TDR0900082	175.72 $\pm$ 0.07	101.04 $\pm$ 0.08	74.60 $\pm$ 0.01	160.61 $\pm$ 0.04	59.50 $\pm$ 0.01	6.39 $\pm$ 0.01	93.57 $\pm$ 0.02
TDR0900002	60.89 $\pm$ 0.09	58.30 $\pm$ 0.06	26.00 $\pm$ 0.02	222.19 $\pm$ 0.02	163.91 $\pm$ 0.01	6.57 $\pm$ 0.01	93.75 $\pm$ 0.00

Values are three replicates determination, means with different letters varied significantly ($P < 0.05$), Past- pasting, temp - temperature.

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