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Effect of Processing Techniques on Functional, Rheological and Sensory Properties of Different Varieties of Yam Flour (Water Yam, White Yam and Aerial Yam)

NWACHUKWU, C. A[1], NWOKEKE, B. C[2], ENYI C. U[3], OGBEDEAGU, C. O[4], KALU, S. C[5]
[1,2, 3,4,5] *University of Agriculture and Environmental Sciences Umuagwo, Imo State, Nigeria.*

Abstract- Yam (Dioscorea spp.) is an important tropical root crop widely cultivated in West Africa, serving as a major source of dietary energy, food security, and income. However, rapid postharvest deterioration and limited processing options restrict its utilization and commercial value. This study evaluated the effects of different processing techniques on the functional, rheological, and sensory properties of flours produced from water yam (Dioscorea alata), white yam (Dioscorea rotundata), and aerial yam (Dioscorea bulbifera). Fresh yam tubers were sorted, washed, peeled, sliced, and subjected to three processing methods: untreated (control), blanching, and natural fermentation before drying, milling, and sieving into flour. Functional properties, including bulk density, water absorption capacity, oil absorption capacity, swelling capacity, and solubility, were determined using standard analytical methods. Rheological properties, namely volumetric flow rate, viscosity, mass flow rate, specific volume, and specific weight, were evaluated using standard laboratory procedures, while sensory quality was assessed by a 20-member semi-trained panel using a nine-point Hedonic scale. Data were analyzed using one-way analysis of variance (ANOVA), and treatment means were separated using Duncan's Multiple Range Test at p < 0.05. Processing techniques significantly (p < 0.05) influenced the functional, rheological, and sensory properties of the yam flours. Fermentation improved bulk density and sensory quality, producing flours with the highest overall acceptability, particularly from water yam. Blanching enhanced oil absorption capacity and solubility, whereas untreated samples generally exhibited higher water absorption and swelling capacities. Rheological characteristics varied significantly among processing methods and yam varieties, reflecting differences in flour flow behaviour and handling properties. Overall, fermented water yam flour recorded the best quality attributes, including superior colour, taste, texture, flavour, and consumer acceptability, while aerial yam flour generally received lower sensory scores. The study demonstrates that fermentation is the most effective processing technique for improving the quality and utilization potential of yam flours. These findings provide valuable information for food processors and researchers seeking to develop high-quality flour-based products and promote the utilization and value addition of both conventional and underutilized yam species.

Keywords: Dioscorea Spp., Fermentation, Blanching

I. INTRODUCTION

1.1 Background of the Study

Yam (Dioscorea spp.) is one of the most important food crops cultivated in tropical and subtropical regions of the world, particularly in West Africa, where it serves as a staple food and a major source of carbohydrates for millions of people. Nigeria is the world's largest producer of yam, accounting for over 60% of global production, followed by Ghana, Côte d'Ivoire, Benin, and Togo. Yam contributes significantly to food security, household income, employment generation, and rural development in these countries. Besides its economic importance, yam is highly valued because of its versatility in processing into various traditional and industrial food products such as pounded yam, boiled yam, fried yam, yam flakes, yam chips, yam starch, and yam flour (FAOSTAT, 2024; Adepoju & Boyejo, 2021). The genus Dioscorea comprises over 600 species, although only a few are economically important for food purposes. Among these, white yam (Dioscorea rotundata), water yam (Dioscorea alata), and aerial yam (Dioscorea bulbifera) are widely cultivated and consumed in many parts of Africa and Asia. White yam is the most commercially valuable species because of its excellent cooking qualities, desirable texture, and consumer acceptance. Water yam possesses relatively high moisture content, attractive yield, and disease resistance, making it increasingly important in yam production. Aerial yam, though less extensively utilized, has gained attention because of its rich nutritional composition, medicinal properties, and adaptability to diverse agroecological conditions. Despite these advantages, aerial yam remains underutilized due to limited knowledge of its processing characteristics and product quality (Otegbayo et al., 2020; Behera et al., 2021).

Fresh yam tubers contain approximately 65–80% moisture, making them highly susceptible to physiological deterioration and microbial spoilage shortly after harvest. Significant postharvest losses are common during storage, transportation, and marketing due to respiration, sprouting, pest infestation, and microbial attack. Processing yam into stable products such as flour is one of the most effective methods of extending shelf life, reducing storage losses, minimizing transportation costs, and ensuring year-round availability. Yam flour is widely used for the preparation of reconstituted foods, bakery products, composite flours, instant meals, and traditional dishes such as "amala." Its relatively low moisture content enhances storage stability while preserving much of the nutritional value of the fresh tubers (Afoakwa & Sefa-Dedeh, 2019; Olatunde et al., 2022). The quality of yam flour is greatly influenced by the processing techniques employed before drying and milling. Common processing methods include blanching, fermentation, soaking, steaming, boiling, drying, and chemical pretreatments. These techniques affect the physicochemical, functional, rheological, and sensory characteristics of the resulting flour by altering starch granules, protein structure, enzymatic activity, and moisture distribution. Blanching, for instance, inactivates enzymes responsible for enzymatic browning and reduces microbial load, while fermentation enhances nutritional quality, improves digestibility, modifies starch functionality, and develops desirable flavour compounds through microbial metabolism (Adebo et al., 2018; Adebiyi et al., 2019).

Functional properties describe the behaviour of flour during food preparation, processing, and storage. Important functional characteristics include bulk density, water absorption capacity, oil absorption capacity, swelling capacity, solubility, dispersibility, foaming properties, and emulsification capacity. These properties determine the suitability of flour for different food applications such as baking, extrusion, infant food formulation, and instant food production. Flours possessing high water absorption capacity generally produce softer doughs and improved product yield, while appropriate bulk density facilitates packaging and transportation. Similarly, swelling capacity influences the consistency and texture of reconstituted products (Onwuka, 2018; Iwe et al., 2020). Rheological properties describe the deformation and flow behaviour of food materials under applied forces. These properties are particularly important in understanding flour performance during mixing, cooking, extrusion, baking, and reconstitution. Parameters such as viscosity, mass flow rate, volumetric flow rate, specific volume, and specific weight determine processing efficiency, product consistency, and consumer acceptability. Processing treatments such as blanching and fermentation induce physicochemical changes in starch granules and proteins, thereby modifying the rheological behaviour of yam flour. Such modifications are valuable in selecting suitable processing methods for industrial applications and product development (Maziya-Dixon et al., 2019; Sefa-Dedeh & Afoakwa, 2021).

Sensory evaluation remains an indispensable aspect of food quality assessment because consumer acceptance depends largely on organoleptic characteristics such as colour, aroma, taste, texture, and overall acceptability. Even nutritionally superior products may experience poor market acceptance if sensory attributes are compromised during processing. Processing methods can significantly influence colour development through enzymatic or non-enzymatic browning, modify flavour through fermentation metabolites, and alter texture by changing starch gelatinization patterns. Consequently, sensory evaluation provides essential information for selecting processing methods capable of producing flour with desirable consumer attributes (Lawless & Heymann, 2018; Stone et al., 2020). Recent interest in utilizing underexploited yam species has intensified due to the increasing demand for climate-resilient crops capable of improving food security. Water yam and aerial yam possess considerable production advantages, including high yield potential, drought tolerance, and adaptability to marginal soils. However, limited information exists regarding the comparative influence of different processing techniques on the functional, rheological, and sensory qualities of flour produced from these yam varieties. Comparative evaluation of these species under standardized processing conditions would provide valuable information for food processors, plant breeders, nutritionists, and policy makers seeking to diversify yam utilization and reduce dependence on white yam alone (FAOSTAT, 2024; Otegbayo et al., 2020).

Furthermore, increasing demand for gluten-free foods has stimulated interest in yam flour as an alternative ingredient in bakery and composite flour products. Understanding how processing techniques influence flour functionality is therefore essential for improving product quality and expanding industrial utilization. Scientific information generated from this study will contribute to the optimization of processing methods for different yam varieties and facilitate their incorporation into value-added food products with improved consumer acceptability and commercial potential. Therefore, this study seeks to evaluate the effects of different processing techniques on the functional, rheological, and sensory properties of flour produced from water yam (Dioscorea alata), white yam (Dioscorea rotundata), and aerial yam (Dioscorea bulbifera), with the aim of identifying the most suitable processing method for producing high-quality yam flour for domestic and industrial applications.

II. MATERIALS AND METHODS

2.1 Study Location

This study was carried out in the Food Processing and Product Development Laboratory, Department of Food Science and Technology, University of Agriculture and Environmental Sciences, Umuagwo, Imo State, Nigeria. The proximate, functional, rheological and sensory analyses were conducted in the Food Chemistry and Quality Control Laboratories using standard analytical procedures.

2.2 Materials

2.2.1 Raw Materials

Fresh mature tubers of water yam (Dioscorea alata), white yam (Dioscorea rotundata), and aerial yam (Doscorea bulbiferai) were purchased from Ekeonuwa Market, Owerri, Imo State, Nigeria. The tubers were selected based on uniform maturity, freedom from insect infestation, bruises, mould growth and physical damage.

2.3 Preparation of Yam Flour

Fresh yam tubers were washed thoroughly under running tap water to remove adhering soil and foreign materials. The tubers were peeled manually with stainless steel knives and sliced into approximately 3–5 mm thickness using a mechanical slicer.The slices were divided into three portions corresponding to the processing treatments.

2.3.1 Preparation of Control Yam Flour

The sliced yam samples were immediately dried in a hot-air cabinet dryer at 60°C for 24 hours according to the modified method of Falade and Okafor (2015).The dried slices were milled into flour using a laboratory hammer mill and sieved through a 250 µm sieve.The flour samples were packaged in airtight polyethylene bags and stored at ambient laboratory temperature until analysis.

2.3.2 Preparation of Blanched Yam Flour

Fresh yam slices were blanched in hot water maintained at 80 ± 2°C for 5 minutes using a thermostatically controlled water bath. The blanched slices were drained, cooled rapidly, and dried in a cabinet dryer at 60°C for 24 hours. The dried samples were milled, sieved through 250 µm mesh, packaged and stored for analysis.

2.3.3 Preparation of Fermented Yam Flour

Fresh yam slices were submerged completely in potable water and allowed to ferment naturally for 72 hours (3 days) at room temperature (28 ± 2°C). At the end of fermentation, the slices were drained, rinsed lightly with distilled water and dried in a cabinet dryer at 60°C for 24 hours. The dried samples were milled into flour using a hammer mill and sieved through 250 µm mesh. The flour samples were

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packaged in moisture-proof polyethylene bags until required for analysis.

2.4 Sample Coding
The samples were coded as shown in Table 1

Table 1: Description of Sample codes

Sample Codes	Description
T_1	Control Water Yam
T_2	Blanched Water Yam
T_3	Fermented Water Yam
U_1	Control Aerial Yam
U_2	Blanched Aerial Yam
U_3	Fermented Aerial Yam
V_1	Control White Yam
V_2	Blanched White Yam
V_3	Fermented White Yam

2.5 Determination of Functional Properties of yam flour samples
The functional properties of the flour samples were determined in triplicate.

2.5.1 Bulk Density Determination
Bulk density was determined according to Onwuka (2018). Approximately 10 g of flour was transferred into a 50 mL graduated measuring cylinder and tapped gently until a constant volume was obtained. Bulk density was calculated as:

Bulk Density (g/mL) = Weight of sample (g) / Volume occupied (mL)

2.5.2 Water Absorption Capacity Determination
Water absorption capacity was determined using the method of Beuchat (1977). One gram of flour was mixed with 10 mL distilled water, stirred for 30 minutes, centrifuged at 3000 rpm for 20 minutes, and the supernatant discarded. Water absorption capacity was expressed as millilitres of water absorbed per gram of flour.

2.5.3 Oil Absorption Capacity Determination
Oil absorption capacity was determined following Onwuka (2018). One gram of flour was mixed with 10 mL refined vegetable oil, centrifuged and the retained oil measured. Results were expressed as mL oil/g flour.

2.5.4 Swelling Capacity Determination
Swelling capacity was determined according to Leach et al. (1959). One gram of flour was dispersed in 10 mL distilled water, heated at 80°C for 30 minutes, cooled and centrifuged. The increase in sediment volume was recorded and expressed as swelling capacity.

2.5.5 Solubility Determination
The supernatant obtained during swelling capacity determination was evaporated to dryness. The dried residue was weighed and expressed as percentage solubility.

2.6 Determination of Rheological Properties of the yam Flour Samples
2.6.1 Volumetric Flow Rate
Volumetric flow rate was determined using the funnel discharge method. A known volume of flour slurry was allowed to flow through a standardized funnel while the discharge time was recorded. Volumetric flow rate was calculated as:

Q=VtQ=\frac{V}{t}Q=tV

Where:
Q = volumetric flow rate (mL/s)
V = volume discharged
t = time

2.6.2 Mass Flow Rate
Mass flow rate was determined using:

M=mtM=\frac{m}{t}M=tm

Where:
M = mass flow rate (g/s)
m = mass discharged
t = discharge time

2.6.3 Apparent Viscosity
Viscosity was measured using a Brookfield DV-E Viscometer fitted with spindle No. 4 operating at 100 rpm. Flour slurry (10% w/v) was prepared and

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maintained at 30°C before measurement. Results were expressed in Pa.s.

2.6.4 Specific Volume

Specific volume was determined using the seed displacement method. Specific volume was calculated as:

Specific Volume = Volume (mL) / Weight (g)

2.6.5 Specific Weight

Specific weight was calculated as the reciprocal of specific volume.

Specific Weight = Weight / Volume

2.7 Sensory Evaluation

Sensory evaluation was conducted using twenty (20) semi-trained panelists selected from staff and students of the Department of Food Science and Technology. The flour samples were prepared into reconstituted yam paste under identical conditions. Samples were coded with three-digit random numbers and presented randomly. Panelists evaluated colour, taste, texture, flavor, overall acceptability using a 9-point Hedonic Scale.

2.8 Statistical Analysis

All analyses were conducted in triplicate and results expressed as Mean ± Standard Deviation. The data obtained were subjected to one-way Analysis of Variance (ANOVA) using IBM SPSS Statistics Version 29.0 (IBM Corp., Armonk, NY, USA).

III. RESULTS AND DISCUSSION

Table 2: Functional Properties of Yam Flours

Parameters	T_1	T_2	T_3	U_1	U_2	U_3	V_1	V_2	V_3	LSD
Bulk Density (g/mL)	$0.57^{f} \pm 0.01$	$0.60^{c} \pm 0.01$	$0.61^{a} \pm 0.01$	$0.56^{g} \pm 0.02$	$0.59^{d} \pm 0.01$	$0.60^{b} \pm 0.01$	$0.56^{h} \pm 0.01$	$0.58^{e} \pm 0.01$	$0.59^{d} \pm 0.02$	0.00
Water Absorption Capacity (mL/g)	$1.40^{a} \pm 0.02$	$1.20^{d} \pm 0.03$	$1.30^{b} \pm 0.02$	$1.30^{b} \pm 0.01$	$1.00^{f} \pm 0.02$	$1.10^{e} \pm 0.01$	$1.30^{b} \pm 0.02$	$1.10^{e} \pm 0.02$	$1.20^{c} \pm 0.03$	0.00
Oil Absorption Capacity (mL/g)	$0.10^{c} \pm 0.01$	$0.20^{b} \pm 0.01$	$0.10^{c} \pm 0.00$	$0.20^{b} \pm 0.02$	$0.30^{a} \pm 0.01$	$0.20^{b} \pm 0.01$	$0.20^{b} \pm 0.01$	$0.30^{a} \pm 0.02$	$0.20^{b} \pm 0.01$	0.20
Swelling Capacity	$0.85^{a} \pm 0.02$	$0.76^{f} \pm 0.01$	$0.81^{b} \pm 0.01$	$0.82^{b} \pm 0.02$	$0.74^{h} \pm 0.01$	$0.79^{d} \pm 0.01$	$0.80^{c} \pm 0.02$	$0.70^{i} \pm 0.01$	$0.75^{g} \pm 0.02$	0.00
Solubility (%)	$2.54^{f} \pm 0.03$	$3.43^{a} \pm 0.04$	$2.86^{c} \pm 0.02$	$2.80^{e} \pm 0.03$	$3.21^{b} \pm 0.02$	$2.80^{e} \pm 0.03$	$2.81^{d} \pm 0.02$	$3.38^{a} \pm 0.03$	$2.82^{d} \pm 0.02$	0.38

Values are expressed as Mean ± Standard Deviation of triplicate determinations (n = 3). Means within the same row bearing different superscript letters are significantly different ($p < 0.05$), while means with the same superscript are not significantly different. Least Significant Difference (LSD) values are shown in the last column.

Key

- T1 – Control Water Yam Flour
- T2 – Blanched Water Yam Flour
- T3 – Fermented Water Yam Flour
- U1 – Control Aerial Yam Flour
- U2 – Blanched Aerial Yam Flour
- U3 – Fermented Aerial Yam Flour
- V1 – Control White Yam Flour
- V2 – Blanched White Yam Flour
- V3 – Fermented White Yam Flour

3.1 Functional Properties of Yam Flours

The functional properties of the different yam flour samples produced from water yam (Dioscorea alata), aerial yam (Dioscorea bulbifera), and white yam (Dioscorea rotundata) processed by control (raw), blanching, and fermentation methods are presented in Table 2. Functional properties are important quality indices because they determine the suitability of flour for various food applications, including bakery products, infant foods, thickening agents, and reconstituted foods.

The bulk density of the yam flour samples ranged from 0.56 to 0.61 g/mL, with significant ($p < 0.05$) differences observed among the treatments. Fermented water yam flour (T3) recorded the highest bulk density (0.61 g/mL), whereas control white yam flour (V1) exhibited the lowest value (0.56 g/mL). The slight increase in bulk density observed in fermented and blanched samples may be attributed to structural modifications of starch granules and reduction in particle porosity during processing. Fermentation enhances starch degradation and facilitates closer packing of flour particles, resulting in increased density. Higher bulk density is advantageous where greater quantities of flour are required in a limited packaging volume, while lower bulk density is desirable for complementary foods because it permits the formulation of energy-dense products with reduced viscosity. The values obtained are comparable to those reported by Adebowale et al. (2008), Otegbayo et al. (2018), and Oluwalana et al. (2020), who observed bulk density values ranging from 0.50–0.70 g/mL for various yam flour products. Similar increases following fermentation have also been reported by Chinenye et al. (2022), who attributed the improvement to changes in starch composition and particle size distribution.

Water absorption capacity varied significantly ($p < 0.05$) among the flour samples, ranging from 1.00 to 1.40 mL/g. Control water yam flour (T1) exhibited the highest water absorption capacity (1.40 mL/g), whereas blanched aerial yam flour (U2) had the lowest (1.00 mL/g).The reduction in water absorption capacity following blanching may result from partial gelatinization of starch and denaturation of hydrophilic proteins, reducing available water-binding sites. Conversely, the relatively high water absorption observed in the control and fermented samples may indicate the presence of intact starch granules and exposed hydrophilic polysaccharides capable of retaining more water. High water absorption capacity is a desirable functional property in food formulations because it enhances dough handling characteristics, improves product yield, and contributes to desirable mouthfeel in reconstituted foods. Similar observations have been reported by Falade and Okafor (2015), Olatunde et al. (2019), and Awolu et al. (2021), who found that processing methods significantly influence the hydration characteristics of yam flour.

Oil absorption capacity ranged from 0.10 to 0.30 mL/g, with blanched aerial yam flour (U2) and blanched white yam flour (V2) recording the highest value (0.30 mL/g), while both control and fermented water yam flours (T1 and T3) showed the lowest value (0.10 mL/g).The increase in oil absorption capacity after blanching may be attributed to protein unfolding and exposure of non-polar amino acid residues capable of binding lipid molecules. Improved oil absorption enhances flavour retention and contributes to better palatability of food products such as snacks, baked goods, and meat analogues. The observed values agree with reports by Iwe et al. (2017), Otegbayo et al. (2018), and Adegunwa et al. (2020), who reported that thermal processing generally increases oil-binding capacity by modifying protein conformation and exposing hydrophobic binding sites.

Swelling capacity differed significantly ($p < 0.05$) among the treatments, ranging between 0.70 and 0.85. Control water yam flour (T1) recorded the highest swelling capacity (0.85), whereas blanched white yam flour (V2) had the lowest value (0.70).The reduction in swelling capacity observed after blanching and fermentation is likely due to partial hydrolysis of starch molecules and disruption of starch granule integrity during processing. Fermentation promotes enzymatic degradation of amylopectin, while blanching induces partial gelatinization, both of which reduce the ability of starch granules to absorb water and swell. Swelling capacity influences the consistency and viscosity of flour-based foods and is particularly important in products such as pounded yam, soups, and porridges. Similar reductions following thermal and fermentation treatments have been documented by Adebowale et al. (2005), Falade et al. (2020), and Olatunde et al. (2019).

Solubility values ranged from 2.54 to 3.43%, with blanched water yam flour (T2) recording the highest solubility (3.43%), followed closely by blanched white yam flour (V2) (3.38%). The lowest solubility was observed in control water yam flour (T1) (2.54%).The increase in solubility following blanching may be attributed to starch gelatinization and breakdown of molecular structures during heat treatment, resulting in the release of soluble carbohydrates and proteins. Fermentation also slightly increased solubility compared with the control due to enzymatic hydrolysis of starch and cell wall polysaccharides. Higher solubility improves the ease of reconstitution, digestibility, and suitability of flour for infant foods, beverages, and instant food formulations. Similar findings have been reported by Otegbayo et al. (2018), Chinenye et al. (2022), and Oluwalana et al. (2020), who observed increased solubility following thermal and biological processing of yam flours.

Overall, the processing methods significantly ($p < 0.05$) influenced the functional characteristics of the yam flours. Fermentation generally improved bulk density, while blanching enhanced oil absorption capacity and solubility. In contrast, the untreated control samples retained superior water absorption and swelling capacities. These findings demonstrate that processing techniques modify the physicochemical characteristics of yam starch and proteins, thereby affecting the suitability of the flour for different food applications. From an industrial perspective, fermented yam flour may be more appropriate for products requiring compact packaging and improved flour density, whereas blanched flour may be better suited for bakery products and flavour-rich formulations because of its higher oil absorption and solubility. Control flour, with its superior water absorption and swelling characteristics, would be advantageous in traditional foods such as pounded yam, thick porridges, and soup thickeners. The results corroborate previous studies indicating that varietal differences and processing methods are major determinants of the functional properties of yam flour (Falade & Okafor, 2015; Otegbayo et al., 2018; Awolu et al., 2021; Chinenye et al., 2022).

Table 3: Rheological Properties of Yam Flours

Parameters	T_1	T_2	T_3	U_1	U_2	U_3	V_1	V_2	V_3
Volumetric flow rate (m/s)	$1.21^{a} \pm 0.02$	$1.11^{a} \pm 0.03$	$1.09^{a} \pm 0.01$	$1.22^{g} \pm 0.02$	$1.14^{d} \pm 0.01$	$1.10^{b} \pm 0.02$	$1.23^{h} \pm 0.03$	$1.15^{e} \pm 0.02$	$1.12^{c} \pm 0.01$
Viscosity (g·s/m²)	$0.73^{a} \pm 0.01$	$0.78^{d} \pm 0.02$	$0.75^{b} \pm 0.01$	$0.75^{b} \pm 0.02$	$0.79^{f} \pm 0.01$	$0.77^{e} \pm 0.02$	$0.74^{c} \pm 0.01$	$0.76^{e} \pm 0.01$	$0.76^{c} \pm 0.02$
Mass flow rate (g/s)	$0.68^{c} \pm 0.01$	$0.67^{b} \pm 0.02$	$0.66^{c} \pm 0.01$	$0.68^{b} \pm 0.01$	$0.67^{a} \pm 0.01$	$0.66^{b} \pm 0.02$	$0.67^{b} \pm 0.01$	$0.68^{a} \pm 0.01$	$0.66^{b} \pm 0.02$
Specific volume (mL/g)	$0.93^{a} \pm 0.01$	$0.93^{f} \pm 0.01$	$0.92^{b} \pm 0.02$	$0.93^{b} \pm 0.01$	$0.92^{h} \pm 0.01$	$0.92^{d} \pm 0.02$	$0.93^{c} \pm 0.01$	$0.92^{i} \pm 0.01$	$0.93^{g} \pm 0.02$
Specific weight (g/mL)	$0.09^{f} \pm 0.00$	$0.09^{a} \pm 0.00$	$0.09^{c} \pm 0.00$	$0.09^{e} \pm 0.00$	$0.09^{b} \pm 0.00$	$0.09^{e} \pm 0.00$	$0.09^{d} \pm 0.00$	$0.09^{a} \pm 0.00$	$0.09^{d} \pm 0.00$

Values are expressed as Mean ± Standard Deviation of triplicate determinations (n = 3). Means within the same row with different superscript letters differ significantly ($p < 0.05$), while means with the same superscript are not significantly different.

Key

- T1 – Control Water Yam Flour
- T2 – Blanched Water Yam Flour
- T3 – Fermented Water Yam Flour
- U1 – Control Aerial Yam Flour
- U2 – Blanched Aerial Yam Flour
- U3 – Fermented Aerial Yam Flour
- V1 – Control White Yam Flour
- V2 – Blanched White Yam Flour
- V3 – Fermented White Yam Flour

3.2 The rheological properties of yam flours

The rheological properties of yam flours produced from water yam (Dioscorea alata), aerial yam

(Dioscorea bulbifera), and white yam (Dioscorea rotundata) processed by different techniques (control, blanching, and fermentation) are presented in Table 3. Rheological properties are important quality attributes that determine the flow behavior, consistency, handling characteristics, and suitability of flour for various food applications. The observed variations among the samples indicate that both yam variety and processing technique significantly ($p < 0.05$) influenced the rheological characteristics of the flour.

The volumetric flow rate ranged from 1.09 to 1.23 m/s, with the highest value observed in control white yam flour (V1, 1.23 ± 0.03 m/s), closely followed by control aerial yam flour (U1, 1.22 ± 0.02 m/s) and control water yam flour (T1, 1.21 ± 0.02 m/s). The lowest value was recorded for fermented water yam flour (T3, 1.09 ± 0.01 m/s). The reduction in volumetric flow rate following fermentation may be attributed to enzymatic degradation of starch granules and partial hydrolysis of polysaccharides during microbial fermentation, resulting in increased cohesiveness and reduced flowability of the flour particles. Blanching also reduced flow rate but to a lesser extent than fermentation. Similar reductions in flow characteristics after fermentation have been reported by Oluwalana et al. (2018), Ijarotimi et al. (2021), and Adebo et al. (2020), who attributed these changes to modifications in starch structure and particle interactions. The relatively higher flow rates observed in the control samples indicate better free-flowing characteristics, which are desirable during industrial handling, packaging, and transportation of flour.

Viscosity values varied from 0.73 to 0.79 g·s/m². The highest viscosity was obtained in blanched aerial yam flour (U2, 0.79 ± 0.01 g·s/m²), whereas control water yam flour (T1, 0.73 ± 0.01 g·s/m²) exhibited the lowest value. The increase in viscosity after blanching could result from partial starch gelatinization and structural reorganization during heat treatment, which enhances the water-binding ability of starch molecules. Heat processing causes starch granules to swell, increasing paste viscosity during hydration. Fermentation produced intermediate viscosity values because microbial enzymes partially hydrolyzed starch, reducing the extent of molecular interactions responsible for paste thickening. These findings agree with those reported by Hoover (2010), Srichuwong et al. (2017), and Falade and Okafor (2020), who observed that thermal treatments generally increase flour viscosity, whereas fermentation moderates viscosity through starch degradation.Higher viscosity is advantageous in food products requiring thick consistency such as pounded yam flour, sauces, soups, and complementary foods because it contributes to desirable mouthfeel and product stability.

Mass flow rate ranged between 0.66 and 0.68 g/s, with only slight variations among the flour samples. Control water yam flour (T1) and blanched white yam flour (V2) recorded the highest values (0.68 g/s), while fermented samples generally showed slightly lower values (0.66 g/s).The relatively narrow range indicates that processing methods had only minor effects on the mass transfer characteristics of yam flour. However, the slight reduction observed after fermentation could be attributed to changes in flour particle size, moisture distribution, and increased cohesiveness resulting from microbial metabolism. These findings corroborate those of Kadan et al. (2015) and Adegunwa et al. (2019), who reported that processing-induced structural modifications affect powder flow behavior without causing substantial changes in mass flow rate.The uniformity of mass flow across treatments suggests that all flour samples possess acceptable handling properties suitable for commercial processing.

Specific volume ranged from 0.92 to 0.93 mL/g, indicating minimal variation among the processed flours. Control samples generally exhibited slightly higher specific volume than fermented samples. The slight decrease observed after fermentation may be associated with increased particle packing resulting from degradation of cellular materials during microbial activity. Reduced particle size enhances packing efficiency and consequently lowers specific volume. These findings agree with reports by Sefa-Dedeh and Afoakwa (2018) and Otegbayo et al. (2020), who found that fermentation often produces denser flour particles with lower specific volume. Although the differences were statistically significant

($p < 0.05$), they are relatively small and unlikely to adversely affect flour functionality during product formulation.

Specific weight remained virtually constant (0.09 g/mL) across all samples, although statistical analysis detected significant differences among treatments due to the low experimental variability. The uniformity of specific weight suggests that processing methods had negligible influence on the density characteristics of yam flour. Similar observations have been reported by Adebowale et al. (2017) and Iwe et al. (2018), who noted that flour density is primarily influenced by particle composition rather than moderate processing treatments. Stable specific weight is advantageous because it ensures consistency during flour packaging, transportation, and formulation calculations in food processing industries.

Overall, the results demonstrate that processing techniques significantly influenced the rheological behavior of yam flours. Fermentation generally reduced volumetric flow rate and specific volume while moderately affecting viscosity and mass flow rate. Blanching tended to increase viscosity, probably because of partial starch gelatinization. Among the yam varieties, white yam generally exhibited superior flow characteristics, while aerial yam produced flour with relatively higher viscosity following blanching. These rheological modifications are important because they influence mixing characteristics, reconstitution behavior, dough formation, cooking quality, and consumer acceptability. The results therefore suggest that appropriate processing techniques can be employed to tailor yam flour for specific food applications such as instant flour products, bakery formulations, traditional stiff dough "amala", and complementary foods.

Table 4: Sensory Evaluation Scores of Yam Flour Samples

Parameters	T_1	T_2	T_3	U_1	U_2	U_3	V_1	V_2	V_3
Colour	$5.20^c \pm 0.24$	$2.20^e \pm 0.18$	$8.50^a \pm 0.16$	$1.80^e \pm 0.15$	$2.10^e \pm 0.20$	$3.60^d \pm 0.22$	$6.10^b \pm 0.19$	$4.00^d \pm 0.25$	$8.20^a \pm 0.18$
Taste	$7.00^a \pm 0.21$	$4.40^b \pm 0.26$	$8.20^a \pm 0.17$	$2.40^c \pm 0.15$	$4.30^b \pm 0.22$	$6.60^a \pm 0.20$	$6.90^a \pm 0.19$	$6.90^a \pm 0.21$	$7.90^a \pm 0.16$
Texture	$7.90^b \pm 0.18$	$4.80^c \pm 0.23$	$8.40^a \pm 0.15$	$2.50^d \pm 0.18$	$4.70^c \pm 0.19$	$6.60^b \pm 0.20$	$7.70^b \pm 0.17$	$8.20^a \pm 0.14$	$7.30^b \pm 0.20$
Flavour	$5.70^c \pm 0.22$	$5.00^c \pm 0.19$	$7.90^a \pm 0.15$	$3.50^d \pm 0.21$	$3.50^d \pm 0.18$	$5.40^c \pm 0.20$	$6.20^b \pm 0.17$	$5.80^c \pm 0.21$	$7.10^a \pm 0.16$

Values are expressed as Mean ± Standard Deviation of triplicate determinations ($n = 3$). Means within the same row with different superscript letters are significantly different ($p < 0.05$), whereas means with the same superscript are not significantly different.

Key
- T1 – Control Water Yam Flour
- T2 – Blanched Water Yam Flour
- T3 – Fermented Water Yam Flour
- U1 – Control Aerial Yam Flour
- U2 – Blanched Aerial Yam Flour
- U3 – Fermented Aerial Yam Flour
- V1 – Control White Yam Flour
- V2 – Blanched White Yam Flour
- V3 – Fermented White Yam Flour

3.3 The sensory attributes of yam flour

The sensory attributes of yam flour samples prepared from water yam, aerial yam, and white yam processed using different techniques are presented in Table 4. Sensory quality remains one of the most important determinants of consumer preference and market acceptance because it directly influences purchasing decisions. The attributes evaluated included colour, taste, texture, and flavour.

Colour scores ranged from 1.80 to 8.50, with the highest score recorded for fermented water yam flour (T3, 8.50 ± 0.16), closely followed by fermented white yam flour (V3, 8.20 ± 0.18). The lowest score was observed in control aerial yam flour (U1, 1.80 ± 0.15).The superior colour ratings of fermented samples may be attributed to enzymatic reactions during fermentation that produced a more appealing cream colour while reducing enzymatic browning. Fermentation also improves colour uniformity by reducing undesirable pigments. Conversely, aerial yam generally received lower colour scores, probably because of its naturally darker flesh and greater susceptibility to enzymatic browning. These observations are consistent with findings reported by Otegbayo et al. (2018), Falade and Okafor (2020), and Oluwalana et al. (2019), who reported improved colour acceptability of fermented yam products.

Taste scores ranged from 2.40 to 8.20. Fermented water yam flour (T3) recorded the highest score (8.20 ± 0.17), while control water yam (T1), fermented aerial yam (U3), control white yam (V1), blanched white yam (V2), and fermented white yam (V3) also received high ratings. The lowest taste score occurred in control aerial yam flour (U1, 2.40 ± 0.15). Fermentation significantly enhanced taste due to microbial production of desirable flavour compounds and reduction of bitter phytochemicals. The process also decreases anti-nutritional compounds such as oxalates and tannins that may contribute to undesirable taste. These findings agree with Adebo et al. (2020), Ijarotimi et al. (2021), and Ogunsakin et al. (2023), who reported that fermentation considerably improves the palatability of root- and cereal-based foods.

Texture scores varied from 2.50 to 8.40, with the highest value recorded for fermented water yam flour (T3, 8.40 ± 0.15) followed by blanched white yam flour (V2, 8.20 ± 0.14). Improved texture in fermented samples may result from partial breakdown of starch and cell-wall components, producing smoother and more cohesive reconstituted products. Blanching also improved texture through partial starch gelatinization. These observations agree with reports by Adegunwa et al. (2019), Otegbayo et al. (2020), and Srichuwong et al. (2017), who found that fermentation and heat treatments improve the textural characteristics of yam flour products.

Flavour scores ranged between 3.50 and 7.90. Fermented water yam flour (T3) received the highest score (7.90 ± 0.15), followed by fermented white yam flour (V3, 7.10 ± 0.16). The lowest flavour ratings were observed for control and blanched aerial yam flours (3.50 ± 0.21 and 3.50 ± 0.18, respectively). The improved flavour observed after fermentation is associated with the production of volatile aromatic compounds including organic acids, aldehydes, alcohols, and esters, which enhance overall sensory quality. Fermentation also masks undesirable earthy flavours naturally present in yam tubers. These findings support those of Steinkraus (2018), Adebo et al. (2020), and Ogunsakin et al. (2023), who reported that fermentation substantially improves aroma and flavour development in traditional fermented foods.

The sensory evaluation clearly demonstrates that fermentation produced the most acceptable yam flour, particularly for water yam (T3) and white yam (V3). These samples consistently received the highest scores for colour, taste, texture, and flavour. In contrast, aerial yam flour generally exhibited lower sensory acceptability irrespective of processing method, although fermentation considerably improved its quality compared with the untreated sample. The results indicate that fermentation is the most effective processing technique for enhancing consumer acceptability of yam flour because of its ability to improve flavour, reduce undesirable compounds, modify texture, and produce more attractive colour. These findings suggest that fermented water yam and fermented white yam flours possess excellent potential for commercial production of high-quality yam flour products.

IV. CONCLUSION

This study evaluated the effects of different processing techniques (blanching and fermentation) on the functional, rheological, and sensory properties of flour produced from three yam varieties, namely water yam (Dioscorea alata), white yam (Dioscorea rotundata), and aerial yam (Dioscorea bulbifera). The findings demonstrated that both yam variety and processing technique significantly ($p < 0.05$) influenced the quality characteristics of the resulting flours. The functional properties revealed that fermentation generally improved bulk density and enhanced desirable characteristics such as swelling capacity and water absorption in some yam varieties, while blanching significantly increased oil absorption capacity and solubility. Fermented water yam flour exhibited the highest bulk density (0.61 g/mL), indicating improved packing characteristics, whereas control water yam flour showed superior water absorption capacity (1.40 mL/g), and suggesting better hydration potential for food formulations. Blanched aerial and white yam flours recorded the highest oil absorption capacities (0.30 mL/g), indicating greater potential for use in flavour-retaining food products.

The rheological evaluation showed that processing methods modified the flow behaviour of the yam flours. Control samples generally exhibited higher volumetric flow rates, while blanched samples showed relatively higher viscosity, suggesting that thermal treatment enhanced starch gelatinization and increased resistance to flow. Fermentation slightly reduced viscosity and mass flow rate in most samples, which could improve ease of reconstitution during food preparation. Although variations in specific volume and specific weight were relatively small, the differences observed indicate that processing affected flour structure and particle characteristics.

Sensory evaluation further revealed that fermentation considerably improved consumer acceptability. Fermented water yam flour received the highest scores for colour (8.50), taste (8.20), texture (8.40), and flavour (7.90), while fermented white yam flour also achieved high acceptability scores across all sensory attributes. In contrast, aerial yam flour, particularly the unprocessed and blanched samples, recorded relatively lower sensory ratings, indicating that additional processing optimization may be required to improve its organoleptic quality.

Overall, fermentation proved to be the most effective processing technique for enhancing both the functional performance and sensory quality of yam flours, particularly for water yam and white yam. The study also demonstrated that water yam and white yam possess considerable potential as alternative flour sources for various food applications, thereby promoting value addition, reducing post-harvest losses, and expanding the utilization of underutilized yam varieties. Furthermore, the findings contribute valuable information for food processors, researchers, and the food industry in developing high-quality yam-based products with improved processing characteristics and consumer acceptance.

V. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are made:

1. Fermentation should be adopted as the preferred processing technique for producing yam flour because it significantly improves the functional, rheological, and sensory properties of the flour.
2. Water yam and white yam should be promoted for commercial flour production due to their superior processing performance and higher consumer acceptability.
3. Further studies should investigate the proximate composition, mineral profile, vitamin content, antioxidant properties, and anti-nutritional factors of differently processed yam flours to provide a more comprehensive nutritional evaluation.
4. Future research should evaluate the pasting properties, starch digestibility, glycemic index, and storage stability of processed yam flours for wider industrial application.
5. The suitability of these yam flours should be investigated in the production of bakery products, complementary foods, noodles, breakfast cereals, extruded snacks, and gluten-free food formulations.
6. Additional processing techniques such as microwave treatment, infrared drying, steam blanching, freeze-drying, and combined fermentation–drying methods should be explored to further improve flour quality.
7. Consumer acceptance studies involving larger and more diverse populations should be conducted to validate the market potential of processed yam flour products.
8. Government agencies, agricultural extension services, and food industries should encourage the commercialization of value-added yam

flour products to increase utilization of indigenous yam varieties, reduce post-harvest losses, improve food security, and create additional income opportunities for farmers and food processors.

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