# The Impact of Thermal and Hydration Pre-treatments on Percentage Yield, Moisture Content, and Functional Properties of *Dioscorea hirtiflora* Yam Flour

**Estomini, F.S.**

Department of Science and Laboratory Technology, Dar es Salaam Institute of Technology, P.O. Box 2958, Dar es Salaam.

*Corresponding author's email: *estominif@gmail.com*

**Abstract**

*The objective of this study was to investigate the effects of thermal (boiling) and hydration (soaking) treatments on the yield, moisture content, and selected functional properties of flour from Dioscorea hirtiflora yams. The mature tubers were cleaned, peeled, sliced, boiled at 100°C for 10-40 minutes or soaked in water (ambient temperature for 20-80 minutes). Both the processed and control (raw) samples were oven-dried, milled, and sieved to obtain flour. The results showed that both boiling and soaking significantly reduced the flour yield compared to the raw sample (25.88%). Boiling for 40 minutes reduced the yield to 18.67%, while soaking for 80 minutes reduced it further to 15.87% ($p < 0.05$ for both). Moisture content (dry basis) decreased to 7.26% after 10 minutes of boiling, but increased to 11.62% with extended soaking ($p < 0.05$), while still within acceptable limits. Water absorption capacity was significantly enhanced, reaching 293.33% (20 minutes boiling) and 283.00% (80 minutes soaking), while wettability time decreased from 574.33 s (raw) to 9.33 s (boiled) and 387.33 s (soaked) ($p < 0.05$). Bulk density significantly decreased from 0.97 to 0.61 g/mL ($p < 0.05$), with dispersibility remaining above 50% ($p > 0.05$). Compared to the raw sample, gelatinization temperature decreased by up to 8°C depending on the pre-treatment duration ($p < 0.05$), and the lowest gelation concentration remained at 4% ($p > 0.05$). Soaking increased the foaming capacity from 15.2% to 52%, whereas flour boiled for 40 minutes showed reduced foaming stability compared to raw flour. In contrast, soaking for 20 minutes-maintained foam stability at 71%. The swelling power peaked at 60°C (maximum 4.62 g/g at 40 minutes boiling), without significant changes from the pre-treatments ($p > 0.05$), and oil absorption, particularly for palm oil, increased to 213.33% ($p < 0.05$). In general, short boiling (10-20 minutes) or moderate soaking (20-40 minutes) effectively balanced the yield and functional enhancements, improving water absorption, gelatinization, and oil uptake. These results suggest that D. hirtiflora flour could be ideal for baked and gluten-free products that require controlled moisture and oil levels, enabling the development of innovative food products. Short boiling or moderate soaking is recommended to enhance flour quality; further studies should assess the nutritional and sensory qualities of the resulting products.*

***Keywords:*** Boiling, *Dioscorea hirtiflora*, Functional properties, Ming'oko, Soaking, Yam flours.

## Introduction

Yams (*Dioscorea* species) are a significant agricultural commodity worldwide, especially in tropical and subtropical areas where they are essential for food security, nutrition, and local economies (Ufondu *et al*., 2022). People value domesticated varieties for their culinary applications, while wild yams serve as essential famine foods during times of scarcity (Doka *et al*., 2016).

*Dioscorea hirtiflora*, a species of wild yam, is of significant importance in several African countries. In Tanzania, the yam is particularly important in the Lindi and Mtwara regions, where it plays a crucial role in ensuring food security during periods of scarcity (Mwanjala *et al*., 2024). Locally referred to as *"Ming'oko"* these tubers are harvested from forests and are traditionally prepared by boiling (Majule *et al*., 2010; Mwanjala *et al*., 2024). In addition to fulfilling subsistence needs, surplus tubers are sold in local markets, thereby substantially contributing to enhanced nutrition and income generation in impoverished areas (Majule *et al*., 2010. Their nutritional profile, which is rich in carbohydrates, fibres, vitamin C, and antioxidants (Mwanjala *et al*., 2024), highlights the necessity of refining processing techniques to fully exploit their food potential. Furthermore, with increasing urban demand, they are becoming more available as either raw or boiled snacks seasoned with salt and chili sauce in some local markets in Dar es Salaam city.

The transformation of yams into flour presents notable benefits compared to fresh tubers, such as prolonged shelf life and enhanced storage properties (Soro *et al*., 2020). This processed form has various applications in the culinary and industrial sectors, with pre-treatment methods such as thermal (boiling) and hydration (soaking) significantly affecting the functional properties (Otegbayo *et al*., 2024). Essential quality indicators include the water absorption capacity, bulk density, and gelation properties, which together influence the processing performance and quality of the final product quality (Makanjuola & Coker, 2019). Processing methods can enhance various traits in different types of yams (Princewill-Ogbonna & Ezembaukwu, 2015). This makes them easier to use in specific products such as gluten-free baked goods (Retnowati *et al*., 2019). For instance, after boiling, *D. praehensilis* (forest yams) can serve as a substitute for wheat flour in bread (Soro *et al*., 2020), whereas soaking a commonly cultivated yam species, *D. alata* (water yam), enhances the flavour of instant “poundo” yam (Adeola *et al*., 2012). Traditionally, native people in Lindi and Mtwara process *D. hirtiflora* tubers into "Chikandanga," a pounded product combined with manioc flour and seed additives to create a relish dish known as *"Nnabuhulile"* (Majule *et al*., 2010). However, commercial-scale processing and characterization of their functional properties remain underdeveloped.

Standard flour production includes peeling, slicing, blanching, drying, and milling (Setyawan *et al*., 2021), which are essential for reducing moisture (Wahab *et al*., 2016). Functional enhancements may increase moisture content by chance, thereby threatening storage stability (Ugwuanyi *et al*., 2020). Pre-processing yams can assist flours in achieving optimal moisture levels of less than 14% (Kasaye *et al*., 2018); however, processing typically reduces the flour yield by removing moisture and starch. For example, *D. alata* yields decrease from 29% to 19% during processing (Harijono *et al*., 2013). Current shade drying methods for *D. hirtiflora* yield a product with excessively high moisture levels exceeding 69% (fresh mass basis) (Mwanjala *et al*., 2024), which does not meet the typical criteria for flour, posing serious risks of microbial spoilage and challenges related to storage and transportation (Raji *et al*., 2022). The stigma associated with *D. hirtiflora* tubers as a "famine food" has also limited their commercial potential, despite their established traditional uses. Therefore, this study investigated the impact of pre-processing techniques (boiling and soaking) on the quality of *D. hirtiflora* flour, focusing on yield, moisture regulation, and functional properties. Optimization of these methods has the potential to enhance commercialization and contribute to food security. By integrating traditional and contemporary approaches, this study offers a sustainable framework for the utilization of this underutilized wild plant resource.

## Materials and methods

### Materials

Fresh *Dioscorea hirtiflora* tubers were obtained directly from Mbagala Rangi Tatu Market, situated in Temeke District, Dar es Salaam Region, Tanzania (Latitude 6.9196° S, Longitude 39.2667° E). Selection was based on mature yams that were harvested and brought to the market on the same day of purchase, with freshness indicators including firmness, the absence of bruising, rotting, or sprouting, and an intact outer skin (Plate 1). Tubers showing signs of immaturity (e.g., soft texture, pale or thin skin) or over-maturity (e.g., sprouting or shrivelling) were excluded. The tubers were transported from the market to the Laboratory of Food Science at the Department of Science and Laboratory Technology of Dar es Salaam Institute of Technology (DIT), Tanzania, within 2 hours under ambient conditions, ensuring that the samples arrived in good condition with minimal risk of spoilage or moisture loss. All the reagents used were of analytical grade.

**Plate 1: Sample of fresh wild yams (Dioscorea hirtiflora) tubers**

**Preparation of *D. hirtiflora* flour**

*D. hirtiflora* flour was prepared following the methods described by Songuimondenin *et al*. (2018) and Ugwuanyi *et al*. (2020), with minor modifications. Fresh yam tubers were cleaned, peeled, and sliced into 2 mm-thick pieces. The slices were divided into three groups: raw (control), boiled, and soaked. The boiled samples were further subdivided into four treatments (DhB10, DhB20, DhB30, and DhB40), each boiled for 10, 20, 30, or 40 minutes at 100°C, followed by air cooling for 20 minutes at room temperature. The soaked samples were split into four treatments (DhS20, DhS40, DhS60, and DhS80), each soaked for 20, 40, 60, or 80 minutes. All samples were dried at 60°C in oven (CARBOLITE, Serial No. 20-902317; England). for 24 hours, ground using a heavy-duty blender (Silvercrest, Model MOWHOOTB, 8000 W, China), fitted with stainless steel cross blades, at maximum rotational speed, and then sieved through a 250 µm mesh to obtain fine flour (Plate 2). The flour was stored in airtight food-grade low-density polyethylene (LDPE) bags at ambient temperature until further analysis.

**Plate 2: Samples of processed flours of wild yams (*Dioscorea hirtiflora*)**

**Determination of moisture content and percentage yield of *D. hirtiflora* flour**

The moisture content and percentage yield of flour were measured using the air oven method, and the percentage yield (% w/w) was calculated by weighing the weight (g) of flour produced per initial weight of peeled sliced yams of each sample, as described by Setyawan *et al*. (2021).

**Determination of functional properties of *D. hirtiflora* flour**

***Determination of water absorption capacity (WAC)***

The water absorption capacity (WAC) was determined following the method described by Princewill-Ogbonna and Ezembaukwu (2015), with minor modifications. Ten millilitres (10 mL) of distilled water (V1) were mixed with one gram (1 g) of the flour sample (W) in 15 mL polypropylene centrifuge tubes (conical bottom, screw cap, 17 mm diameter, 120 mm length, 1 mm thickness) and homogenized using a vortex mixer (Model G560E; Scientific Industries Inc., USA) at maximum speed for 30 seconds. The dispersions were left to stand at room temperature for 30 minutes, then centrifuged using a bench-top centrifuge (Model: NINENBO NB 6H; NINENBO, China) at 4000 rpm for 30 minutes. The volume of supernatant in the graduated cylinder was recorded (V2). The amount of water absorbed (total minus free) was multiplied by its density (1 g/ml) and converted to a percentage. The water absorption capacity was calculated using equation 1.

$$WAC = \frac{V1 - V2}{W} \times Density\ of\ water \quad (1)$$

**Determination of wettability (WET)**

The wettability of the flour samples was determined using a modified method described by Princewill-Ogbonna and Ezembaukwu (2015). One gram (1g) of flour was placed into a 25 mL graduated glass cylinder (1 cm internal diameter), and the open end was sealed with a finger. The cylinder was inverted 10 cm above a 600 mL beaker containing 500 mL of distilled water at room temperature. Upon removal of the finger, the sample was allowed to fall freely into the water. The wettability time (s) was recorded as the time taken for all flour particles to become completely wetted and submerged below the water surface.

**Determination of bulk density (BD)**

Bulk density (BD) was determined according to the methodology outlined by Asaam *et al*. (2018). A 10 g sample was carefully transferred into a 100 mL graduated cylinder, which was subsequently tapped 20 times on a laboratory bench to remove air pockets and achieve a consistent sample level. The final volume of the sample was recorded, and the bulk density was calculated using equation 2.

$$BD\ (g/ml) = \frac{Weight\ of\ sample\ (g)}{Volume\ of\ sample (ml)} \quad (2)$$

**Determination of dispersibility (DSP)**

Dispersibility (DSP) was determined using the method described by Awolu (2017). Ten grams of each sample were placed in a graduated cylinder. Then, water was added to a 100 mL mark. The mixture was shaken vigorously and allowed to stand for 3 hours. The volume of settled particles was noted, and the dispersibility was calculated using equation 3.

$$DSP(\%) = \frac{Volume\ of\ settled\ particles}{Volume\ of\ sample} \times 100 \quad (3)$$

**Determination of gelatinization temperature (GT)**

This value was determined according to the method outlined by Princewill-Ogbonna and Ezembaukwu (2015). A 10% suspension of D. hirtiflora yam flour was prepared in a test tube and heated in a boiling water bath with continuous stirring. The GT was recorded as the temperature observed 30 s after gelatinization was visually detected.

**Determination of the least gelation concentration (LGC)**

The lowest gelation concentration (LGC) was determined according to the method outlined by Kisambira *et al*. (2015). Sample dispersions at concentrations of 2, 4, 6, 8, 10, 12, and 14% (w/v) were prepared using distilled water, adjusted to a pH of 7.0 using a calibrated bench top pH meter (Bioevopeak, China) by adding 0.1 M NaOH or 0.1 M HCl dropwise under continuous stirring at room temperature and homogenized in a blender (Silvercrest, Model MOWHOOTB, 8000 W, China) at maximum speed for 2 minutes. Subsequently, 5 mL of each dispersion was transferred to three test tubes, heated to 100 °C in a water bath for one hour, and then cooled to 4 °C in an ice bath. LGC was identified as the lowest concentration at which all dispersions formed gels that remained stable and did not slip from inverted tubes.

**Determination of foam capacity (FC) and foam stability (FS)**

The foaming capacity and stability were determined using the methods described by Kisambira *et al.* (2015), with slight modification. Deionized water was used to prepare a 1% concentration of the sample, which was adjusted to pH 7.4 by adding 1.0 N NaOH and 1.0 N HCl. Subsequently, 100 mL of the concentrated suspension (V1) was blended for 4 minutes using a heavy-duty blender (Silvercrest, Model MOWHOOTB, 8000 W, China) fitted with stainless steel cross blades, at a maximum rotational speed and poured into a 250 mL graduated cylinder, and the volume of foam (V2) was immediately recorded. Thereafter, the volume of the foam was recorded after an interval of 15 minutes of standing as (VF) at room temperature for the calculation of foam stability.

Foam capacity was calculated based on equation 4.

$$(FC = \frac{V2 - V1}{V1}) \times 100 \quad (4)$$

Foam stability was calculated based on equation 5.

$$FS = (\frac{VF - V1}{V2 - V1}) \times 100 \quad (5)$$

**Determination of swelling power (SP)**

Swelling power (SP) was measured using a modified method based on the work of Awolu (2017) and Songuimondenin *et al*. (2018). One gram of each flour sample was mixed with distilled water to a total volume of 10 mL in a pre-weighed polypropylene centrifuge tubes (conical bottom, screw cap, 17 mm diameter, 120 mm length, 1 mm thickness) and stirred to form a uniform slurry. The slurry was then heated to 30 °C in a water bath for 30 minutes under constant stirring. This process was repeated for the additional samples at 45, 60, 75, and 90 °C. After heating, the tubes were dried, cooled to room temperature, and centrifuged using a bench-top centrifuge (Model: NINENBO NB 6H; NINENBO, China) at 3000 rpm for 15 minutes. The supernatant was decanted, and the swollen sediment was weighed to calculate the swelling power using the following equation 6:

$$\%\,SP = (\frac{Weight\ of\ wet\ gel}{Weight\ of\ sample}) \times 100 \quad (6)$$

**Determination of oil absorption capacity (OAC)**

The oil absorption capacity (OAC) was determined as outlined by Awolu (2017), with slight modifications. One gram (1g) of the sample (W0) was weighed into pre-weighed 15 mL polypropylene centrifuge tubes (conical bottom, screw cap, 17 mm diameter, 120 mm length, thickness 1 mm) and thoroughly mixed with 10 mL (V1) of refined sunflower oil using a vortex mixer (Model G560E; Scientific Industries Inc., USA) at maximum speed for 30 seconds. The samples were allowed to stand for 30 minutes. The sample-oil mixture was centrifuged by using a bench-top centrifuge (Model: NINENBO NB 6H; NINENBO, China) at 3000 rpm for 20 minutes. Immediately after centrifugation, the volume of free oil (supernatant) was recorded directly from a graduated centrifuge tube (V2). For each sample, the procedure was repeated for crude palm and crude coconut oils. The oil absorption capacity (ml/g of sample) was calculated using equation 7.

$$OAC = \frac{V1 - V2}{W0} \times 100 \quad (7)$$

**Statistical Analysis**

Statistical analysis was performed using one-way ANOVA ($p<0.05$) and then the Newman-Keuls test to compare the results. Results are presented as mean ± SD from triplicate analyses, analysed using GraphPad InStat software (v. 3.0).

**Results and discussion**

**Percentage yield and Moisture content**

The processing methods significantly influenced the flour yield of *D. hirtiflora*. Raw tubers showed the highest flour recovery at 25.88 ± 0.83%, while boiling for 40 minutes reduced the yield to 18.67 ± 0.68% (Table 1). Soaking for 80 minutes further decreased it to 15.87 ± 0.87% ($p<0.05$; Table 2). These reductions align with findings in other wild yam species, such as *D. esculenta* (Chinese yam) and *D. bulbifera* (aerial yam) where boiling and soaking cause losses of soluble solids (Xiao *et al*., 2017; Setyawan *et al*., 2021). In this study, factors such as maturity, varietal traits, and environmental conditions were kept consistent across all samples; however, these factors are well-documented in the literature to significantly influence yield variations among yam species or growing locations (Sanful & Engmann, 2016; Quintana *et al*., 2023). In contrast, cultivated yams (*D. rotundata* and *D. alata*) tend to achieve higher flour recoveries (19–29%) (Harijono *et al*., 2013; Pushpakumara *et al*., 2024). The comparatively lower flour yields of *D. hirtiflora* (15.87–25.88%) resulting from processing establish a basis for enhancing its application in value-added food products.

The moisture content also varied with processing methods; raw flour contained 11.16 ± 0.03%, which decreased to 7.26 ± 0.03% following blanching (DhB10; Table 1) and to 10.24 ± 0.22% after short soaking (DhS20; Table 2). Blanching causes greater moisture loss due to thermal modification of starch/protein matrices and evaporation (Adejumo, 2013; Ojinnaka *et al*., 2017), while soaking reduces moisture through solubilization effects (Quintana *et al*., 2023). Extended boiling and soaking increased moisture content, likely due to enzymatic carbohydrate breakdown and environmental water uptake after drying (Raji *et al*., 2022). The moisture content of *D. hirtiflora* flour (7.26-11.62%) is comparable to that of *D. dumetorum* (bitter yam 8.57-12.86%) (Ugwuanyi *et al.,* 2020), *D. bulbifera* (aerial yam 9.47-9.91%) (Ojinnaka *et al*., 2017), and *D. rotundata* (white yam 8.83-9.67%) (Adejumo, 2013), but higher than that of *D. opposita* (Chinese yam 4.32-5.39%) (Quintana *et al*., 2023). Despite its slightly higher moisture content, it remains below the Codex Alimentarius Commission's 12-13% safe storage threshold ensuring stability for transportation and processing (Carter *et al*., 2015; Retnowati *et al*., 2019).

**Functional Properties of *D. hirtiflora* Yam Flour**

The functional properties of flour refer to the attributes that influence its behaviour during processing, storage, and preparation, ultimately determining the quality and consumer acceptance of the final product. These characteristics are essential in assessing the potential applications of food ingredients across various product formulations (Duru *et al*., 2018). In the present study, the functional properties assessed include water absorption capacity, oil absorption capacity, swelling power, gelatinization temperature, least gelation concentration, bulk density, wettability, dispersibility, foam capacity, and foam stability. The subsequent sections present and discuss the results for each of these parameters.

**Water Absorption Capacity**

Boiling significantly enhanced the water absorption capacity (WAC) of *D. hirtiflora* flour, reaching 293.03 ± 5.07% after 20 minutes (DhB20; Table 1), compared to raw flour (193.33 ± 3.77%; Table 1), likely due to starch gelatinization (Chimphepo *et al*., 2021). Similar increases have been reported in other yam species such as *D. cayenensis-rotundata* (white yam) and *D. bulbifera* (aerial yam) (Daouda *et al*., 2014; Princewill-Ogbonna & Ezembaukwu, 2015). The WAC of *D. hirtiflora* also exceeded that of *D. praehensilis* (forest yam; 178.8%), *D. bulbifera* (149%), and wheat flour (161%), the latter commonly used as a reference due to its global importance and well-characterized functional properties (Princewill-Ogbonna & Ezembaukwu, 2015; Ajani *et al*., 2016; Songuimondenin *et al*., 2018). The high WAC of *D. hirtiflora* flour therefore indicates promising application in moisture-demanding products such as thickened soups, sauces, and gravies (Eke-Ejiofor, 2015; Khemthong *et al*., 2024).

Soaking treatments resulted in an increase in WAC to 283.00 ± 2.00% after 80 minutes (DhS80; Table 2), which can be attributed to the gradual hydration of starch (Chandra *et al*., 2015; (Duru *et al*., 2018). Similar trends have been observed in *D. dumetorum* and *D. rotundata* (Abiodun *et al*., 2013; Adejumo, 2013). Enhanced WAC contributes to improved dough handling, crumb softness, and shelf life in bakery products (Buckman *et al*., 2018), underscoring its applicability in various culinary and industrial contexts.

**Wettability**

Boiling significantly enhanced wettability of *D. hirtiflora* flour, reducing the wettability time from 574.33 ± 8.39 seconds for raw flour (Dh0) to 9.33 ± 0.58 seconds after boiling for 40 minutes (DhB40), as demonstrated in Table 1. This enhancement is attributed to alterations in the physical structure, likely due to the disintegration of starch granules, which facilitates rapid water absorption (Songuimondenin *et al*., 2018). The response of *D. hirtiflora* to boiling is less pronounced than that of other yam varieties such as *D. rotundata* and *D. dumetorum* (Makanjuola & Coker, 2019). The brief wetting time of boiled flour indicates its potential suitability for instant food applications, possibly in combination with milk (Songuimondenin *et al*., 2018).

Soaking also reduced the wettability time, from 574.33 ± 8.39 seconds to 387.33 ± 2.52 seconds after 80 minutes (DhS80), as detailed in Table 2. The increase in hydrophilic compounds resulting from hydrolysis during soaking contributes to a reduction in the wetting time (Wisaniyasa *et al*., 2015). However, soaked flour remains less suitable for reconstituted food products than boiled flour because of its relatively longer wetting time (Songuimondenin *et al*., 2018).

**Table 1: Percentage yield, moisture content, and functional properties of flour from raw and boiled wild yam *D. hirtiflora* tubers**

| Parameter | Flours | | | | |
|---|---|---|---|---|---|
| | $Dh_0$ | $DhB_{10}$ | $DhB_{20}$ | $DhB_{30}$ | $DhB_{40}$ |
| Yield % | 25.88± 0.83$^a$ | 24.88± 0.68$^{ab}$ | 23.97± 0.51$^b$ | 21.33± 0.73$^c$ | 18.67± 0.68$^d$ |
| Moisture% | 11.16± 0.03$^a$ | 7.26± 0.03$^b$ | 9.11± 0.07$^c$ | 9.08± 0.04$^c$ | 8.84± 0.05$^d$ |
| WAC % | 193.33± 3.7$^a$ | 276.67± 2.9$^b$ | 293.03± 5.1$^c$ | 265.00± 5.0$^{bd}$ | 259.00± 3.6$^d$ |
| WET (s) | 574.33± 8.4$^a$ | 15.00± 1.00$^b$ | 13.33± 1.53$^b$ | 10.00± 1.00$^b$ | 9.33± 0.58$^b$ |
| BD (g/ml) | 0.97± 0.01$^a$ | 0.97± 0.01$^a$ | 0.83± 0.01$^b$ | 0.72± 0.02$^c$ | 0.67± 0.03$^d$ |
| DSP (%) | 62.27± 0.23$^a$ | 60.80± 0.80$^{ab}$ | 59.87± 0.23$^b$ | 57.47± 0.61$^c$ | 54.00± 1.00$^d$ |
| GT (°C) | 65.33± 1.53$^a$ | 61.67± 1.53$^b$ | 60.33± 0.58$^{bc}$ | 59.33± 0.58$^{bc}$ | 58.67± 0.58$^c$ |
| LGC | 4.00± 0.00$^a$ | 4.00± 0.00$^a$ | 4.00± 0.00$^a$ | 4.00± 0.00$^a$ | 4.00± 0.00$^a$ |
| FC % | 52.00± 1.11$^a$ | 24.00± 0.96$^b$ | 16.00± 1.33$^c$ | 16.00± 1.49$^c$ | 15.2± 1.12$^c$ |

*$Dh_0$, $DhB_{10}$, $DhB_{20}$, $DhB_{30}$ and $DhB_{40}$ are flours processed by pre-boiling D. hirtiflora for 0, 10, 20, 30 and 40 minutes, respectively. WAC = Water Absorption Capacity, WET = Wettability, BD = Bulk density, DSP (%) = Dispersibility, GT = Gelation temperature, LGC = Least gelation concentration, FC = Foam capacity. Each value is an average of three replicate. Values are mean ± standard deviation. Means not sharing a similar superscript letter in a row are significantly different at (p ≤ 0.05).*

**Bulk density**

Boiling resulted in a reduction in the bulk density (BD) of *D. hirtiflora* flour from 0.97± 0.01 g/ml (Dh0) to 0.67± 0.03 g/ml (DhB40; $p < 0.05$; Table 1), attributed to modifications in the starch-protein matrix (Adejumo 2013; Kamal *et al*., 2020). Similar trends have been observed in the flours of *D. dumetorum, D. rotundata*, pigeon peas, and chickpeas (Adejumo, 2013; Abiodun & Akinoso, 2015; Akubor, 2017; Guemra *et al.*, 2024). Conversely, the BD of *D. praehensilis* increases after boiling (Songuimondenin *et al*., 2018), a phenomenon ascribed to variables such as measurement method, particle morphology, and starch polymer properties (David *et al*., 2015; Akubor, 2017; Makanjuola & Coker, 2019). The BD range for *D. hirtiflora* flour (0.67-0.97 g/ml) is lower than that of *D. praehensilis* (0.94-1.13 g/ml) but is comparable to *D. rotundata* (0.79-0.97 g/ml), (Falade & Omiwale, 2015), boiled cassava flour (0.86 g/ml), and other yam flours (0.97 g/ml) (Kasaye *et al*., 2018). A higher BD is a desirable characteristic for the packaging of food materials of high nutrient contents, whereas a lower BD is beneficial for complementary foods (Awolu, 2017).

Soaking reduced BD from 0.97± 0.01 g/ml (Dh0) to 0.61± 0.01 g/ml after 80 minutes (DhS80), as shown in Table 2. Adejumo (2013) attributed this to the leaching of soluble components and hydration, which softens tissues and loosens the starch. These observations align with those for cocoyam (0.77-0.90 g/ml), plantain-tiger nut (0.81-0.92 g/ml), *D. alata* (0.65-0.75 g/ml), and *D. rotundata* (0.66-0.76 g/ml) flours (Obadina *et al*., 2014; Adegunwa *et al*., 2017; Akinoso *et al*., 2021). The decreased BD enhances dispersibility and results in thinner dough, which is advantageous for food formulations intended for convalescing children (Chandra *et al*., 2015; Kasaye *et al*., 2018).

**Dispersibility**

Boiling resulted in a reduction of *D. hirtiflora* flour dispersibility from 62.27± 0.23% (Dh0) to 54.00± 1.00% (DhB40) after 40 minutes ($p \leq 0.05$; Table 1), which can be attributed to thermal expansion, starch agglomeration, and protein denaturation (Awolu, 2017; Guemra *et al*., 2024). Similar reductions observed in *D. praehensilis* suggested a species-wide effect (Songuimondenin *et al*. 2018). These values were consistent with those reported for *D.*

*alata* flour (62.83%) (Wahab *et al*., 2016). A dispersibility greater than 50% is considered high, making it suitable for dense viscous dishes and instant foods (Godfrey *et al*., 2023; Kosoko *et al*., 2023).

Soaking similarly decreased dispersibility to 53.33± 0.58% (DhS80) after 80 minutes ($p<0.05$; Table 2), this effect was less pronounced than that of boiling possibly due to starch degradation and the leaching of soluble matter (Awolu, 2017). Extended soaking has been shown to reduce dispersibility below 53.33%, potentially compromising lump-free reconstitution compared to raw flour (Awoyale *et al*., 2022).

**Gelatinization temperature**

The gelatinization temperature (GT) denotes the specific point at which starch granules experience irreversible expansion in water, lose their crystalline structure, and subsequently form a gel (Chakraborty *et al*., 2022). Upon boiling the *D. hirtiflora* flour, a significant reduction in GT was observed. This decrease is statistically significant ($p<0.05$), with the temperature dropping from 65.33 °C in raw flour (Dh0) to a range of 61.67 °C to 58.67 °C with prolonged boiling, as presented in Table 1. This phenomenon suggests that boiling disrupts the crystalline structure of starch granules, facilitating gel formation at lower temperatures (Chandra *et al*., 2015), and indicates a lack of stability in flour at elevated temperatures (Akubor, 2017). The alteration in gelatinization temperature may be attributed to an imbalance in amylose and amylopectin content (Akubor, 2014; Mary *et al*., 2017). A higher amylose content accelerates gelation because amylose gels more rapidly than amylopectin (Ojinnaka *et al*., 2017). It is plausible that heat causes amylopectin to dissolve more readily than amylose, thereby reducing the energy required to gelatinize boiled *D. hirtiflora* tuber flour.

The gelatinization temperature (GT) of *D. hirtiflora* flour decreased when pre-soaked, as indicated in Table 2. Extended soaking durations resulted in more significant reductions in GT, ranging from 63.67 °C to 56.33 °C, which were notably lower than the GT of DhS80 at 65.33 °C ($p<0.05$). This pattern aligns with the theory that soaking permits water to infiltrate the starch granules, weakening their structure and thus lowering the energy required for gelatinization (An & King, 2007). Additionally, soaking may trigger pre-gelatinization, further decreasing the onset temperature (Suzuki *et al*., 2023). However, proteins and lipids present in the flour can affect gelatinization; proteins may act as barriers, while lipids can delay granule swelling (An & King, 2007; Shao *et al*., 2023),

**Table 2: Percentage yield, moisture content, and functional properties of flour from raw and soaked wild yam *D. hirtiflora* tubers**

| Parameter | Flours | | | | |
|---|---|---|---|---|---|
| | $Dh_0$ | $DhS_{20}$ | $DhS_{40}$ | $DhS_{60}$ | $DhS_{80}$ |
| Yield % | $25.88\pm 0.83^{a}$ | $23.83\pm 0.77^{a}$ | $19.78\pm 0.64^{b}$ | $17.58\pm 0.81^{c}$ | $15.87\pm 0.87^{d}$ |
| Moisture% | $11.16\pm 0.03^{a}$ | $10.24\pm 0.22^{b}$ | $10.23\pm 0.01^{b}$ | $11.14\pm 0.1^{a}$ | $11.62\pm 0.11^{d}$ |
| WAC % | $193.33\pm 5.77^{a}$ | $210.00\pm 7.00^{b}$ | $270.00\pm 0.0^{c}$ | $275.00\pm 5.00^{c}$ | $283.00\pm 2.00^{c}$ |
| WET (s) | $574.33\pm 8.39^{a}$ | $509.00\pm 4.00^{b}$ | $429.67\pm 5.7^{c}$ | $396.00\pm 5.29^{d}$ | $387.33 \pm 2.52^{d}$ |
| BD (g/ml) | $0.97\pm 0.01^{a}$ | $0.77\pm 0.00^{b}$ | $0.72\pm 0.02^{c}$ | $0.64\pm 0.02^{d}$ | $0.61\pm 0.01^{d}$ |
| DSP (%) | $62.27\pm 0.23^{a}$ | $61.07\pm 0.46^{a}$ | $58.93\pm 0.46^{b}$ | $57.07\pm 0.46^{c}$ | $53.33\pm 0.58^{d}$ |
| GT (°C) | $65.33\pm 1.53^{a}$ | $63.67\pm 0.58^{ab}$ | $62.00\pm1.00^{b}$ | $59.00\pm1.00^{c}$ | $56.33\pm 0.58^{c}$ |
| LGC | $4.00\pm 0.00^{a}$ | $4.00\pm 0.00^{a}$ | $4.00\pm 0.00^{a}$ | $4.00\pm 0.00^{a}$ | $4.00\pm 0.00^{a}$ |
| FC % | $52.00\pm 1.11^{a}$ | $48.00\pm 2.03^{a}$ | $50.00\pm 2.11^{a}$ | $26.00\pm 1.674^{b}$ | $24.00\pm 1.25^{b}$ |

*$Dh_0$, $DhS_{20}$, $DhS_{40}$, $DhS_{60}$ and $DhS_{80}$ are flours processed by pre-soaking D. hirtiflora yams for 0, 20, 40, 60 and 80 minutes respectively. WAC = Water Absorption Capacity, WET = Wettability, BD = Bulk density, DSP (%) = Dispersibility, GT = Gelation temperature, LGC = Least gelation concentration, FC = Foam capacity. Each value is an average of three replicate. Values are mean ± standard deviation. Means not sharing a similar superscript letter in a row are significantly different at ($p \leq 0.05$).*

which explains why soaked samples showed a higher GT than boiled ones. *D. hirtiflora* flour requires a longer time to gelatinize at 56.33-63.67 °C compared to other yam species such as *D. cayensis* (yellow yam 69.4 °C), *D. rotundata* (71.5 °C), *D. alata* (76.5 °C), and *D. dumetorum* (78.1 °C) (Farhat *et al*., 1999; Alves *et al*., 2002). This lower temperature suggests reduced energy needs for cooking and processing, potentially lowering costs and cooking duration. However, it might also affect the thermal stability and gel-forming capacity of flour, influencing the texture and quality of the product (Iuga & Mironeasa, 2020; Otegbayo *et al*., 2024).

**The lowest gelation concentration (LGC)**

The lowest gelation concentration (LGC) for *D. hirtiflora* flour was 4%, a value that remained consistent across all samples and treatments, as presented in Tables 1 and 2. LGC, which specifies the minimum amount of flour necessary to form a self-supporting gel in a given volume of water, is essential for assessing thickening capacity and influencing product texture (Awoyale & Olatoye, 2023). The LGC value identified in this study aligns with that of *D. rotundata* starches, but is notably lower than those of other yam species, which range from 4% to 16% (Otegbayo *et al*., 2014; Songuimondenin *et al*., 2018). These variations may be attributed to the differing ratios of constituents such as proteins, carbohydrates, and lipids in various yam varieties (Chandra *et al*., 2015). An LGC of 4% indicates that brief boiling or soaking does not significantly alter the structure or composition of the starch responsible for gelation. The implication of the low LGC of this yam flour is that its starch may readily form gels, making it suitable for use as a thickener, stabilizer, or gelling agent in various applications in the food industry (Otegbayo *et al*., 2014).

**Foaming Capacity**

Foaming capacity (FC) is an indicator of the interfacial area generated by flour proteins, with flours exhibiting high FC producing significant air bubbles encapsulated by thin protein layers (Padhan & Panda, 2020). Boiling significantly reduced the FC of *D. hirtiflora* flour (Table 1), with values ranging from 15.2± 1.12 % (DhB40) to 24± 0.96 % (DhB10), all statistically lower than Dh0 ($p<0.05$). This reduction is attributed to heat-induced protein denaturation, which impairs foam formation and stability (Daouda *et al*. 2014). Nevertheless, *D. hirtiflora* flour demonstrated a lower FC than defatted groundnut flour (97-97.5 %) and egg white powder (97.5 %) as cited by Kisambira *et al*. (2015). Conversely, its FC is superior to that of other boiled yam species such as *D. rotundata*, *D. dumetorum, D. cayenensis, D. alata* and *D. prahensils* (Daouda *et al*., 2014; Wahab *et al*., 2016; Duru *et al*., 2018; Songuimondenin *et al*., 2018). The elevated FC of raw D. hirtiflora flour suggests its potential application in aerated foods such as ice cream and cakes, as well as non-food foaming agents (Kisambira *et al*., 2015).

Soaking also resulted in a reduction in FC with DhS60 (26± 1.674 %) and DhS80 (24± 1.25 %) significantly lower ($p < 0.05$) than Dh0 (52± 1.66%), DhS20 (48± 2.03%), and DhS40 (50± 2.11%) (Table 2). Soaked flour retained a higher FC than boiled flour, likely because soaking prevents heat-induced protein denaturation and minimizes the leaching of bioactive compounds, such as phenols, which destabilize the foam (Amon *et al*., 2014). These findings contrast with those of other yam species such as *D. bulbifera* and *D. alata* where FC increased with soaking, possibly because of differences in species, natural pH of yam flour, processing methods, and protein solubility (Kisambira *et al*., 2015; Mary *et al*., 2017). Flours with reduced FC may be suitable for non-foaming products (Wahab *et al*., 2016), such as fillers and stabilizers, or in systems where excessive foam is undesirable, such as sauces or soups.

**Foam stability**

Boiling significantly reduces the foam stability of yam flours, a crucial attribute of the product's texture and appearance. Samples DhB10 to DhB40 exhibited stability ranging from 57% to 26% after 15 minutes and approximately 25% after 60 minutes, whereas raw flour (Dh0) maintained stability for over 120 minutes (Fig. 1). Similar reductions were observed in *D. cayenensis-rotundata* and *D.*

*praehensilis* with raw flours demonstrating higher FS compared to boiled samples (Daouda *et al*., 2014; Songuimondenin *et al*., 2018). Boiling induces protein denaturation and starch gelatinization (Harijono *et al*., 2013; Songuimondenin *et al*., 2018). Native proteins in raw yam flour contribute to its enhanced foam stability compared to boiled flour, which exhibits reduced stability due to denaturation, thereby limiting its suitability for aerated food applications that require high porosity (Akubor, 2017).

Soaking treatments (Fig. 1) revealed that DhS20, DhS40, DhS60, and DhS80 had 71%, 33%, 39%, and 76% stability at 15 minutes, respectively, decreasing to 8%, 1%, 8%, and 5%, respectively, at 120 minutes. Shorter soaking periods (e.g., DhS20) better preserved the foam stability, maintaining 71% at 15 minutes and 8% at 120 minutes, making it suitable for applications requiring foam retention. This finding is consistent with studies on other yams; *D. alata* and *D. bulbifera*, where shorter soaking preserved foam stability (Amon *et al*., 2014). The ability of flour to produce stable and homogeneous foams is critical for the preparation of foods, such as cakes and confectionery (Nina *et al*. 2017).

**Swelling Power**

The swelling power (SP) of *D. hirtiflora* flour increased with extended boiling duration (10-40 minutes), reaching a maximum at DhB40 (Fig. 2). The raw flour (Dh0) demonstrated the lowest swelling values, ranging from 2.21 g/g at 90 °C to 2.67 g/g at 60 °C, likely due to the presence of intact starch granules with higher amylose content, because the higher the amylose contents the lower the swelling power (Otegbayo *et al*., 2011). Boiling enhanced the swelling power, with DhB10 and DhB20 achieving 3.65 g/g and 3.53 g/g at 60°C, respectively, further boiling (DhB30 and DhB40) resulted in increased swelling to 4.61 g/g and 4.62 g/g at 60°C, attributed to excessive gelatinization and decrease in amylose due to solubilisation (Abiodun & Akinoso, 2015; Ufondu *et al*., 2022). These observations were consistent with the findings of flour from the wild yam Dioscorea praehensilis tuber (Songuimondenin *et al*., 2018). The swelling values of *D. hirtiflora* flour (2.21-4.62 g/g) were lower than those of *D. bulbifera* (7.19%) and *D. dumetorum* (12.35%) (Sanful & Engmann, 2016; Engmann & Sanful, 2019), possibly due to species or methodological differences (Godfrey *et al*., 2023).

Soaking also influenced the swelling power

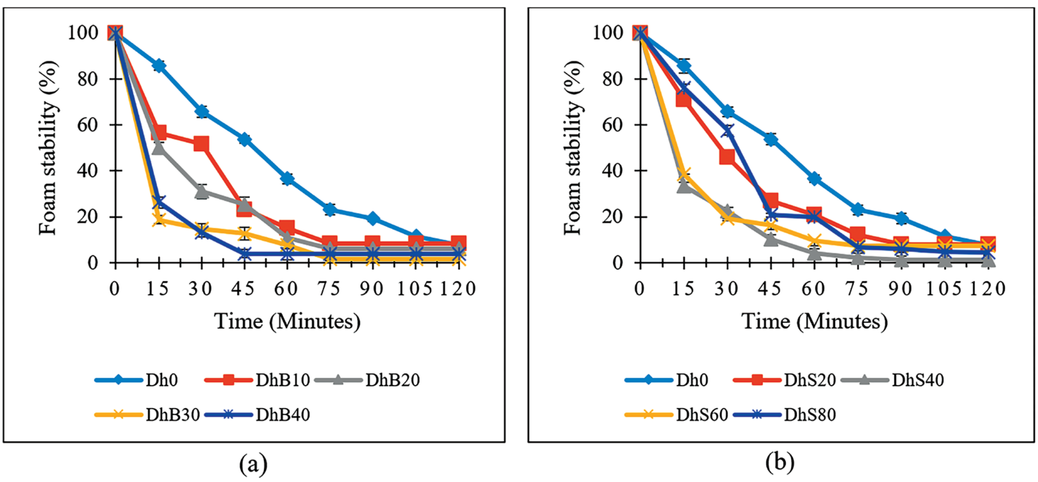


**Figure 1: Foam stability (FS) of flours from *D. hirtiflora* yam tubers (a) Flours from boiled tubers (b) Flours from soaked tubers**

*Dh0 = flour of raw tubers (control), DhB10, DhB20, DhB30 and DhB40 are flours processed by pre-boiling yams for 10, 20, 30 and 40 minutes respectively. DhS20, DhS40, DhS60 and DhS80 are flours processed by pre-soaking yams for 20, 40, 60 and 80 minutes respectively.*

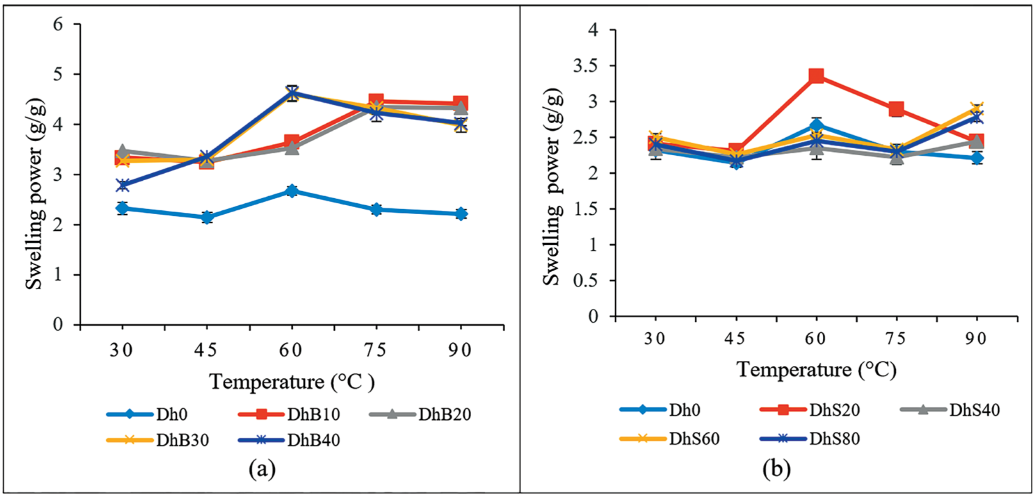


**Figure 2: Swelling power (SP) of flours from *D. hirtiflora* yam tubers at variable temperatures (a) Flours from boiled tubers (b) Flours from soaked tubers**

*Dh0 = flour of raw tubers (control), $DhB_{10}$, $DhB_{20}$, $DhB_{30}$, and $DhB_{40}$ are flours processed by pre-boiling yams for 10, 20, 30, and 40 minutes, respectively. DhS20, DhS40, DhS60, and DhS80 are flours processed by pre-soaking yams for 20, 40, 60, and 80 minutes, respectively.*

(Fig. 2). Raw flour (Dh0) achieved a maximum of 2.67 g/g at 60°C, indicating the onset of gelatinization. Brief soaking (DhS20) increased the swelling power to 3.36 g/g at 60°C, which suggested limited hydration without granule breakdown. Prolonged soaking (DhS40 to DhS80) reduced the swelling power to 2.35-2.45 g/g at 60°C, potentially due to partial starch hydrolysis and amylopectin leaching (Abiodun & Akinoso, 2015; Ufondu *et al.*, 2022). Similar patterns were observed in *D. hispida* (Indian three-leaved yam) and *D. dumetorum*, where soaking restricted swelling owing to water saturation (Okoyeuzu *et al.*, 2020). The moderate swelling power of boiled (2.35-3.36 g/g) and soaked (2.21-4.62 g/g) *D. hirtiflora* flour demonstrates its effective water absorption and binding properties, rendering it suitable for incorporation into various food products. Specifically, it can serve as a thickening agent in soups, sauces, and gravies owing to its capacity to absorb water and form a stable gel structure (Awolu & Olofinlae, 2016; Buckman *et al.*, 2018).

## Oil absorption capacity (OAC)

Pre-boiling and pre-soaking treatments significantly enhanced the oil absorption capacity (OAC) of *D. hirtiflora* yam flour. The OAC for palm oil increased from 172.50% in the raw flour (Dh0) to 213.33% after 40 minutes of pre-boiling (DhB40). For sunflower oil, the OAC ranged from 150.00% to 158.83%, while that of coconut oil ranged from 110.00% to 128.00% (Fig. 3). This improvement is attributed to the breakdown of starch and proteins during boiling, creating more hydrophobic sites for oil adherence (Kasaye *et al.*, 2018; Melese & Keyata, 2022). Statistical analysis revealed significant differences in the OAC among the three oils ($p<0.05$). Similar variations have been observed in *D. praehensilis* flour, highlighting the influence of the oil type on OAC enhancement (Songuimondenin *et al.*, 2018). The OAC of *D. hirtiflora* flour is lower than that of *D. bulbifera* (220-320%) (Princewill-Ogbonna & Ezembaukwu, 2015), but higher than that of *D. cayenensis-rotundata* (60-90%) and plantain flour (108-112%) (Daouda *et al.*, 2014; Songuimondenin *et al.*, 2018). These differences are due to the varying hydrophilic components in different yam species (Daouda *et al.*, 2014; Kosoko *et al.*, 2023), making *D. hirtiflora* suitable for high oil absorption applications.

Pre-soaking enhanced the oil absorption

capacity (OAC) of the *D. hirtiflora* flour. Palm oil OAC increased from 172.5% to 204.33% after 80 minutes (DhS80), sunflower oil from 150.00% to 202.67%, and coconut oil from 110.00% to 121.33% (Fig. 3). Soaking improves the hydration and reorganization of flour components, thereby enhancing hydrophobic site accessibility (Chandra *et al.*, 2015). Sunflower oil showed a notable increase after 20 minutes (DhS20), while additional soaking had a minimal impact on palm and coconut oils. This is linked to the higher unsaturation and lower viscosity of sunflower oil, which promote rapid absorption (Arias *et al.*, 2023). The OAC of D. hirtiflora flour, particularly palm oil, exceeds that of soaked *D. hispida* and *D. dumetorum* yams (70-179%) (Okoyeuzu *et al.*, 2020) owing to their differences in proximate composition and functional properties (Duru *et al.*, 2018; Mwanjala *et al.*, 2024). The high OAC makes *D. hirtiflora* flour suitable for applications that require oil retention, such as bakery products (desserts, doughnuts) and sausages enhancing flavour and mouthfeel (Adegunwa *et al.*, 2017; Godfrey *et al.*, 2023).

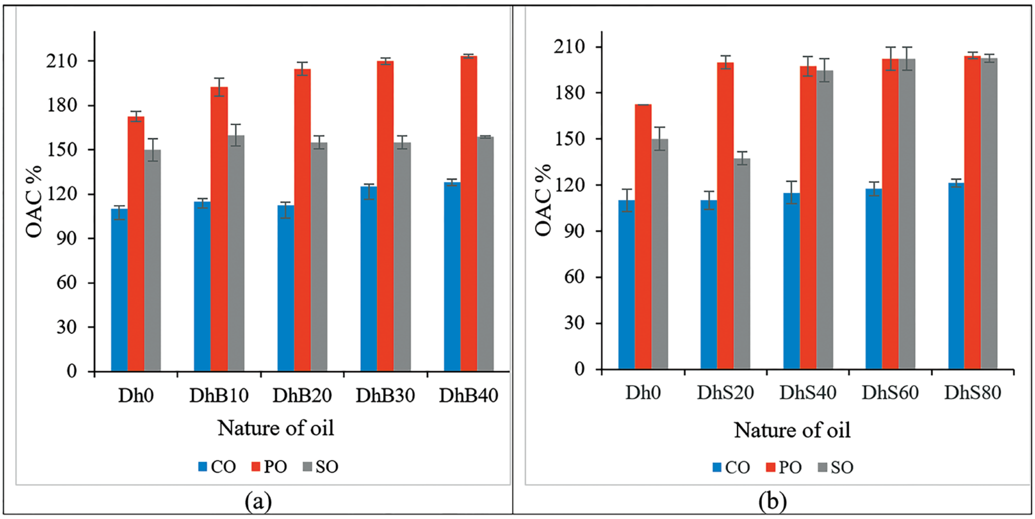


**Figure 3: Oil absorption capacity (OAC) of flours from *D. hirtiflora* yam tubers (a) Flours from boiled tubers (b) Flours from soaked tubers**

*Coconut oil (CO), palm oil (PO), sunflower oil (SO). Dh0 = flour of raw tubers (control), $DhB_{10}$, $DhB_{20}$, $DhB_{30}$, and $DhB_{40}$ are flours processed by pre-boiling yams for 10, 20, 30, and 40 minutes, respectively. DhS20, DhS40, DhS60, and DhS80 are flours processed by pre-soaking yams for 20, 40, 60, and 80 minutes, respectively.*

## Conclusions and Recommendations

The study demonstrated that thermal and hydration pre-treatments, such as boiling and soaking, significantly influence the yield, moisture content, and functional properties of *Dioscorea hirtiflora* yam flour, enabling its customized use. Boiling for a brief period (10-20 minutes) maintained yields of approximately 24% and lowered moisture to 7.26%, meeting the safe storage criteria, while extended boiling (40 minutes) reduced the yield to 18.67%. Longer soaking (80 minutes) decreased the yield to 15.87% but increased the moisture content to 11.62% due to rehydration. Both pre-treatments improved functional properties: boiling for 20 minutes increased water absorption capacity (WAC) to 293%, and soaking for 80 minutes reached 283%, making them ideal for thickening soups and sauces. Wettability was greatly enhanced by boiling (9.33 seconds), which is beneficial for instant foods, whereas soaking took 387 seconds. The bulk density was lowered (boiling: 0.67 g/ml; soaking: 0.61 g/ml), making it suitable for low-density complementary foods. The dispersibility remained above 50%, supporting the formation of viscous dishes. The gelatinization temperature dropped to 58.67°C (boiling) and 56.33°C (soaking), reducing energy needs. However, its reduced foaming capacity limits its use in aerated foods. The swelling power reached a peak of 4.62 g/g (boiling) but decreased with prolonged soaking, while oil absorption increased to 213.33% (boiled, palm oil) and to 202.67% (soaked, sunflower oil), enhancing its use in baked goods and meats. Optimal processing (10-20 minutes boiling or 20-40 minutes soaking) strikes a balance between the yield and functionality. Future studies should explore pasting behaviour, rheological properties, and sensory performance in food matrices, as well as in composite blends, to address yield losses. Overcoming the "famine food" stigma through consumer education and market trials is crucial to unlocking commercial potential, leveraging *D. hirtiflora's* nutritional and functional advantages to boost food security and economic resilience in vulnerable areas.

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**Conflict of Interest**

The author declares no conflict of interest.

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**References**

Abiodun, O.A., & Akinoso, R. (2015). Textural and sensory properties of trifoliate yam (*Dioscorea dumetorum*) flour and stiff dough 'amala'. *Journal of food science and technology,* 52, 2894-2901.

Abiodun, O.A., Akinoso, R., Oladapo, A.S., & Adepeju, A.B. (2013). Influence of soaking method on the chemical and functional properties of trifoliate yam (*Dioscorea dumetorum*) flours. *Journal of Root Crops,* 39(1): 84-87

Adegunwa, M.O., Adelekan, E.O., Adebowale, A.A., Bakare, H.A., & Alamu, E.O. (2017). Evaluation of nutritional and functional properties of plantain (Musa paradisiaca L.) and tiger nut (*Cyperus esculentus* L.) flour blends for food formulations. Cogent Chemistry, 3(1): 1383707.

Adejumo, B.A., Okundare, R.O., Afolayan, O.I., & Balogun, S.A. (2013). Quality attributes of yam flour (Elubo) as affected by blanching water temperature and soaking time. *International Journal of Engineering and Science,* 2(1): 216-221.

Adeola, A.A., Otegbayo, B.O., & Ogunnoiki, S. (2012). Preliminary studies on the development and evaluation of instant pounded yam from Dioscorea alata. *Journal of Applied Sciences and Environmental Management,* 16(3).

Ajani, A.O., Fasoyiro, S.B., Arowora, K.A., Ajani, O.O., Popoola, C.A., & Zaka, K.O. (2016). Functional properties of composite flour made from wheat and breadfruit. Applied Tropical Agriculture, 21(2): 89-93.

Akubor, P.I. (2017). Effect of processing methods on the chemical composition and functional properties of pigeon pea seed. *Asian Journal of Advances in Agricultural Research,* 2(2): 1-8.

Alves, R.M., Grossmann, M.V., Ferrero, C., Zaritzky, N.E., Martino, M.N., & Sierakoski, M.R. (2002). Chemical and functional characterization of products obtained from yam tubers. Starch-Stärke, 54(10): 476-481.

Amon, A.S., Soro, R.Y., Assemand, E.F., Dué, E.A., & Kouamé, L.P. (2014). Effect of boiling time on chemical composition and physico-functional properties of flours from taro (Colocasia esculenta cv fouê) corm grown in Côte d'Ivoire. *Journal of Food Science and Technology,* 51: 855-864.

An, H.J., & King, J.M. (2007). Thermal characteristics of ohmically heated rice starch and rice flours. *Journal of food*

*Science,* 72(1): C084-C088.

Asaam, E.S., Adubofuor, J., Amoah, I., & Apeku, O.J.D. (2018). Functional and pasting properties of yellow maize–soya bean–pumpkin composite flours and acceptability study on their breakfast cereals. Cogent Food & Agriculture, 4(1), 1501932.

Awolu, O.O. (2017). Optimization of the functional characteristics, pasting and rheological properties of pearl millet-based composite flour. Heliyon, 3(2).

Awolu, O.O., & Olofinlae, S. J. (2016). Physico-chemical, functional and pasting properties of native and chemically modified water yam (Dioscorea alata) starch and production of water yam starch-based yoghurt. Starch-Stärke, 68(7-8): 719-726.

Awoyale, W., Oyedele, H., Adenitan, A.A., Adesokan, M., Alamu, E.O., & Maziya-Dixon, B. (2022). Correlation of the quality attributes of fufu flour and the sensory and instrumental texture profiles of the cooked dough produced from different cassava varieties. *International Journal of Food Properties,* 25(1): 326-343.

Awoyale, W., Shıttu, S.O., & Olatoye, K.K. (2023). Development of Instant Wasa-Wasa from White-Fleshed Yam Tuber. Research in Agricultural Sciences, 54(3): 143-152.

Buckman, E.S., Oduro, I., Plahar, W.A., & Tortoe, C. (2018). Determination of the chemical and functional properties of yam bean (*Pachyrhizus erosus* (L.) Urban) flour for food systems. Food science & nutrition, 6(2): 457-463.

Carter, B.P., Galloway, M.T., Morris, C.F., Weaver, G.L., & Carter, A.H. (2015). The case for water activity as a specification for wheat tempering and flour production. Cereal Foods World, 60(4): 166-170.

Chakraborty, I., N, P., Mal, S.S., Paul, U.C., Rahman, M.H., & Mazumder, N. (2022). An insight into the gelatinization properties influencing the modified starches used in food industry: A review. Food and Bioprocess Technology, 15(6): 1195-1223.

Chandra, S., Singh, S., & Kumari, D. (2015). Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. *Journal of food science and technology*, 52: 3681-3688.

Chimphepo, L., Alamu, E.O., Monjerezi, M., Ntawuruhunga, P., & Saka, J.D. (2021). Physicochemical parameters and functional properties of flours from advanced genotypes and improved cassava varieties for industrial applications. LWT, 147, 111592.

Daouda, K., Koné, M.F., Martin, D.K., Soumaila, D., & Kouamé, L.P. (2014). Effect of cooking time on biochemical and functional properties of flours from yam" kponan"(*Dioscorea cayenensis-rotundata*) tubers. *British Journal of Applied Science & Technology,* 4(23): 3402.

David, O., Arthur, E., Kwadwo, S.O., Badu, E., & Sakyi, P. (2015). Proximate composition and some functional properties of soft wheat flour. *International Journal of Innovative Research in Science, Engineering and Technology,* 4(2): 753-758.

Desalegn Melese, A., & Olika Keyata, E. (2022). Impacts of Pretreatment Techniques on the quality of tuber flours. *The Scientific World Journal,* 2022(1): 9323694.

Doka, I.G., El Tigani, S., & Yagi, S. (2016). Nutritional Profile and Radical Scavenging Capacity of Tubers of Two Dioscorea Species. *Advance Journal of Food Science and Technology*, 11(3): 262-268.

Duru, FC, Uneanya, G.C., Ohaegbulam, P.O., Ochulor, D.O., & Nnaji, K.A. Effect of Cooking and Soaking on the Proximate Composition, Anti-Nutrient and Functional Properties of Bitter Yam. *International Journal of Agricultural Research and Food Production,*3(1)

Eke-Ejiofor, J. (2015). Physico-chemical and pasting properties of starches from cassava, sweet potato and three leaf yam and their application in salad cream production. *International Journal of Biotechnology and Food Science,* 3(2): 23-30.

Engmann, F.N., & Sanful, R.E. (2019). Evaluation of the physico-chemical, functional and sensory attributes of instant fufu developed from bitter yam (*Dioscorea dumetorum*). *International Journal of Food and Nutrition Research,* 3(26): 10-28933.

Falade, K.O., & Omiwale, O.O. (2015). Effect of pretreatments on color, functional and pasting properties of white (*Dioscorea rotundata*) and yellow yam (Dioscorea cayenensis) varieties. *Journal of Food Processing and Preservation*, 39(6): 1542-1554.

Farhat, I. A., Oguntona, T., & Neale, R.J. (1999). Characterisation of starches from West African yams. *Journal of the Science of Food and Agriculture,* 79(15): 2105-2112.

Godfrey, E.O., Faith, O., & Esther, I. I. (2023). Comparative Assessment of the Proximate Composition, Functional Properties and Amino Acid Profile of *Dioscorea bulbifera, Dioscorea alata* and *Dioscorea rotundata* Found in Minna, Niger State. Biology, Medicine, & Natural Product Chemistry, 12(1): 177-185.

Guemra, I., Adoui, F., Sabba, E., Ferhat, R., & Benatallah, L. (2024). Influence of Soaking, Boiling, Roasting, and Germination on the Composition and Functional Properties of Algerian Chickpea Flour, and the Consumer Acceptability of Chickpea Cheese Analogue. *Journal of Food Quality & Hazards Control,* 11(2).

Harijono, T.E., Saputri, D.S., & Kusnadi, J. (2013). Effect of blanching on properties of water yam (*Dioscorea alata*) flour. *Advance Journal of Food Science and Technology,* 5(10): 1342-1350.

Iuga, M., & Mironeasa, S. (2020). A review of the hydrothermal treatments impact on starch-based systems properties. Critical Reviews in Food Science and Nutrition, 60(22): 3890-3915.

Kamal, M.M., Ali, M.R., Shishir, M.R.I., & Mondal, S.C. (2020). Thin-layer drying kinetics of yam slices, physicochemical, and functional attributes of yam flour. *Journal of Food Process Engineering,* 43(8): e13448.

Kasaye, T., Melese, A., Amare, G., & Hailaye, G. (2018). Effect of fermentation and boiling on functional and physico chemical properties of yam and cassava flours. *Journal of Agricultural Science and Food Research*, 9(4): 1000231.

Khemthong, C., Suttisansanee, U., Chaveanghong, S., Chupeerach, C., Thangsiri, S., Temviriyanukul, P., ... & On-Nom, N. (2024). Physico-functional properties, structural, and nutritional characterizations of Hodgsonia heteroclita oilseed cakes. Scientific Reports, 14(1): 19241.

Kisambira, A., Muyonga, J. H., Byaruhanga, Y. B., Tukamuhabwa, P., Tumwegamire, S., & Grüneberg, W.J. (2015). Composition and functional properties of yam bean (*Pachyrhizus* spp.) seed flour. Food and Nutrition Sciences, 6(8): 736-746.

Kosoko, S.B., Orunaboka, W.T., & Aina, A.S. (2023). Quality Characterization of Instant Pounded Yam Flour and its Composites Using Principal Component Analysis. *Asian Food Science Journal*, 22(10): 132-146.

Majule, A.E., Liwenga, E.T., & Ndangalasi, H. J. (2010). Socio-economics of non-wood food forest products to the community in the southern coastal areas of Tanzania. Revista Română de Geografie Politică Year, 12(2): 309-328.

Makanjuola, O.M., & Coker, O.J. (2019). Assessment of sensory, functional and pasting properties of different yam cultivar flours subjected to the same processing condition. *Global Scientific Journal,* 7(10): 672-687.

Mary, B.F., Bosede, O.F., Saheed, A., & Ayobami, A.R. (2017). Effect of processing methods on the functional properties of cocoyam flour. *American Journal of Food Science and Nutrition Research,* 4(6): 203-206.

Mwanjala, T.S., Washa, W.B., & Nnungu, S.I. (2024). Nutritional Potential and Antioxidant Activity of Dioscorea spp. Tubers from Mtwara Rural District, Tanzania. *Tanzania Journal of Science,* 50(4): 765-775.

Nina, K.C.J., Ghislaine, D.C., Hubert, K.K., Patrice, A.Y.D., Patrice, K.L., & Alphonse, K. (2017). Biochemical and Functional Properties of Yam Flour during the Postharvest Conservation of Dioscorea alata Cultivar «Azaguié». *Current Journal of Applied Science and Technology,* 21(6): 1-10.

Obadina, A.O., Babatunde, B.O., & Olotu, I. (2014). Changes in nutritional composition, functional, and sensory properties of yam flour as a result of pre-soaking. Food science & nutrition, 2(6): 676-681.

Ojinnaka, M.C., Okudu, H., & Uzosike, F. (2017). Nutrient composition and functional properties of major cultivars of aerial yam (*Dioscorea bulbifera*) in Nigeria. Food Science and Quality Management, 62(1): 1-2.

Okoyeuzu, F.C., Eze, R.C., & Okoronkwo, N. C. (2020). Soaking Effects of Chips from Two Bitter Yam Species on Chemical and Functional Compositions of the Flour. *American Journal of Food Science and Technology*, 8(4): 161-165.

Otegbayo, B.O., Tanimola, A.R., Ricci, J., & Gibert, O. (2024). Thermal properties and dynamic rheological characterization of dioscorea starch gels. Gels, 10(1): 51.

Otegbayo, B., Bokanga, M., & Asiedu, R. (2011). Physicochemical properties of yam starch: Effect on textural quality of yam food product (pounded yam). *Journal of Food, Agriculture & Environment*, 9(1): 145-150.

Otegbayo, B., Oguniyan, D., & Akinwumi, O. (2014). Physicochemical and functional characterization of yam starch for potential industrial applications. Starch-Stärke, 66(3-4): 235-250.

Princewill-Ogbonna, I., & Ezembaukwu, N. (2015). Effect of Various Processing Methods on the Pasting and Functional Properties of Aerial Yam (Dioscorea bulbifera) Flour. *British Journal of Applied Science & Technology,* 9(5): 517–526.

Pushpakumara, A.G.S.K., Wickramaarachchi, L.A., Kariyawasam, K.P., & Herath, H.M. T. (2024). Purple Yam Flour (*Dioscorea alata* Linn.) Processing and Development of Instant Pudding Mix. *Journal of Food Science and Nutrition*, 10(208): 2.

Quintana, S. E., Pérez-Mendoza, J., & Zapateiro, L.A.G. (2023). Physicochemical, Structural, and Rheological Properties of Hawthorn Yam (*Dioscorea Rotundata*) Flour. *Current Research in Nutrition and Food Science Journal*, 11(3): 954-963.

Raji, A.O., Aruna, T.E., Afolayan, O.A., Sanusi, S.M., & Sani, M. (2022). Influence of fermentation period on the quality of wild yam (Discorea Villosa) flour. ASRIC *Journal on Agricultural Sciences*, 9.

Retnowati, D.S., Ratnawati, R., & Kumoro, A. C. (2019). Nutritional characteristics and potential applications of flour prepared from Indonesian wild white yam (*Dioscorea esculenta* L.). Reaktor, 19(2): 43-48.

Sanful, R.E., & Engmann, F.N. (2016). Physico-chemical and pasting characteristics of flour and starch from aerial yam. *American Journal of Food Science and Nutrition*, 3(1): 1-7.

Setyawan, N., Maninang, J.S., Suzuki, S., & Fujii, Y. (2021). Variation in the physical and functional properties of Yam (*Dioscorea* spp.) Flour produced by different processing techniques. Foods, 10(6): 1341.

Shao, Y., Jiao, R., Wu, Y., Xu, F., Li, Y., Jiang, Q., & Mao, L. (2023). Physicochemical and functional properties of the protein–starch interaction in Chinese yam. Food Science & Nutrition, 11(3): 1499-1506.

Songuimondenin, S., Martin, K.T., Siaka, B., Appolinaire, K.K., Hubert, K.K., & Parfait, K.E.J. (2018). Functional Properties of Flours from Fresh and Boiled Wild Yam *Dioscorea praehensilis* Tubers. Advances in Research, 17(3): 1-13.

Soro, S., Kouassi, K.J.D., Konan, H.K., & Kouadio, E.J. (2020). Appropriate ratio of wild yam (*D. praehensilis*) flour to add to wheat flour for bread making process. *European Journal of Biology and Biotechnology*, 1(2).

Suzuki, N., Abiko, M., Yano, H., Koda, T., Nishioka, A., & Fujita, N. (2023). Effect of shearing and heat milling treatment temperature on the crystallinity, thermal properties, and molecular structure of rice starch. Foods, 12(5): 1041.

Ufondu, H.E., Maziya-Dixon, B., Okoyeuzu, C.F., Okonkwo, T.M., & Okpala, C.O. R. (2022). Effects of yam varieties on flour physicochemical characteristics and resultant instant fufu pasting and sensory attributes. Scientific Reports, 12(1): 20276.

Ugwuanyi, C.A., Asogwa, I.S., & Ani, J.C.

(2020). The effect of boiling and soaking time on the chemical and functional properties of wild bitter yam. International *Journal of Food Science and Nutrition,* 5(4): 63-8.

Wisaniyasa, N.W., Suter, I.K., Marsono, Y., & Putra, I.K. (2015). Germination effect on functional properties and antitrypsin activities of pigeon pea (*Cajanus cajan* (L.) Millsp.) sprout flour. Food Science and Quality Management, 43, 79-83.

Xiao, H.W., Pan, Z., Deng, L.Z., El-Mashad, H.M., Yang, X.H., Mujumdar, A.S., ... & Zhang, Q. (2017). Recent developments and trends in thermal blanching–A comprehensive review. Information processing in agriculture, 4(2): 101-127.