

Evaluation of Physicochemical, Physical, Functional, and Optical Properties of Stored and Fresh Yam Tubers for Production of Quality Instant Pounded Yam Flour

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Abstract

Yam tubers are the most suitable food products closely integrated into the social, cultural, economic, and religious aspects of life. However, yams do not store well due to their perishable nature, which causes them to lose freshness and enter a dormant state rapidly. This study aims to use a single-cyclone flash dryer to produce high-quality instant pounded yam flour. As drying is a crucial method for maintaining food/agricultural produce to prevent post-harvest losses, selecting a suitable dryer is also key to producing quality flour. This study utilized a flash dryer due to its high efficiency and low energy consumption including high operating temperature (up to 200°C). The study uses white yam variety (*Dioscorea rotundata*) in two states: stored yams and fresh-harvested yams, with moisture contents of 59% and 72%, respectively. Findings from this study indicates that stored yam samples yield 29.12% more flour than fresh yam samples, indicating higher yields for food processors if stored yam is considered for IPYF production. Also, this study found that the moisture content of the samples significantly influences the flour's nutritional composition, as stored samples require lower drying temperatures than fresh yam samples. In addition, larger particle-size samples (4.5 µm) have lower moisture content post-grating, which affects the drying temperature and duration. This indicates that stored yam tubers are preferred due to their high quality and profitability. This study found that, despite the high drying temperature, the drying time is very short, helping preserve the nutritional and other essential properties of IPYF.

Keywords: Quality Flour, Post-Harvest, Energy-Efficient, Cost-Effective.

Introduction

Yams are among the most valuable tuber crops grown across almost all regions of Nigeria, particularly in the Middle Belt (Benue State). It provides sustenance for more than 180 million people (Amaefula, 2021). Yam tubers are the most suitable food products closely integrated into the social, cultural, economic, and religious aspects of life (Taylor et al., 2019). Seasonal yam tuber production provides abundant storage, making them available throughout the month (Addae, 2013; Taylor et al., 2019). However, long-term storage is

challenging as yams lose their freshness, especially moisture, and gradually approach the dormant stage (Nwogha et al., 2022; Dapaah, 2014). This occurs after 2 weeks to 6 months of storage, leading to food waste and insecurity, and requiring immediate attention (Huang, 2024; Tenadu, 2016).

Several dishes can be produced from yams, such as yam porridge or boiled, roasted, or fried yams, enjoyed with stew, vegetables, or egg sauce. Another primary staple of yams is a popular, starchy Nigerian food made by drying thinly sliced fermented yams (Yam flakes called *elubo*) with traditional sun drying or conventional dryers, then grinding them into smooth flour that is reconstituted with hot water to form a paste or gel called *Amala*. It is eaten similarly to mashed potatoes. It can be enjoyed with a variety of soups, but it is considered a delicacy when eaten with Bean soup, jute leaf, or vegetable soup. Yam flour is often consumed up to three times a day in some regions of the West African part of Nigeria. This has historically addressed issues of poverty and malnutrition.

Pounded yams, a white dough made by boiling yam tubers and pounding them with a mortar and pestle, are labor-intensive. It is a crucial staple served on special occasions and is enjoyed mostly with vegetable soups. The traditional method of pounding yams requires vital processes such as peeling, boiling, cooking, and pounding, often involving multiple people depending on the quantity of yams (Plate 1). This labor-driven process underscores the need for innovation and efficiency in food production. The incorporation of yams into daily diets, coupled with vegetables and proteins, to provide a balanced diet, has substantially resolved the issues of poverty and malnutrition among the populace.



Plate 1: Traditional Method of Yam Pounding with a Mortar and Pestle
Source: (Abulude et al., 2018)

Recent discoveries have led to the production of Instant Pounded Yam Flour (IPYF), another staple food produced from parboiled mashed yams using a high-level processing operation that includes peeling, washing, blanching, grating, drying, and packaging in a moisture-

proof material. The IPYF flour can be stored for up to six months (Otegbayo et al., 2012) and, when reconstituted with hot water, yields a porridge-like white dough like pounded yams. This has eliminated the laborious process of pounding yams. Although food processors can quickly pound cooked yams quickly, they can only serve 7 to 10 people (Olaleye et al., 2020). IPYF can serve more, but safety concerns arise from processing and drying.

Drying plays a crucial role in producing flour, including IPYF, yam flour, and high-quality cassava flour (HQCF), among other products (Jimoh et al., 2023). The use of a flash dryer (FD) stands out among conventional dryers due to its energy efficiency and the quality of dried products that is produced. The drying process eliminates food contamination and produces high-quality flour, reducing the stress associated with traditional pounding methods, which require hard labor. Adegbite et al. (2023) described the working efficiency of the flash dryer designed in their study, which has a capacity of 298kg per hour. When the dryer was used to dry cassava flour, the moisture content of the damp cassava cake was reduced from 47.06% wet basis to 9.6% dry basis. The dryer produced 186.34kg of dried product, yielding an energy efficiency of 80.8%, a specific energy consumption of 2570 kJ/kg, and an evaporated water of 4560%. These results indicate that the FD is efficient in energy consumption, reduces production costs, and is a promising dryer for enhancing the global market for cassava flour. In addition, Tran et al. (2022) stated that FD is energy-efficient and cost-effective, capable of achieving higher air velocity than a larger blower and achieving a productivity profitability of about 12%. FD is also considered most suitable due to its high operating temperature (up to 200°C) and quick drying time (Zhan et al., 2024; Acosta-Piatini et al., 2024). This may be due to the product's direct contact with a large surface area of heat and mass transfer over a very short time, leading to high drying rates and, hence, a high drying capacity (Bello et al., 2020).

Problem Statement

Factors such as limited durability, quality deterioration, inactivity during storage, the laborious process of pounding yams, and the risk of contamination should be considered to ensure food safety in the production process of instant pounded yam flour (IPYF). Selecting an appropriate type of dryer is essential for maintaining the nutritional composition of these food products during the drying process. Drying, or dehydration, is a reliable method for preserving food in a stable, storable state. However, maintaining the nutritional content and preventing prolonged drying periods or elevated drying temperatures is crucial for food quality and safety. When the flour is dried, its physicochemical, physical, and functional characteristics must closely resemble those of fresh food. This ensures that the flour is not simply consumed as a secondary product but is instead utilized to produce nutritious meals. This study investigates the physicochemical, functional, and physical properties of IPYF dried in a single cyclone flash dryer. Also, it assesses the flash dryer's operational effectiveness in producing quality IPYF. Figure 1 presents a detailed overview of the IPYF production process. The Figure provides a comprehensive assessment of the challenges

associated with yam tubers and the need to prioritize quality and safety in their processing into a stable form to produce high-quality flour using a flash dryer.

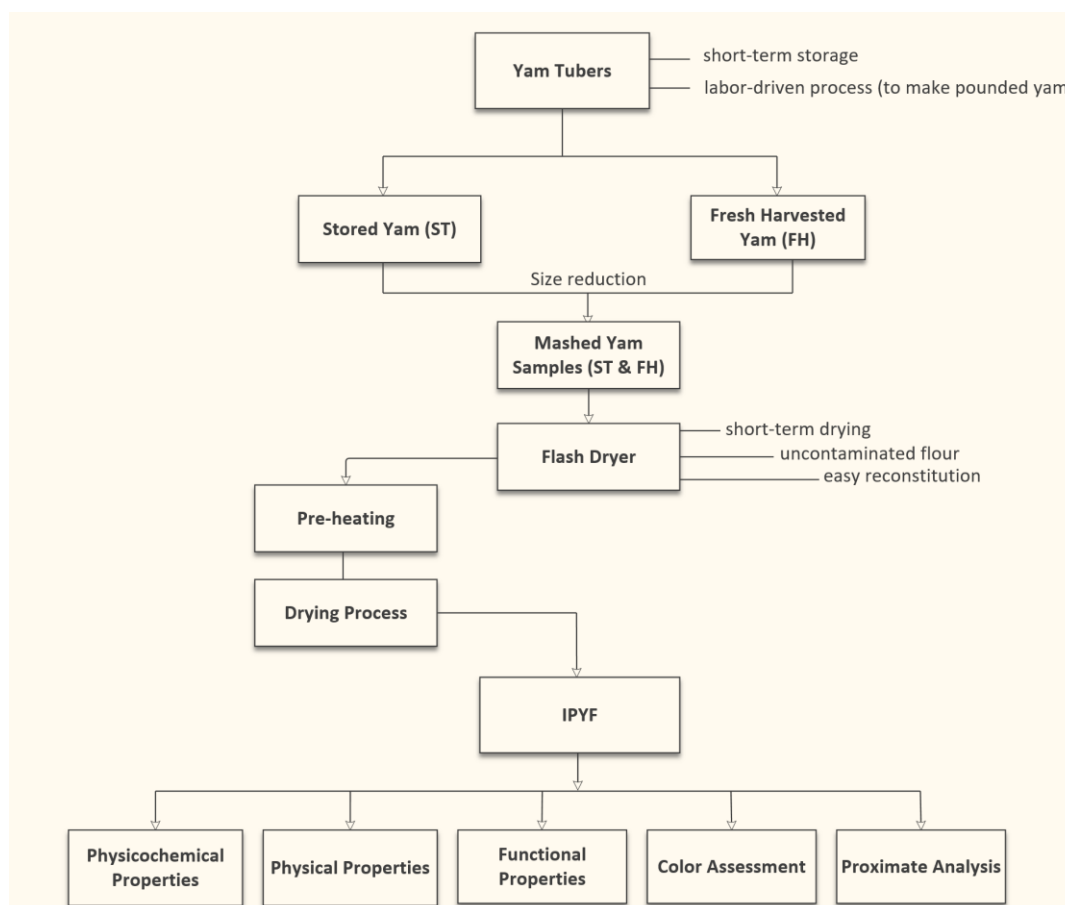


Figure 1: High-Level Overview of IPYF Quality Expectation Regarding Flash Drying

Scope of the Study

This study explores the production of IPYF using a single cyclone flash dryer to validate the traditional method of pounding yam flour. White yam tubers of two different moisture levels (i.e., stored yam and freshly harvested yam) were used to compare the nutritional composition and other important parameters. Laboratory analysis of the yam flour samples was carried out to determine quality metrics, including physicochemical, physical, functional, proximate analyses, and color assessment, to demonstrate the significance of using a flash dryer and the better option. The findings from this study will provide key guidance on the choice of the type/suitable yam tuber for IPYF production and give a recommendation for the use of a flash dryer to reduce production costs and ensure food quality.

Materials and Methods

Materials

Raw Materials for IPYF

Stored (ST) and freshly harvested (FH) white yam tubers, *Discorea rotundata* variety of 59% and 72% moisture content on a wet basis, were used in this study. The tubers were obtained in Ekiti State, South-West Nigeria. Notably, most yams used in the production of IPYF are not sourced from this region. This region was selected to assess the viability of locally cultivated yams for IPYF production and to alleviate the inconvenience of traveling long distances to obtain raw materials for IPYF processing. The yam was carefully protected from any damage or factors that could cause decay to ensure the high quality of the final product.

The Description of the Flash Dryer Used

Flash dryers (FD) are unique drying machines designed for high-moisture materials with a constant-rate drying zone at a lower operation cost than conventional dryers (Jokiniemi et al., 2011). This is because the dryer can be powered by different fuel mixtures (such as a mixture of petrol and spent oil) to reduce high fuel costs. This makes a flash dryer an efficient drying technique for high-moisture-content products, designed to minimize operational expenses. FD operates at high gas temperatures (up to 200 °C) with a large surface area, making it possible to dry the product quickly (usually 0.5 - 10 seconds) as the hot air meets the damp product. The short residence time allows minimal contact of the product with the dryer surfaces, enabling proper mixing with clean, uncontaminated drying air (Tran et al., 2022). This helps produce highly clean, safe flour with a low moisture content. The dryer operates at an inlet temperature range of ambient dehumidified air for sensitive products to above 160 – 200 °C for robust products (Baeyens et al., 1995). The evaporative cooling at the dryer's inlet allows for higher drying temperatures without overheating the product. This also helps preserve the flour's color as much as possible, just like the fresh sample. The performance of a flash dryer, however, depends on the throughput capacity, which ranges from a few kilograms per hour (kg/hr) to about hundreds of tonnes per hour (tons/hr), which is based on the product bulk density (Ray, 2023; Li et al., 2019). A cyclone, primarily a cylindrical shell divided by a conical orifice into many chambers, separates the particulate products from the spent air after the drying operation. A single cyclone FD was used in this study.

Methodology

Sample Preparation for Drying Process in a Flash Dryer

The production process of IPYF involves a direct operation, as illustrated in the flow diagram in Figure 2. Each of the FH and ST yam tubers was thoroughly cleaned with potable water to remove soil, and weighed to a precise mass of 28.5 kg each. Subsequently, they were peeled and sliced with a sharp stainless-steel kitchen knife into circular pieces 3 cm – 5 cm thick to facilitate the parboiling process.

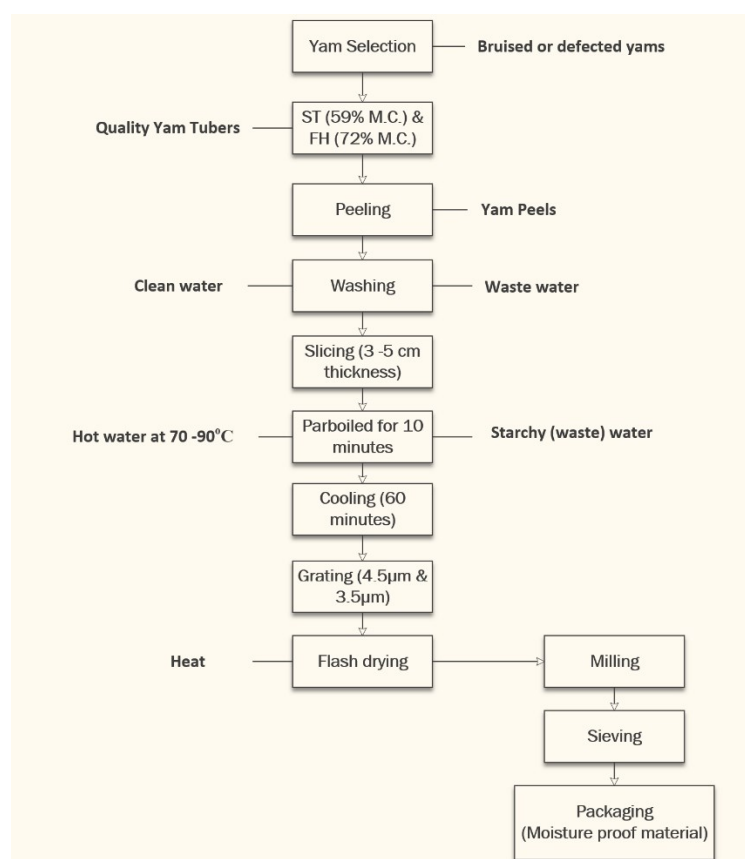


Figure 2: Instant Pounded Yam Flour Process Flow

The yam slices were parboiled in hot water at 70 to 90°C for 10 minutes to preserve their white color, reduce nutrient loss, and tenderize the tuber tissue, which helps decrease drying time. Yam tends to turn brown without this process, defeating the goal of maintaining the white color required by the IPYF. The parboiled (partially cooked) samples were cooled in an open area for about 60 minutes. Each of the ST and FH yam samples was divided into two equal portions, resulting in four samples (two from each of the 3–5cm slices of ST and FH yam). Each portion was then grated using drums with hole sizes of 3.5 µm and 4.5 µm, designated as *G*₁ and *G*₂, respectively. Next, the samples were dried using a flash dryer. The dryer comprised a heating unit, drying duct, and separator, with the heating unit including a burner and a double-pipe heat exchanger (as in Plate 2) (Kuye et al. 2011). The dryer was preheated to about 175°C to ensure consistent operation with wet samples. Each sample was fed into the preheated dryer individually, traveling through the screw conveyor and into the pneumatic tube, where hot air from the combustion chamber carried the product into the drying duct. A single cyclone separates the dried flour, and a powerful low-pressure fan removes excess moisture, ensuring sufficient resilience time. The dryer is powered by a mixture of petrol and spent oil in a 1:4 ratio (i.e., 1 part gasoline to 4 parts spent oil).



Plate 2: The Flash Dryer process showing Heat Exchanger

Each batch of the mashed samples weighing 14.25kg was introduced into the dryer, where a screw conveyor and pneumatic tube transport them in a high-velocity hot air stream, which conveys the products through a drying duct. The velocity of the heated air must be greater than the free-fall velocity of the largest particle to be dried (Ray, 2023), as shown in Figure 3. One of the features of a flash dryer is the relatively short contact duration between hot air and the product to dry (usually $0.5 - 10 \text{ seconds}$). A cyclone and bag filter separate the dried material and spent air (Trakumas et al., 2001). An adequate resilience time is ensured by utilizing a powerful low-pressure fan, which completes the removal of excess moisture from the product. The sample, after drying, was packaged in a moisture-proof material, as shown in Plate 3.

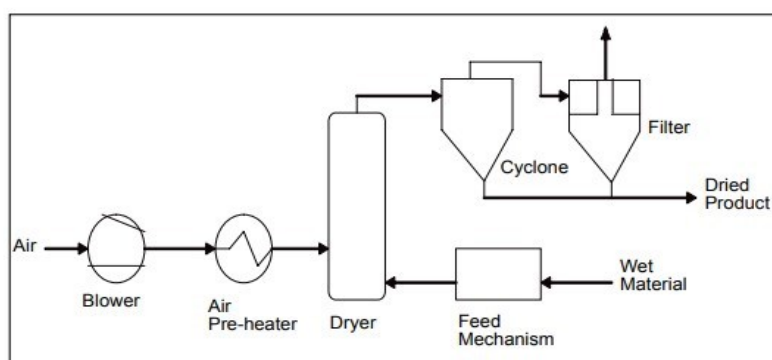


Fig. 3. The Operational System of the Flash Dryer

Source: (Kuye et al., 2011)



Plate 3: Sample of IPYF after drying

Assessment of the Physicochemical Properties of IPYF

The samples weighing 0.5 kg were analyzed for their physicochemical properties at the Anatomy Laboratory Department at the University of Ibadan, Nigeria. The chemical analysis used the procedures outlined in the methods of Aprianita et al. (2014) to evaluate moisture content, ash, crude fiber, crude fat, crude protein, and carbohydrates.

$$\%Carbohydrate = 100 - \%(MC + A + F + CF + CP) \quad (1)$$

where MC , A , F , CF , and CP were percentages of moisture content, ash, fat, crude fiber, and crude protein contents, respectively.

Determination of Physical Properties

The pasting properties of the IPYF samples were assessed using a Rapid Visco-Analyser (RVA), as outlined by AOAC (2023). The physical characteristics' standard deviation (S.D.) was calculated using the methodology of Frost (2021) as represented in Equation 2. This was conducted to assess the dataset's variability; a low standard deviation indicates that the values are closer to the mean (i.e., the expected value). Conversely, a high standard deviation indicates that the data points are dispersed across a wide range of values (Olaoye & Oyewole, 2012). This signifies that the data meets the requisite quality assurance standards.

$$SD = \sqrt{\sigma} \quad (2)$$

where S.D. is the standard deviation, and σ is the variance.

Determination of Functional Property Parameters

The bulk density was assessed utilizing the methodology established by Arise et al. (2023). An empty calibrated centrifuge was weighed to determine loose bulk density. The tube was subsequently filled with a 5 ml sample. The weight of the tube and its contents were

measured and documented. The difference was subsequently used solely to determine the sample's weight. The tube contained a 5 ml sample for bulk density assessment and was continuously monitored until a volume alteration occurred. The mass of the tube and its contents were measured and documented. The difference established the sample's weight exclusively.

Densities were calculated from the values obtained as follows:

$$\rho = \frac{W_s}{V_c} \quad (3)$$

where: ρ = density, W_s = weight of the sample and V_c = volume occupied

The IPYF samples, which consist of water and Oil absorption capacities (WAC and OAC), were determined using the modified method (Lebot et al., 2023).

Determination of Color

The color of the IPYF samples was measured with a Minolta CR-310 (Minolta Camera Co. Ltd, Osaka, Japan) tristimulus colorimeter. Before the determinations, the device was calibrated with a reference white porcelain tile ($L_o = 97.63$, $a_o = 0.31$, and $b_o = 4.63$). The color of the flours was described in L^* , a^* , and b^* values.

where: L^* represents lightness (with 0 = darkness/blackness to 100 = perfect/brightness); a^* corresponds to the extent of green color (in the range from negative = green to positive = redness); b^* represents blue in the range from negative = blue to positive = yellow.

Chemical Laboratory Analysis

The effects of particle size, drying temperature, and blanching parameters on the nutritional quality of the dried product were evaluated by analyzing the processed product for proximate composition. The proximate analysis assesses some functional properties of the sample as affected by the parameters mentioned earlier. Such properties include crude fat, protein, carbohydrate levels, and amylase.

Statistical Analysis

Quadratic programming (nonlinear multiple regression) was formulated and solved using the ANOVA 2010 package to assess proximate analysis and determine the level at which the densities affected the functional properties of the IPYF sample (if any). However, the multiple regression equations (as shown in the following equation) can be used to solve the process model.

$$Y = b_0 + b_1x_1 + b_2x_2 \quad (4)$$

where Y = food nutrition parameters are dependent variables when combining the independent variables, b_0 , b_1 , b_2 = regression coefficients, x_1 , x_2 = independent variables (such as moisture content and particle size). The variance (ANOVA) multiple regression analysis was done using Excel Solver.

Results

The results from the laboratory analysis of the IPYF are given in Tables 1 and 4, as well as in the Appendices.

Physicochemical Properties of IPYF

The physicochemical properties of the IPYF derived from FH and ST yam are detailed in Table 1, with the variance analysis provided in Appendix B-1 to B-10. The analysis of variance revealed a significant impact of the physicochemical properties on the utilized yam varieties. The crude protein data (Table 1) indicate a significant difference ($p < 0.05$) among the samples, with the ST yam sample, 4.5 μm exhibiting the highest crude protein content (2.45%). In contrast, the FH yam, 3.5 μm , displayed the lowest value (2.10%). This indicates that the ST yam sample with a greater particle size possesses a higher protein content than the FH sample. Protein is a vital nutrient, supplying the amino acids necessary for optimal body maintenance and growth. Proteins are structural constituents of tissues, blood, enzymes, hormones, and immunoglobulins (Nwakaudu et al., 2017). The maximum and minimum ash content measurements are 3.80% for FH, 4.5 μm , and 2.30% for ST yam sample, 3.5 μm .

The elevated ash level indicates that the FH sample possesses a more outstanding mineral content than the ST sample, attributable to its freshness and lack of storage treatment, in contrast to the ST sample which underwent preservation before its utilization in the production of IPYF flour. The ether extract values ranged from 0.55% (ST, 4.5 μm) to 0.37% (FH, 4.5 μm), indicating a significant difference at $P < 0.05$. Ether extract, also known as crude fat, signifies the oil content in a feed and serves as the standard metric for fat in food products (Nwachukwu & Aluko, 2021). The elevated ether extract in the stored yams signifies a higher fat content compared to the fresh yams. The crude fiber content varied from 2.60% to 2.50% for ST yam (4.5 μm and 3.5 μm) and 2.20% to 2.30% for FH yam (4.5 μm and 3.5 μm), respectively. Crude fiber quantifies the indigestible components of certain foods, including cellulose, pentosan, and lignin. Due to this fact, the high content of crude fiber (CF) in ST yam may indicate that FH yam samples with a lower value of CF content will digest more quickly than the ST yam sample. The carbohydrate level in all the samples ranges from 91.43% to 92.3%, within the recommended range for healthy growth. However, excessive consumption of carbohydrate foods can cause obesity, type II diabetes, and cancer. Yam tubers, with 70% starch content, are a good source of energy and not unhealthy.

Table 1: Physicochemical Properties of Instant Pounded Yam Flour

Sample	MC (%)	PS (μm)	CP (%)	Ash (%)	EE (%)	CF (%)	DM (%)	CHO (%)
FH (G ₂)	83.7	3.5	2.1	3.8	0.37	2.2	91.85	91.43
ST (G ₁)	83.7	4.5	2.45	2.7	0.55	2.6	93.09	91.7
ST (G ₂)	52.63	3.5	2.38	2.3	0.52	2.5	93.17	92.3
FH (G ₁)	52.63	4.5	2.14	3.2	0.4	2.3	92.2	91.96
FH (G ₂)	83.7	3.5	2.1	3.8	0.37	2.2	91.85	91.43
ST (G ₁)	83.7	4.5	2.45	2.7	0.55	2.6	93.09	91.7
ST (G ₂)	52.53	3.5	2.38	2.3	0.52	2.5	93.17	92.3

Where: MC is the moisture content, PS is the particle size, CP is the crude protein, EE is the ether extract, CF is the crude fiber, DM is the dry matter, CHO is the carbohydrate.

Physical Properties of IPYF

The physical properties of IPYF were assessed by the characteristics shown in Table 2. It indicates that the stored yam sample exhibits elevated amylose and amylopectin values of 17.69% and 36.79%, respectively, whereas the fresh yam sample displays lower values of 15.86% and 31.88%. This aligns with the findings of Mgbechidinma et al. (2023), who reported that elevated amylose/amylopectin ratios indicate type A starch, characterized by high digestibility. The elevated digestibility of certain starchy products may be significant in culinary applications, particularly for infants and the elderly, who necessitate more easily digestible foods. Samples with reduced amylose/amylopectin ratios may indicate low digestibility, potentially serving as a preventive measure against obesity, diabetes, and associated diseases when incorporated as food ingredients (Grace & Jeyakumar, 2020). The viscosity of a material is influenced by the morphology and swelling capacity of the granule, as well as the interaction between amylopectin granules (Pranoto, 2022; Nadia et al., 2014). It also signifies the water-binding capacity of the starch, occurring at the equilibrium between swelling, which increases viscosity, and alignment, which decreases it. The final viscosity reflects the material's capacity to create a viscous paste following cooking and cooling (Oluwamukomi et al., 2015). The study indicates that stored yam samples with a viscosity of 26.80% may yield a more viscous paste upon cooking than fresh yam samples with a lower viscosity. This may be due to the prolonged storage of yams, resulting in moisture loss, in contrast to fresh yam, which retains their moisture content.

The pasting temperature of the fresh yam sample is 71.8 °C, exceeding that of the stored yam, which is 67.5 °C. This indicates a substantial significance at $P \leq 0.05$. The presence of pasting properties indicates the gelatinization time during processing, particularly when it is elevated. The temperature is associated with water-binding capacity. An elevation in pasting temperature indicates an enhanced water-binding capacity of starch, attributed to the degree of association among starch granules (Batey & Curtin, 2000). The elevated pasting temperature (71.8°C) in fresh yam samples may signify superior gelatinization (i.e., water binding capacity) compared to dry yam samples with a lower pasting temperature (i.e., 67.5°C). The standard deviation (S.D.) was derived from Equation 2, as presented in

Table 2. The calculated standard deviation for all physical properties was minimal, indicating that the values fall within the anticipated range.

Table 2: Physical properties of Instant Pounded Yam flour

Sample	PS (μm)	Amylose (%)	Viscosity (%)	PC ($^{\circ}\text{C}$)	PT ($^{\circ}\text{C}$)	Solubility (%)	Amylopectin (%)
ST (G ₁)	4.5	17.69	26.8	71.2	67.5	46.85	36.79
ST (G ₂)	3.5	17.62	26.3	70.8	67.2	46.79	36.74
FH (G ₁)	4.5	15.97	23.5	68.4	71.8	42.68	31.88
FH (G ₂)	3.5	15.88	23.1	68.1	71.5	42.59	31.83
ST (G ₁)	4.5	17.67	26.7	71	67.35	46.65	36.77
ST (G ₂)	3.5	17.59	26.27	70.8	67.2	46.59	36.83
FH (G ₁)	4.5	15.95	23.5	68.2	71.6	42.48	31.64
FH (G ₂)	3.5	15.86	23.1	67.9	71.37	42.39	31.67
SD		0.89	1.62	1.41	2.13	2.10	2.51

where PS is the particle size, PC is the pasting clarity, PT is the pasting clarity, SD is the Standard deviation

Assessment of the Optical Properties of IPYF (i.e., the Color)

The optimal characteristics of the IPYF sample related to its color are shown in Table 3 and Appendix B. It presents the results of Hunter's L*a*b color analysis of the samples, indicating the lightness level of the flour. The study demonstrated that, despite the elevated drying temperature applied to the samples, the creamy color is preserved post-drying, indicating that the flash dryer effectively maintains the sample's composition. Another commercial IPYF exhibits more excellent brightness than the experimental IPYF, potentially attributable to the variety of yam tubers utilized in the experiment. Nonetheless, the nutritional attributes of the flour conform to the production standards established by the Food and Agriculture Organization for Instant Pounded Yam Flour. This refers to the sample requiring treatment with a food-grade anti-browning agent that is safe for health and can achieve a whiter hue. The procedure outlined by Xu et al., (2021); Naskar et al., (2022); Nanam et al., (2011) indicates that "the yam sample intended for processing into IPYF should be pre-heated with sodium meta-bisulfite before drying to preserve the appealing whitish color of yam flour." The procedure involved peeling and washing the yams, then slicing them thinly to a 1-2 cm thickness. Immerse a 0.5% sodium meta-bisulfite solution for approximately 3 minutes, then rinse in clean water. Parboil for a designated duration, grate using a 4.5 μm grater, and dry in a flash dryer. The study determined that moisture content, reflecting the harvest and storage duration of yam tubers (whether fresh or stored), significantly influences the functional properties of instant pounded yam flour. The fresh yam sample exhibited a more significant initial moisture content and a more translucent hue than the dry yam sample.

Table 3: Optical Property of the IPYF Produced

Sample	PS (μm)	% L	A (Yellowishness)%	B (Blueish)%	Dispersibility (%)
FH(G ₁)	4.5	61.20	14.80	2.30	81.74
FH(G ₂)	3.5	60.80	14.30	1.80	81.68
FH(G ₁)	4.5	56.30	56.30	3.40	81.71
FH(G ₂)	3.5	56.10	56.10	2.70	81.63
ST(G ₁)	4.5	61.20	14.80	2.30	86.39
ST(G ₂)	3.5	60.80	14.30	1.80	86.44
ST(G ₁)	4.5	56.30	56.30	3.40	81.67
ST(G ₂)	3.5	56.10	56.10	2.70	86.68

The dispersibility of a mixture in water reflects its reconstitution capability; thus, greater dispersibility correlates with superior reconstitution properties (Arise et al., 2023). This study's findings indicate that the dry yam sample, with a dispersibility of 86.44%, reconstitutes more effectively than the fresh yam, with a low dispersibility of 81.63%. The dry yam may have been stored for an extended period before its conversion into yam flour, resulting in moisture loss, in contrast to freshly harvested tubers that retain their moisture content.

Functional Properties

Loose and Packed Bulk Densities

The functional properties of the sample are shown in Table 4, while the ANOVA Tables are shown in Appendix B7 and 8. The result shows that the loose bulk density of the yam flour samples varied from 0.4239 *g/ml* to 0.4128 *g/ml* for fresh and stored yam, respectively. The packed bulk density ranged between 0.5411 *g/ml* and 0.5273 *g/ml* for fresh and stored yam samples. The difference observed in bulk density value is found to be insignificant. Bulk density indicates the relative volume of packaging materials required, which is suitable for greater ease of dispersibility and paste thickness reduction, especially if it is of increased size. On the other hand, low bulk density flours are good physical qualities for determining transportation and storability due to their easy handling. This result, therefore, showed that flour with high bulk density should be used where such properties are required.

Table 4: Functional property parameters of Instant Pounded Yam Flour

Sample	Loose bulk density (g/ml)	Packed bulk density (g/ml)	WAC(g/100g)	OAC(g/100g)	SP(g/g)
FH(G ₁)	0.4239	0.5407	165	83	15.10
FH(G ₂)	0.4236	0.5411	162	86	15.3
ST(G ₁)	0.4128	0.5269	176	95	18.6
ST(G ₂)	0.4125	0.5273	173	92	18.4
FH(G ₁)	0.4239	0.5407	165	83	15.10
FH(G ₂)	0.4236	0.5411	162	86	15.3

Sample	Loose bulk density (g/ml)	Packed bulk density (g/ml)	WAC(g/100g)	OAC(g/100g)	SP(g/g)
ST (G ₁)	0.4128	0.5269	176	95	18.6
ST (G ₂)	0.4125	0.5273	173	92	18.4

The statistical analysis indicates that these differences were insignificant at $P \leq 0.01$. Simultaneously, the packed bulk density of approximately 0.53 g/ml for fresh harvest yam aligns with the findings of Olumurewa & Alejolowo (2020). In contrast, the loose bulk density of 0.4125 g/ml for stored yam contrasts with the 0.60 g/ml reported by the same authors. Olaoye & Oyewole (2012) documented a packed bulk density of 0.62 g/ml for white yam flour, contrasting with the experimental value of 0.541 g/ml and a loose bulk density of 0.412 g/ml, in opposition to the 0.74 g/ml reported by (Hung & Morita, 2005). The observed variations in the results may be attributed to the differences in the state or form of the tubers utilized (fresh versus stored yam tubers). Factors including age, variety, growing season, and cultivar type of root tubers can influence the physicochemical properties (Niba et al., 2002).

Flour Yield of Instant Pounded Yam Flour Produced

The study found that stored yam samples yield 29.12% more flour than fresh yam samples, indicating that food processors prefer stored yam tubers over fresh yam tubers for instant pounded yam flour production. The samples' moisture content significantly influences the flour's nutritional composition; as stored samples require lower drying temperatures while fresh yam samples require higher temperatures due to elevated moisture content. Larger particle-sized samples (4.5 μm) have lower moisture content post-grating affecting the drying temperature and duration. This suggests that larger particle sizes of stored yams are better regarding nutritional and physical composition than fresh yam samples. This indicates that stored yam tubers are preferred for their high quality and profitability.

Conclusions and Future Work

Conclusions

The study determined that drying is a very efficient technique for keeping food products in a suitable state for long-term storage. Despite the high operational temperature, not all drying methods affect the flour's nutritional composition, as in the case of the experimental flash dryer used in this study. The flash dryer used in this study efficiently maintains the nutritional composition of the IPYF and prevents any potential contamination that may occur during the drying process. The flour yield in stored yam is better than freshly harvested tubers; this may enhance profit, especially when used commercially. Both samples of yams demonstrate enhanced physicochemical and functional properties after drying and meet the requirements established by the Food and Agriculture Organization for Instant Pounded Yam Flour.

Future Work

More yam varieties can be used to compare the nutritional characteristics. Also, taking cognizance of the actual length of storage and other environmental conditions where the yam is stored can help keep track and relate the results of the analysis in comparison with the fresh yams.

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Appendix A

Table A1: Physicochemical Properties of the IPYF Showing the ANOVA Results

		Sum of Squares	df	Mean Square	F	Sig.
Crude protein	Between Groups	.006	1	.006	.208	.664
	Within Groups	.175	6	.029		
	Total	.181	7			
Ash	Between Groups	.020	1	.020	.048	.834
	Within Groups	2.500	6	.417		
	Total	2.520	7			
Ether extract	Between Groups	.002	1	.002	.240	.642
	Within Groups	.045	6	.008		
	Total	.047	7			
Crude fiber	Between Groups	.020	1	.020	.667	.445
	Within Groups	.180	6	.030		
	Total	.200	7			

		Sum of Squares	df	Mean Square	F	Sig.
Dry matter	Between Groups	.036	1	.036	.086	.779
	Within Groups	2.535	6	.422		
	Total	2.571	7			
Cho	Between Groups	.002	1	.002	.018	.898
	Within Groups	.824	6	.137		
	Total	.827	7			

Table A2: Physical Properties of the IPYF Showing the ANOVA Results

		Sum of Squares	df	Mean Square	F	Sig.
loose_bulk_density	Between Groups	.000	1	.000	8214.000	.000
	Within Groups	.000	6	.000		
	Total	.000	7			
packed_bulk_density	Between Groups	.000	1	.000	7141.500	.000
	Within Groups	.000	6	.000		
	Total	.000	7			
WAC	Between Groups	242.000	1	242.000	80.667	.000
	Within Groups	18.000	6	3.000		
	Total	260.000	7			
OAC	Between Groups	162.000	1	162.000	54.000	.000
	Within Groups	18.000	6	3.000		
	Total	180.000	7			
SP	Between Groups	21.780	1	21.780	1633.500	.000
	Within Groups	.080	6	.013		
	Total	21.860	7			

Table A3 Functional Properties of the IPYF Showing the ANOVA Results

		Sum of Squares	df	Mean Square	F	Sig.
amylose	Between Groups	5.969	1	5.969	2423.761	.000
	Within Groups	.015	6	.002		
	Total	5.983	7			
viscosity	Between Groups	20.705	1	20.705	325.480	.000
	Within Groups	.382	6	.064		
	Total	21.086	7			
paste	Between Groups	15.680	1	15.680	392.000	.000
	Within Groups	.240	6	.040		

		Sum of Squares	df	Mean Square	F	Sig.
	Total	15.920	7			
pasting	Between Groups	36.210	1	36.210	1353.225	.000
	Within Groups	.161	6	.027		
	Total	36.371	7			
solubility	Between Groups	35.028	1	35.028	2291.938	.000
	Within Groups	.092	6	.015		
	Total	35.120	7			
Amylopectin	Between Groups	50.552	1	50.552	6597.261	.000
	Within Groups	.046	6	.008		
	Total	50.597	7			

Appendix B

The Analysis of Variance (ANOVA) of some Parameters

Table B-1. The ANOVA of multiple regression of Crude protein as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	0.180	100	0.09005	1000.6	3.10126E-07	2
Residual	0.000450	0	9E-05			5
Total	0.181	100				7

Table B-2. The ANOVA of multiple regression of Ash as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	2.020	80	1.010	10.10	0.01754	2
Residual	0.500	20	0.100			5
Total	2.520	100				7

Table B-3. The ANOVA of multiple regression of Dry matter as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	2.479	96	1.239	67.02	0.000245	2
Residual	0.09245	4	0.01849			5
Total	2.571	100				7

Table B-4. The ANOVA of multiple regression of CHO as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	2.479	96	1.239	67.02	0.000245	2

Residual	0.09245	4	0.01849			5
Total	2.571	100				7

Table B-5. The ANOVA of multiple regression of Amylose as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	5.999	100	2.999	74982.5	6.41821E-12	2
Residual	0.000200	0	4E-05			5
Total	5.999	100				7

Table B-6. The ANOVA of multiple regression of Viscosity as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	21.53	100	10.77	10765.0	8.21415E-10	2
Residual	0.00500	0	0.00100			5
Total	21.54	100				7

Table B-7. The ANOVA of multiple regression of Paste clarity as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	15.37	100	7.685	7685.0	1.90716E-09	2
Residual	0.00500	0	0.001000			5
Total	15.38	100				7

Table B-8. The ANOVA of multiple regression of Solubility as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	35.04	100	17.52	194665	5.91039E-13	2
Residual	0.000450	0	9E-05			5
Total	35.04	100				7

Table B-9. The ANOVA of multiple regression of oil absorption capacity as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	162.00	90	81.00	22.50	0.00316	2
Residual	18.00	10	3.600			5
Total	180.00	100				7

Table B-10. The ANOVA of multiple regression of water absorption capacity as a function of moisture and particle size parameters

ANOVA						
Source	SS	SS%	MS	F	F Signif	df
Regression	21.78	100	10.89	680.62	8.10214E-07	2
Residual	0.08000	0	0.01600			5
Total	21.86	100				7

Appendix C

The flour yield of Instant pounded yam flour produced was determined using the expression in equation 5:

$$Yield(\%) = \frac{W_{fd}}{W_{uy}} \quad Yield(\%) = \frac{W_{ff}}{W_{uy}} \quad (5)$$

where: W_{uy} = weight of unpeeled yam = 28.5kg

W_{fd} = weight of flour for dry yam = 8.3kg

W_{ff} = weight of flour for fresh yam = 4.7kg

From here,

$$Yield(\%)_{\text{for dry yam sample}} = \frac{8.3kg}{28.5kg} = 29.12\%$$

$$Yield(\%)_{\text{for fresh yam sample}} = \frac{W_{ff}}{W_{uy}} = \frac{4.7kg}{28.5kg} = 16.49\%$$

Appendix D

Process Models for Food Nutrition Quality Parameters

The food nutrition quality parameters developed for each of the dependent variables are as shown in the following process models:

For Crude protein,

$$Y_{\text{crude protein}} = 2.695 - 0.0095M.C. + 0.05 S.P. \quad (R^2 = 0.998)$$

For Ash;

$$Y_{\text{ash}} = 1.206 + 0.032M.C. + 0.1 S.P. \quad (R^2 = 0.802)$$

For Dry matter,

$$Y_{\text{dry matter}} = 94.46 - 0.0356 M.C. + 0.135 S.P. \quad (R^2 = 0.964)$$

For CHO;

$$Y_{CHO} = 92.66 - 0.00982 M.C. - 0.035 S.P. \quad (R^2 = 0.228)$$

For Amylose;

$$Y_{\text{amylose}} = 20.27 - 0.0557 M.C. + 0.08 S.P. \quad (R^2 = 1.000)$$

For Viscosity;

$$Y_{\text{paste clarity}} = 30.26 - 0.105 M.C. + 0.45 S.P. \quad (R^2 = 1.000)$$

For Paste clarity;

$$Y_{\text{paste clarity}} = 74.26 - 0.0885 M.C. + 0.35 S.P. \quad (R^2 = 1.000)$$

For Solubility;

$$Y_{\text{solubility}} = 53.61 - 0.135M.C. + 0.075 S.P. \quad (R^2 = 1.000)$$

For Ether extract;

$$Y_{ether\ extract} = 0.669 - 0.00483M.C. + 0.03 S.P.$$

For Crude fibre;

$$Y_{crude\ fibre} = 2.658 - 0.00966M.C. + 0.10 S.P.$$

For Pasting temp;

$$Y_{pasting\ temp} = 58.871 + 0.138 M.C. + 0.30 S.P.$$

For Amylopectin;

$$Y_{amylopectin} = 44.88 - 0.158 M.C. + 0.05 S.P.$$

For Water absorption capacity (WAC);

$$Y_{WAC} = 181.13 - 0.354 M.C. + 3.0 S.P.$$

For Oil absorption capacity (OAC);

$$Y_{OAC} = 108.75 - 0.290 M.C. + 6.28037E - 16 (R^2 = 0.900)$$

where Y_{cp} , Y_{ash} , Y_{CHO} , ... denote the food nutrition parameters as stated in each of the equations, $M.C.$ is the sample moisture content, and $S.P.$ is the particle size.