A Study on the Proximate Composition and Functional Properties of Oven-Dried Watermelon Seed

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Abstract
The proximate composition and functional properties of flour produced from watermelon (Citrullus lanatus) seeds using oven drying method were evaluated. The seeds were sourced from local markets in Akwa Ibom State, extracted, cleaned, oven-dried at 65°C for 6 hours, and milled into flour. Proximate analysis revealed moisture content of 5.40 ± 0.10%, ash 1.76 ± 0.1528%, fat 24.50 ± 0.30%, protein 28.03 ± 0.4041%, fibre 4.10 ± 0.10%, carbohydrate 36.40 ± 0.3606%, and energy value 478.23 ± 1.8893 kcal/100g. Functional properties included solubility 12.23 ± 0.2082%, foaming capacity 10.90 ± 0.3606%, bulk density 0.532 ± 0.0704 g/cm^3, swelling power 0.64 ± 0.0493 g/mg, oil absorption capacity 1.70 ± 0.0252 g/g, and water absorption capacity 1.85 ± 0.030 g/g. The results demonstrated that the flour possesses good nutritional profile and functional characteristics suitable for food product development. Comparisons with literature highlighted variations due to processing techniques. Recommendations for future work include sensory evaluation and mineral analysis to further explore applications.

Keywords: *Watermelon seeds, Proximate composition, Functional properties, Oven-drying, Flour*

Introduction

Watermelon is an annual vine crop with high economic value in tropical regions (Tarazona-Díaz *et al*., 2011). The plant features lobed leaves and oval seeds, with fruits varying in size (Arawande and Borokini, 2011). Genetic diversity supports breeding for improved seed traits. Varietal differences in watermelon significantly affect seed nutrient profiles, with seeded varieties like Crimson Sweet exhibiting higher protein levels compared to seedless types such as Sugar Baby. Environmental factors, soil fertility and climate, further influence fat and mineral contents, leading to variations of up to 10% in composition. A high level of water availability and soil with nutrient together with favourable climate usually ensure an optimal crop yield and any restriction in the supply of any of these factors is likely to induce a decrease in crop yield and food security (Usoh *et al.*, 2023). Studies show that diploid varieties tend to have denser seeds with elevated oil content, while triploid hybrids may have reduced fibre. This diversity is important for selecting varieties suited to flour production and nutritional enhancement. The understanding of these differences, therefore aids in breeding programs for optimized seed traits

(Olaitan *et al*., 2023). Watermelon seeds have diverse applications beyond waste, including as snacks, oils, and ingredients in various products, promoting sustainability in agriculture. Traditional and modern uses highlight their nutritional value, with processing methods enhancing versatility. Industrial extraction of oil and protein concentrates expands their role in food and non-food sectors. Potential in value-added products reduces post-harvest losses and boosts economic returns for farmers. Regional challenges in Akwa Ibom State, such as seasonal production, further highlight the need for value-addition strategies.

Research emphasizes efficient utilization to maximize benefits (Peter-Ikechukwu *et al*., 2020). In traditional African and Asian cuisines, watermelon seeds are roasted or ground into meals for porridges and sauces, providing essential nutrients. Medicinally, they are used as diuretics and for treating hypertension due to their citrulline content, which supports vascular health. Folklore applications include teas for digestive issues and wound healing. These uses reflect cultural knowledge of their health benefits, such as anti-inflammatory properties. Modern validation confirms their efficacy in natural remedies (Tarazona-Díaz *et al*., 2011). Watermelon seeds are processed into flour for incorporation in baked goods like biscuits and breads, improving nutritional profile with added protein and fibre. Oil extraction yields edible products high in unsaturated fats, used in cooking and salad dressings. Protein isolates from seeds serve as emulsifiers in processed foods. Industrial milling and fortification enhance shelf life and functionality. These applications support food industry innovation for healthier products (Akusu and Kiin-Kabari, 2021). Proximate composition of watermelon seed flour encompasses moisture, protein, fat, ash, fibre, carbohydrate, and energy, varying based on processing and variety. It provides a foundational understanding of nutritional value and quality. Analysis helps in assessing suitability for food fortification and storage. Differences in composition influence functional behavior in products. Standard methods ensure accurate evaluation (Arawande and Borokini, 2011). Functional properties refer to the physical and chemical behaviors of food components during processing and consumption, which are crucial for determining the suitability of watermelon seed flour in various food applications. These properties include how the flour interacts with water, oil, and air, affecting texture, stability, and overall product quality. Studies have shown that watermelon seed flour exhibits promising functional attributes due to its high protein and fat content, making it a valuable ingredient for fortification. The evaluation of these properties helps in understanding the flour's potential in baking, emulsification, and other food systems. Variations in functional properties can be attributed to processing methods and seed variety, influencing industrial adoption (Peter-Ikechukwu *et al*., 2020).

Problem Statement

The underutilization of watermelon seeds in Nigeria leads to significant agricultural waste and missed opportunities for nutritional enhancement (Akusu and Kiin-Kabari, 2021). Limited data on the proximate and functional properties of oven-dried seed flour restricts its application in food industries (Oyeleke *et al*., 2015). Without standardized evaluations, the potential to combat malnutrition through local resources remains unrealized, exacerbating reliance on imported flours (Peter-Ikechukwu *et al*., 2020). This project addressed these gaps by conducting a detailed analysis using controlled oven drying. Post-harvest losses from seeds contribute to environmental pollution and economic inefficiencies in farming communities. Policy support for by-product processing is lacking due to insufficient technical evidence (Akusu and Kiin-Kabari, 2021). Regional challenges in Akwa Ibom, such as seasonal production, further highlight the need for value-addition strategies.

Specific Objectives

The specific objectives of this study are:

i. To examine the moisture, ash, fat, protein, fibre, carbohydrate, and energy content of the oven-dried watermelon seed flour.

ii. To examine the functional properties, including solubility, foaming capacity, bulk density, swelling power, oil absorption capacity, and water absorption capacity of the processed watermelon seed flour.

iii. To compare the results with existing literature in order to identify potential food applications and areas for further research.

Materials and Method

Procurement of watermelon fruits/samples preparation

Fresh watermelons were purchased from Itam Market, Uyo in Akwa Ibom State, Nigeria, and transported to the laboratory. The fruits were manually split using a clean knife; seeds were extracted by hand, separating from the flesh. The seeds were washed thrice in distilled water to remove pulp residues, and were spread for initial air drying to reduce surface moisture. Batches of 500g were prepared, inspected for defects, and not dehulled. Debris and damaged seeds were removed manually. Sorting was done to select uniform seeds for consistent processing. The seeds were placed in a hot air oven at 65°C for 6 hours. Weight was checked periodically until constant weight was achieved to ensure complete drying. The dried seeds were ground using a hammer mill and passed through a 0.5 mm sieve to obtain fine flour. The flour obtained was stored in airtight bags at room temperature to maintain quality.

Proximate Composition Analysis

The following proximate compositions were determined in triplicate (n = 3):

Moisture Content Determination

Moisture content was determined according to the standard method of analysis of the Association of Official Analytical Chemists (AOAC, 2010), as highlighted by Umoh and Iwe (2022). A beaker that had been cleaned and dried in the oven was weighed after it had cooled in a desiccator (a). The beaker was weighed after adding two grams (2 g) of the flour mix sample, and the weight of the beaker plus sample was recorded (b). After being dried for four hours at 105 °C in the oven, the beaker and its contents were swiftly placed into a desiccator to cool before being weighed again. This process was carried out repeatedly until a consistent weight, (c) was achieved. Equation 2.1 was used to compute the moisture content.

Calculation:

$$\text{Moisture Content (\%)} = \frac{\text{loss in weight due to drying}}{\text{weight of sample taken}}$$
$$= \frac{b-c}{b-a} \times 100$$

Where: a = weight of empty beaker (g) b = weight of beaker + sample (g)
c = weight of beaker + sample after drying (g)

Ash Content Determination

A muffle furnace (Model SXL-1200) was used to ignite a crucible with a lid at 105 °C for one hour. After that, it was weighed and placed in a desiccator to cool (a). The pre-weighed crucible was filled with two grams (2g) of the flour sample, and the weight of the crucible and its content taken (b). In a fume cupboard, bunsen flame was used to burn the crucible and its contents until the smoking stopped. The crucible and content were moved into a muffle furnace and heated to

550 °C for two hours, or until a white ash formed. The crucible was then cooled, covered, and put in a desiccator, before it was weighed (c). Equation 2.2 was used to determine the amount of ash content in the sample (AOAC, 2010).

$$\text{Ash (\%)} = \frac{b-C}{b-a} \times 100$$

Where: a = weight of crucible (g), b = weight of crucible + sample (g),
c = weight of crucible + ash (g)

Crude Fibre Determination

Two grams (2 g) of the sample was defatted with petroleum ether for 2 h. It was boiled for 30 minutes with 200 ml of H_2SO_4 solution, filtered through linen on a fluted funnel and washed with boiling water until the washings were no longer acidic.

After being moved to a beaker, the residue was heated for a further thirty minutes with 200 milliliters of NaOH solution. It was then filtered, and boiling water was used to wash the residue multiple times until it was clear of base (NaOH). Ultimately, the residue underwent two methanol washes, was quantitatively moved into a crucible that had been weighed beforehand, and was oven dried at 105 °C (Io). It was weighed (Ia), chilled in a desiccator, and burned at 550 °C. After burning, the weight loss was also recorded. Using equation 2.3, the crude fiber content was determined (AOAC, 2010).

$$\text{Crude fibre (\%)} = \frac{I_{a-I_o}}{\text{weight of original sample taken}} \text{ X } 100$$

Crude Protein Determination

The method of Kjeldahl, as described by Umoh and Iwe (2022), was used to determine crude protein. Precisely one gram (1g) of the flour sample was weighed and placed into a standard 250 ml Kjeldahl flask together with 1.5 g of catalyst ($CuSO_4$), 1.5g of Na2SO4, and 5 ml of concentrated H_2SO_4. After placing the digesting (Kjeldahl) flask on a heating mantle, it was gradually heated for several hours to produce a clear, blue solution—a measure taken to avoid foaming. After allowing the digested solution to cool, it was quantitatively transferred to a 100 ml standard flask and filled with distilled water to the appropriate level. A twenty milliliter (20 ml) portion of the digest was treated with an equivalent volume of 40% NaOH solution after being pipetted into a semi-micro Kjeldahl distillation unit.

Following a steam distillation process, the ammonia developed into a 100 ml conical flask that held a 10 ml saturated boric acid solution with two drops of Tashirus indicator (double indicator) added. After submerging the condenser tip in the boric acid – double indicator solution, the distillation process was carried out until roughly two thirds of the initial volume was recovered. The distillate was then titrated with 0.1M HCl solution until a purple-pink end-point was noticed, and the tip of the condenser was washed with a few milliliters of distilled water. A blank determination was also performed in the same way, as previously mentioned, with the exception of the sample being excluded. The percentage of nitrogen content was multiplied by a factor (6.25) to obtain the crude protein.

$$\frac{(\text{Sample titre} - \text{blank titre})0.1 \times 0.014}{\text{weight of sample}} \times \frac{100}{20} \times \frac{100}{1} \times 6.25$$

Crude Fat Determination

The extraction thimble was filled with two grams (2 g) of the flour samples after it had been cleaned, dried in the oven, and slightly blocked with cotton wool. A round bottom flask with a capacity of 500 ml was filled with 150 ml of petroleum ether, which has a boiling point ranging from 35 to 60 °C. The round-bottom flask was placed on a heating mantle and the soxhlet extractor was inserted. After being put together, the soxhlet device was left to reflux for almost four hours. A dried, pre-weighed beaker (W_1) was filled with the extract, and the thimble was then cleaned with some ether before being returned to the beaker. After being heated in a steam bath to remove extra solvent, the beaker was cooled in a desiccator and weighed (W_2). The crude fat content was calculated as shown below (AOAC, 2010).

$$\text{Crude fat (\%)} = \frac{\text{weight gain in flask}}{\text{weight of sample}} \times \frac{100}{1}$$

$$= \frac{W_2 - W_1}{\text{weight of sample}} \times \frac{100}{1}$$

Carbohydrate Content Determination

Determination of carbohydrate content of the sample was carried out by subtracting the total estimations (in %) made of nitrogen (protein), fat, ash and crude fibre contents from 100%. The resultant value gave the percentage carbohydrate content by difference (AOAC, 2010).

$$\text{Carbohydrate (\%)} = 100 - (a + b + c + d)$$

Where,

a = percentage protein content
b = percentage lipid content
c = percentage ash content
d = percentage fibre content

Caloric Value Determination

This was obtained using the Atwater factor method. The values of the crude protein, fat, and carbohydrate obtained were multiplied by 4, 9, 4 respectively, and the sum of the products was taken as the caloric or energy value, (in kcal) of the sample (AOAC, 2010).

$$\text{Energy value (kcal)} = (x \times 4) + (y \times 9) + (z \times 4)$$

Where, x = protein content
y = lipid content
z = carbohydrate content

Analysis of Functional Properties

All the functional properties were determined in triplicate (n = 3) as follow:

Determination of Protein Solubility

This was determined according to the method described by Onwuka (2018). 1g flour sample was mixed with 10ml of water, stirred, centrifuged, supernatant dried and weighed.

$$Solubility\ (\%) = \frac{W_7}{W_1} \times 100$$

Where W_7 = weight of dried supernatant, W_1 = initial weight of supernatant.

Determination of Foaming Capacity

This was carried out according to the method described by Umoh (2025). Two grams (2g) of the sample and 100 ml of distilled water were blended, using a blender, at high speed for 5 minutes, and the dispersion poured into a 250 ml measuring cylinder. The volume of the foam at 30 seconds after whipping was expressed as the foaming capacity (in %) of the sample.

Foaming capacity (%) = $\frac{\text{Volume after whipping} - \text{Volume before whipping}}{\text{Volume befoer whipping}} \times 100$

Determination of Bulk Density

The flour sample was filled in a 10 ml dried estimating chamber and the lower part of the chamber tapped a few times on the research center table until there could have been no further lessening of the sample level subsequent to filling to the 10 ml mark (Umoh and Iwe, 2023).

Bulk density (g/cm^3) = $\frac{\text{Weight of sample (g)}}{\text{Volume of sample (cm3)}}$

Determination of Swelling Power

1g of flour sample in 10ml water was heated at 80°C for 30 minutes, centrifuged, sediment weighed (Onwuka 2018).

$$Swelling\ Power\ (g/g) = \frac{W_s w}{W_s}$$

Where W_s = weight of sediment.

Determination of Oil Absorption Capacity (OAC)

The oil absorption capacity of the sample was determined according to the methods described by Umoh and Iwe (2023). Precisely one gram (1 g) of flour mix test was blended in with 10 ml of vegetable oil. The oil and the sample were homogenized for 30 s and allowed to stand for 30 min at room temperature, and afterward centrifuged at 5,000 rpm for 30 min. The volume of free oil (supernatant) was noted straightforwardly from the graduated rotator tube. The amount of oil ingested (total minus free) was then multiplied by its density to convert into grams. Density of oil was taken to be 0.88 g/ml for faded palm oil.

$$\text{OAC (g/g)} = \frac{W_1 - W_2}{W} \times \text{Density of oil}$$

Where: V_1 = Initial volume of oil; V_2 = Final volume after centrifugation; W = Weight of sample.

Determination of Water Absorption Capacity (WAC)

This was carried out according to the methods described by Umoh and Iwe (2023). Ten milliliters (10 ml) of refined water was blended in with one gram (1 g) of test in a blender and homogenized for 30 s, kept at room temperature for 30 min, and centrifuged at 5000 rpm for 30 min. The volume of the supernatant (free water) in a graduated chamber was noted. The amount of water ingested (all out short free) was increased by its density for transformation to grams. Density of water was thought to be 1 g/ml.

$$\text{WAC (g/g)} = \frac{W_1 - W_2}{W} \times \text{Density of water}$$

Where: V_1 = initial volume of water V_2 = final volume after centrifugation; W = weight of sample

Results

The analyses of the proximate composition and functional properties of oven-dried watermelon seed flour yielded the following results, as presented in Table 1 and Table2.

Table 1: Proximate Composition of Oven-Dried Watermelon Seed Flour

Component	Value
Moisture (%)	5.40 ± 0.10
Ash (%)	1.76 ± 0.1528
Fat (%)	24.50 ± 0.30
Protein (%)	28.03 ± 0.4041
Fibre (%)	4.10 ± 0.10
Carbohydrate (%)	36.40 ± 0.3606
Energy (kcal)	478.23 ± 1.8893

Note: Values are mean ± standard deviation of triple determination (n = 3)

Table 2: Functional Properties of Oven-Dried Watermelon Seed Flour

Property	Value
Protein Solubility (%)	12.23 ± 0.2082
Foaming Capacity (%)	10.90 ± 0.3606
Bulk Density (g/cm^3)	5.32 ± 0.0704
Swelling Power (g/g)	0.64 ± 0.0493
Oil Absorption Capacity (g/g)	1.70 ± 0.0252
Water Absorption Capacity (g/g)	1.85 ± 0.030

Note: values are mean ± standard deviation of triple determination (n = 3).

Discussions

The results obtained from the proximate composition and functional properties analyses of oven-dried watermelon (*Citrullus lanatus*) seed flour provide valuable insight into the effect of controlled thermal drying on seed quality and its potential industrial applications.

Proximate Composition

The sample recorded a moisture content of 5.40% (Table 1). The low moisture content recorded is lower than that of fresh seeds (typically 45–55 %) and falls within the safe storage limit of below 10 % recommended for oil-rich seeds (Fellows, 2017). This confirms the effectiveness of oven drying at 65 °C for 6 hours in removing free water, thereby minimizing the risk of microbial growth and lipid oxidation. Compared to sun-dried watermelon seed flour (7.2–9.8 %) reported by Kiin-Kabari and Akusu (2014), the lower value obtained in this study highlights the advantage of controlled mechanical drying in humid tropical environments like Akwa Ibom State. The sample had 1.76% ash content (Table 1). The ash value is relatively low compared to some literature values (3.5–5.0 %). This may be attributed to the non-dehulled nature of the seeds used; the hull is known to contribute significantly to total mineral content (Oyeleke *et al.*, 2015). However, the value still indicates the presence of essential minerals such as potassium, magnesium, and phosphorus, which are vital for nutritional fortification.

The fat content of 24.50% (Table 1) is within the range reported for watermelon seeds (20–47 %) across varieties (Peter-Ikechukwu *et al.*, 2020). The slight reduction compared to some higher values may result from minor oxidative losses during milling and exposure to heat, although the unsaturated fatty acid profile of watermelon seed oil is known to be relatively stable at 65 °C

(Taiwo *et al*., 2008). This high oil content positions the flour as a potential raw material for edible oil extraction or as a high-energy ingredient in food formulations.

As shown in Table 1, the sample recorded 28.03% protein. The protein content is high and comparable to soybean meal (27–30 %), making watermelon seed flour a viable plant-based protein source for combating protein-energy malnutrition in Nigeria. The value aligns closely with findings of Akusu and Kiin-Kabari (2021) (27.40 %) and Peter-Ikechukwu (2020) (28.00 %), confirming that moderate oven drying at 65 °C does not cause significant denaturation of seed storage proteins (albumins and globulins).

The sample had 4.10% crude fibre (Table 1). The fibre content is moderate and beneficial for digestive health. It is higher than values reported for dehulled seeds (2.6–3.8 %), again reflecting the inclusion of the seed coat in this study, which is rich in insoluble fibre.

Carbohydrate content of the sample was recorded as 36.40% (Table 1). Carbohydrates, calculated by difference, constitute the second-largest component after protein and fat. The high calorific value of 478.23kcal (Table 1) makes the flour suitable for incorporation into energy-dense complementary foods and snacks.

Functional properties

The sample recorded bulk density of 0.532g/cm^3, as shown in Table 2. This low value facilitates efficient packaging and storage. Low bulk density is desirable in infant feeding, while flours with high bulk density are used as thickeners in food products (Umoh, 2020).

The sample recorded a water absorption capacity of 1.85g/g (Table 2). The WAC is excellent and superior to many cereal flours (e.g., wheat 0.6–1.2 g/g). High WAC is attributed to the presence of hydrophilic proteins and polysaccharides exposed during milling. This property enhances dough handling characteristics and improves yield in baked products.

The sample had 1.70g/g Oil absorption capacity (Table 2). Good oil-binding capacity is important for flavour retention and mouth-feel in meat analogues, sausages, and doughnuts. The value obtained is higher than that of many legume flours, indicating strong non-polar interactions with the hydrophobic regions of proteins. The results indicate that the sample recorded a foaming capacity of 10.90% (Table 2). Foaming properties are desirable in food products such as cakes, breads, meringues, crackers, ice creams and several other bakery items to maintain their texture and structure throughout the processing and during storage (Nawaz *et al*, 2015; Umoh, 2025). Moderate foaming properties suggest limited suitability for whipped products but acceptable performance in cakes and ice cream where moderate aeration is required. Heat treatment during drying partially denatures globular proteins, reducing foaming compared to raw flour. Protein solubility is relatively low (12.23%), due to thermal denaturation at 65 °C, which is consistent with the findings of Narayana and Narasinga Rao (1982). This affects application in beverages but is advantageous in baked goods where low solubility prevents excessive gluten-like network disruption. The sample had a swelling power of 0.64g/g (Table 2). The moderate swelling power indicates limited starch gelatinization (watermelon seeds contain little starch), but the value is useful in soups and sauces where slight thickening is desired.

Conclusions

This study has successfully assessed the proximate composition and functional properties of watermelon seed flour, highlighting its potential as a sustainable, nutrient-dense ingredient derived from an often-overlooked agricultural by-product. The results demonstrate that oven drying at 65°C for 6 hours produces flour with low moisture, high protein and substantial energy value, which are essential for long-term storage and nutritional enhancement in food products. The functional properties, including moderate foaming capacity and good water absorption capacity, indicate the flour's applicability in baking, thickening, and fortification, where it can improve texture, stability, and nutritional profile without compromising sensory qualities.

Recommendations

Based on the findings, the following recommendations are proposed to maximize the utilization of watermelon seed flour:

i. Agricultural engineers and food processors should adopt oven drying at 65°C for 6 hours as a standard method for seed flour production, as it effectively reduces moisture to safe levels while preserving protein and fat content. This can be implemented in small-scale facilities using locally fabricated dryers to minimize costs and energy use.

ii. There is absolute need for further study to characterize the anti-nutritional factor profile of the watermelon seed flour (e.g., trypsin inhibitors, oxalates, phytates).

iii. Food industries and nutrition programs should incorporate watermelon seed flour at 10-20% levels in composite formulations for baked goods, porridges, and snacks to enhance protein and fibre intake, particularly in school feeding programs and maternal health initiatives to combat malnutrition.

iv. Further research should explore blending watermelon seed flour with staple flours like wheat or cassava to develop gluten-free products, with sensory and shelf-life evaluations to ensure market acceptance.

v. Policy makers should promote incentives for by-product utilization, such as tax breaks for processors, to encourage industrial-scale production and export of seed-derived products, aligning with national agricultural development goals.

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