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Research Article

Effect of Processing on Nutritional and Sensory Quality of Orange-Fleshed Sweet Potato's Porridge and *Ugali* (stiff-porridge) Consumed in the Lake Zone, Tanzania

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Abstract

The orange-fleshed sweet potato (OFSP) is a nutrient-rich crop with high β-carotene content, which helps prevent vitamin A deficiency (VAD). However, its semi-perishability requires proper processing to preserve its nutritional and sensory properties. This study assessed the effects of sun and solar drying on the proximate composition, β-carotene, vitamin C, mineral content, and sensory attributes of OFSP porridge and Ugali (stiff porridge) consumed in the Lake zone of Tanzania. Three variety of OFSP; Ejumla, Jewel, and Carrot Dar, were subjected to solar or sun-drying and subsequently processed into flour. The resulting flours were used to produce porridge and Ugali (stiff porridge). Conventional techniques were employed to evaluate the proximate composition, β-carotene, vitamin C, and micronutrient content of porridge and *Ugali* (stiff porridge). Additionally, sensory analysis was performed to assess the level of acceptability of the items' sensory qualities. There was a significant difference in moisture content, crude protein, and crude fat between porridge and *Ugali* (stiff porridge) for all three varieties of OFSP ($p<0.05$). Moreover, solar-dried products had higher retention of β-carotene (28.79 mg/100 g) and vitamin C (3.29-10.45 mg/100 g). Sun-dried products had lower mineral content than solar-dried products. There was also a significant difference ($p<0.05$) between solar and sun-dried products in all tested essential minerals. The nutrients analyzed were more concentrated in stiff porridge than in regular porridge, such as calcium (21.65mg/100g), potassium (90.70mg/100g), Sodium (169.98mg/100g), magnesium (13.26mg/100g) and zinc (0.51mg/100g). Solar-dried items had the highest acceptability scores (3.0–3.9) compared to sun-dried products, with Ejumla being the most preferred. The findings depict that solar drying preserves OFSP-based food's nutritional and sensory quality better. Solar-dried OFSP may reduce vitamin A deficiency (VAD) and improve nutritional security in Tanzania.

Keywords

OFSP, Solar Drying, Sun-drying, *Ugali*, Porridge, Proximate Composition, β-carotene, Vitamin C, Mineral Content

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1. Introduction

Sweet potato (*Ipomoea batatas L.*), a dicotyledonous plant of the Convolvulaceae family, is a resilient crop that thrives in the diverse agro-ecological zones of tropical and subtropical regions. Its significance in global agriculture is considerable, particularly in sub-Saharan Africa's agriculture, covering approximately 3.2 million hectares and contributing 13.4 million tons of tubers to the food system [1]. Globally, sweet potato ranks as the 7th most important food crop [2] and holds a greater distinction as the fourth crucial staple food in tropical countries [3]. Under these circumstances, Orange-fleshed sweet potato (OFSP), an improved biofortified variety of *Ipomea batatas* L. has gained increasing attention in nutritional research and agricultural development initiatives. Cultivated extensively in tropical and semi-tropical regions, OFSP serves as a vital source of both food and income, especially for rural communities. It stands as an essential staple crop in Africa, providing not only a significant source of energy and dietary fiber but also critical micronutrients [2].

The nutritional prominence of OFSP is particularly attributed to its outstandingly high β-carotene content, converted into vitamin A by the human body, a nutrient essential for maintaining a healthy vision, strong immunity and skin health [1].

These characteristics positions OFSP as a powerful means in addressing the widespread issue of vitamin A deficiency (VAD), a major public health concern affecting about 190 million pre-school children and 19 million pregnant women worldwide [1]. Insufficient intake of vitamin A can lead to a spectrum of adverse health outcomes, ranging from impaired vision, increased susceptibility to infections, hence heightened morbidity and mortality, particularly among young children [4]. The seriousness of this issue is underscored by the situation in Tanzania, where VAD remains a potential health challenge, contributing to morbidity and mortality among children under five, with over 35% of children aged 6 -59 months affected. Acknowledging the severe impact of vitamin A deficiency (VAD), international health bodies are proactively supporting measures like vitamin A supplementation and food fortification, with a focus on at-risk groups in low-income areas [5]. In this landscape, OFSP offers a compelling food-based strategy to combat VAD and undernutrition concurrently [6]. Unlike many other vegetables, OFSP can supply significant amounts of both vitamin A precursors and energy in a single food source, making it particularly valued in regions where access to diverse and nutrient-rich diets is limited.

The impact of micronutrient deficiencies, including vitamin A, is unambiguously illustrated by about 27,000 infant deaths per annum in Tanzania attributed to these deficiencies [7], with poor dietary intake being the main underlying cause. Moreover, studies in Tanzania have revealed a high prevalence of anemia (45%) and vitamin A deficiency (36%) among women of reproductive age [8], underscoring the broader nutritional challenges faced by the population. Outside β-carotene, OFSP is also a source of other beneficial compounds, including antioxidants, dietary fiber, and essential minerals such as iron, calcium, and potassium, thus contributing to overall health and well-being of an individual [3]. The antioxidant properties help mitigate oxidative stress, potentially reducing the risk of chronic diseases, while the fiber content supports digestive health, blood sugar regulation, and weight management [3].

Despite its rich nutrient profile, OFSP is a semi-perishable food that requires appropriate processing techniques to enhance its shelf life and nutritional retention. Fresh roots and tubers can be preserved using various techniques, including freezing, heat treatment, chemical and physical methods, and drying. Among these, drying is a commercially viable and economically sound approach for preserving raw and intermediate sweet potato products by significantly reducing their moisture content, thereby inhibiting microbial growth and enzymatic activity that leads to spoilage and quality deterioration [4]. The drying process can be carried out in various forms, with sun-drying and solar drying being the common practices in regions like Tanzania. Solar drying is a natural technique that uses sunlight to place food on racks within structures that capture and direct heat, facilitating moisture evaporation. This method can be conducted in open-air systems or controlled solar dryers, enhancing drying efficiency and minimizing contamination [3]. In contrast, traditional sun drying involves exposing products such as OFSP directly to sunlight, often on mats or bare ground [4]. Despite its simplicity, several drawbacks are associated with open sun drying, including inconsistent drying rates, exposure to dust, dirt, rain, pests, and potential microbial contamination, ultimately impacting the quality and safety of the dried products [4].

Given the widespread use of both sun-drying and solar drying in Tanzania for preserving OFSP and the potential impact of these methods on the nutritional and sensory attributes of commonly consumed OFSP-based foods such as porridge and stiff-porridge (Ugali), a thorough evaluation is necessary particularly in the Lake Zone region where there is a tremendous consumption of both porridge and stiff-porridge (Ugali).

Nutrient losses, particularly in heat-sensitive vitamins like β-carotene and vitamin C, pose a challenge in optimizing the benefits of OFSP for vulnerable populations. Therefore, this study aims to rigorously evaluate the effect of sun-drying and solar drying on the nutritional and sensory quality of porridge and *Ugali* (stiff-porridge) prepared from OFSP. The findings of this research will provide critical insights in to the optimal drying methods for preserving the nutritional integrity and consumer acceptability of OFSP based foods, thereby contributing valuable knowledge to efforts aimed at leveraging OFSP as a sustainable and effective strategy to combat vitamin A deficiency and improve overall nutritional status in

Tanzania and other regions facing similar challenges globally.

2. Materials and Methods

Sample collection and preparation, OFSP flour preparations, chemical analysis, and sensory evaluation were conducted at the Department of Food Sciences and Agro-Processing laboratory at the Sokoine University of Agriculture (SUA), Morogoro, Tanzania.

2.1. OFSP Flour Preparation

Three cultivars of orange-fleshed sweet potato (OFSP), Ejumla, Jewel, and Carrot Dar, were used for flour preparation. A total of 100 kg of freshly harvested roots were collected from farmers' fields. The roots were thoroughly washed, peeled, and cut into uniform slices. These slices were soaked in a potassium metabisulphite ($K_2 S_2 O_5$) solution for 15 to 20 minutes, followed by steam blanching for 15 minutes. The treated slices were then divided into two equal portions (45 kg each) and dried using two different methods: solar drying and sun drying. Drying continued until the slices reached equilibrium moisture content. The dried slices were ground using an attrition milling machine and then sieved through a 36 mm mesh to obtain fine and uniform flour. The flour was then packed in PET jars, labeled, and stored under ambient conditions for further use.

2.2. Preparation of OFSP Porridge and *Ugali* (Stiff-porridge)

The flour from the three OFSP cultivars was used to prepare porridge and *Ugali* (stiff porridge). The prepared products were stored in PET jars, labeled, and kept in a refrigerator at 4 ℃ for further use.

2.2.1. Porridge Preparation

Porridge was prepared following the method outlined by [9]. One kilogram of flour from each OFSP cultivar (Ejumla, Jewel, and Carrot Dar) was mixed with 1,500 mL of water. The mixture was stirred well in a cooking pot and boiled separately for each cultivar until all particles dissolved, forming a smooth and consistent porridge. During cooking, 20 mL of oil was added. The porridge was cooked at 100 ℃ for 10 minutes before being served; no sugar was added.

2.2.2. *Ugali* (stiff porridge) Preparation

Ugali was prepared using boiled OFSP porridge, which was added to boiling water, while OFSP flour was incrementally incorporated through stirring until a firm and uniform texture was achieved. To get the appropriate consistency of *Ugali*, one kilogram of OFSP flour from each cultivar was combined with 700 mL of boiling water. The mixture was thoroughly stirred in a cooking pot and separately cooked for each cultivar at 70-90 ℃ until achieving a firm and uniform texture.

2.3. Chemical Analysis and Proximate Composition

2.3.1. Moisture Content

Moisture content was determined by [10] method. Five grams of OFSP flour were put in an oven at 105 ℃ for 8 hours to maintain a constant weight. After drying, the dish was removed and cooled in a fused calcium chloride desiccator. The dish containing the dried sample was weighed to determine its weight. The pe cent moisture content was calculated as follows:

$$\text{Moisture (\%)} = \frac{weight\ of\ fresh\ sample\ (g) - weight\ of\ dried\ sample\ (g)}{weight\ of\ fresh\ sample\ (g)} \text{x}100$$

2.3.2. Crude Protein

The determination of crude proteins is described by [11]. Two grams of OFSP flour in the Kjeldahl flask, two tabs of digestion mixture in the flask, 0.1 g of bumping stone into the flask, and 12 ml to 15 ml of sulphuric acid (H_2SO_4) in the flask were boiled using the digester for 45 minutes until the solution became clear blue or green. It was later removed and cooled to 25 ℃ for 20 minutes, and 75 ml of distilled water was added to the same flask. 25 ml of boric acid and three drops of methyl red were put under the condenser on the right-hand side (RHS), with the condenser dipping into the solution. A similar procedure was executed on the left-hand side (LHS), with the tip of the condenser also dipping into the solution. On the side of the Kjeldahl Distillation Unit, placed in a 100 ml cylinder filled with sodium hydroxide (NaOH) solution, the alkali tube was dipped into the cylinder till it reached the bottom. The Kjeldahl Distillation Unit was ON, and the solution was boiled continuously to release the ammonia. The distillate was collected in the Erlenmeyer flask containing boric acid and the ammonia-borax complex to 25 ml in a volumetric flask. Then, 10 ml of the distillate was pipetted into a 50 ml beaker for titration. Titration was done to the endpoint using 0.02 M hydrochloric acid, color change was noted, and the endpoint was recorded. Crude protein was calculated as follows:

$$\text{Nitrogen (\%)} = \frac{Titre\ value\ (mL) x\ Nomality\ of\ acid}{weight\ of\ sample\ (g) x1000} \text{x}100$$

$$\text{Protein} = \text{Nitrogen\% x 6.25}$$

2.3.3. Crude Fat

Crude fat was determined as described by [10] method No. 920.39 with some modifications. Two grams of moisture-free OFSP flour were weighed into a weighed extraction thimble (wholly dried) with porosity permitting rapid ether passage. The thimble with the sample was placed in a Soxhlet’s apparatus in a straight direction so that the condensed ether may drop on it (a layer of defatted cotton wool was placed on top of the sample in the thimble to avoid floating). 50 ml of petroleum ether was added into each extraction cup (before adding petroleum ether, the cups were dried and weighed, and the weight was recorded). The samples were refluxed for 45 minutes at a temperature of 80 ℃ and 15 minutes extra to recover the extract after reflux. The extraction cups were removed, and the contents were dried using a hot air oven at 105 ℃ for 10 minutes. The cups were cooled in the desiccator and weighed. Then, crude fat was calculated as

$$\text{Fat (\%)} = \frac{W2-W1}{W}\text{x}100$$

W=Weight of dried sample

W_1=Weight of empty Soxhlet flask

W_2= Weight of Soxhlet flask containing fat

2.3.4. Crude Fiber

The determination of crude fiber was conducted as described by [12] with some modifications. One gram of moisture and fat-free OFSP flour (the residue of oil fat) was weighed and transferred into the spoutless one-liter beaker. 200 ml of 1.25% sulphuric acid was added, placed on a hot plate, and allowed to reflux for 30 minutes; during the refluxing, the beakers were shaken every 5 minutes. After 30 minutes, it was removed and filtered through a muslin cloth using a suction pump. The residues were washed with hot water till they were free from acid and later transferred to the same beaker, and 200 ml of 1.25% sodium hydroxide (NaOH) solution was added again. The second relaxation took place for 30 minutes. Thereafter, it was removed and filtered through a muslin cloth, and then the residue was washed with hot water till it was free from alkali. However, it was first washed with dilute hydrochloric acid (HCl) before washing it with hot water to facilitate the removal of alkali. The total residue was transferred to a crucible of known weight, placed in a hot air oven, allowed to dry to a constant weight at 1050 C, and recorded. The dried crucible with residue was ignited in a muffle furnace at 550^0 C for 3 hours, cooled in the desiccator, and weighed again. The loss of weight due to ignition was calculated as the percentage of the crude fiber as follows:

$$\text{Fibre} = \frac{W1-W2}{W}\text{x}100$$

Where:

W= Weight of dried sample

W_1= Weight of crucible and content before ashing

W_2 = Weight of crucible containing ash

2.3.5. Total Carbohydrate

The total percentage of carbohydrates was calculated using the method described by [13]. This method involved adding the total values of the sample's crude protein, fat, fiber, moisture, and ash constituents and subtracting them from 100. The value obtained was the fiber’s percentage carbohydrate constituent.

Percentage Carbohydrate = 100 - (%Ash +%Moisture content +%fat +% fiber +%protein)

2.3.6. Total Ash

Determination of total ash as described by [12]. An empty crucible was dried in a hot air oven for 30 minutes, cooled in the desiccator, weighed, and the weight was recorded. Then, 2 g of the OFSP flour sample was measured into the crucible and transferred into the muffle furnace at 550 ℃ for 3 hours. The sample was ignited, and after ignition, it was cooled and weighed; the weight loss due to ignition was recorded. The percentage ash was calculated as follows:

$$\text{Ash (\%)} = \frac{Weight\ of\ ash\ (g)}{Weight\ of\ fresh\ sample}$$

2.4. Beta Carotene Determination

Beta-carotene was analyzed following the method of [14]. A five-gram OFSP floor sample was dissolved in 50 ml of acetone and blended in a mixer. It was filtered, and the residue was re-blended with acetone until it became colorless. The extract was then diluted to 100 ml with acetone. From this extract, 50 ml was mixed with petroleum ether (60–80 ℃) and water in a separatory funnel. The yellow petroleum ether layer containing β-carotene was collected. Additional petroleum ether and water were used until no yellow color remained. The extracts were filtered through anhydrous sodium sulfate, and the filtrate was adjusted to a final volume. Chromatography was done under low light to prevent degradation. Columns were packed with aluminum oxide and sodium sulphate and pre-washed with petroleum ether. A 2 ml β-carotene extract was added, and the orange band was eluted with petroleum ether and 10% acetone. The eluent was measured at 452 nm using a spectrophotometer and compared to a β-carotene standard. The β-carotene concentration was calculated as mg per 100 g of the sample.

2.5. Ascorbic Acid Determination

A study [15] official method was followed to determine ascorbic acid content. A three per cent meta-phosphoric acid solution was used to prepare the sample and standardize the L-ascorbic acid. Afterward, the sample was titrated against 2, 6-dichlorophenol-indophenol (DCPIP) dye till the light pink color persisted for at least 15 sec. The ascorbic acid content was calculated as per the formula given below:

$$\text{Ascorbic acid (mg/100}g) = x = \frac{Titre\ value\ (mL)xDye\ factor * xVolume\ made\ up\ (mL)}{Aliquot\ of\ extract\ (mL)xWeight\ of\ sample\ (g)} \text{x100}$$

$$\text{Dye factor} = \frac{0.5}{Titre\ value\ of\ standard}$$

2.6. Total Energy Determination

Total energy was calculated using the differential method by [12].

Total energy (Kcal) = [(Protein (g) x 4) + (Fat (g) x 9) + (carbohydrates (g) x 4)]

2.7. Mineral Analysis Determination in OFSP Porridge and Stiff Porridge

The mineral contents of fresh and processed samples were determined using [10] with some modifications. Two grams (2 g) of powdered OFSP were placed in a clean porcelain crucible and ashed in a muffle furnace at 500-600 ℃ for 4-6 hours. After that, the ash was cooled, dissolved in dilute hydrochloric acid (HCl), and then diluted with deionized water. An atomic absorption/flame emission spectrophotometer (AA 630-12) was used to measure the amounts of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), zinc (Zn), and iron (Fe) in OFSP samples. The absorbencies of calcium, magnesium, sodium, potassium, zinc, and iron were measured at 422.7 nm, 285.2 nm, 589.0 nm, 766.5 nm, 213.9 nm, and 5248.3 nm, respectively.

The mineral content (mg/100 g) of the OFSP flour was calculated as below:

$$Mineral\ content\ mg/100g = \frac{Rx100ml\ D.F}{S\ x\ 1000} \times 100$$

Where:
R = Reading in ppp of (mg/L)
100 = Volume of sample made (ml)
D.F = Dilution factor
1000 = Conversion factor to mg/100g
S = Sample weight

2.8. Sensory Evaluation

The methodology outlined by [16] was employed for this research. A total of 25 semi-trained panelists from the Department of Food Science and Agro-processing were used to assess the sensory attributes (color, taste, texture, aroma, and overall acceptability) of porridge and *Uji* (stiff porridge). The participants were acquainted with porridge and stiff porridge products. A 5-point hedonic scale was utilized, where 5 represented "like very much" and 1 represented "dislike very much." Panelists evaluated various attributes, including color, taste, texture, aroma, and acceptability. Samples of porridge and stiff porridge were served on disposable plates, each marked with three randomly assigned codes. Warm water was provided for mouth rinsing between tests to cleanse the palate. Panelists were instructed to assess each coded sample's color, taste, texture, aroma, and overall acceptability. Each panelist evaluated one sample at a time until all samples were tested. Their evaluations were recorded on sensory evaluation forms provided to each participant.

2.9. Ethical Consideration

A permit for research was requested from the Vice Chancellor of Sokoine University Agriculture (SUA), and the conduction of research was approved by the Directorate of Postgraduate Studies, Research, Technology Transfer and Consultancy (DPRTC) of SUA. The method used was non-invasive in which panelists was used to asses sensory quality of food products. Before evaluating the sensory attributes of the products, verbal consent was secured from each panelist following a detailed explanation of the study's purpose and significance. Engagement in the study was entirely optional. All the information collected from the panelists was kept confidential under the custody of the investigator.

2.10. Data Analysis

All data were analyzed using Statistical Package for Social Sciences (SPSS) version 27. A one-way analysis of variance (ANOVA) was conducted, followed by a post-hoc Tukey test, with significant differences identified at a 5% significance level. All data were presented as mean ± SD for proximate composition, mineral concentration, and sensory evaluations of porridge and *Ugali* (stiff-porridge).

3. Results and Discussion

3.1. Proximate Analysis of OFSP Porridge and *Ugali* (Stiff Porridge)

Table 1 shows the effects of processing methods on the nutritional contents of OFSP products (porridge and *Ugali*). There were no significant differences in moisture content for different cultivars between the sun and solar drying as processing methods. However, there was a significant difference in moisture content between porridge and stiff porridge for each of the three types of orange-fleshed sweet potato flour ($p<0.05$). The moisture content in porridge ranged from 45.18±0.03 to 58.23±0.32%, but in stiff porridge, it was significantly lower, ranging from 21.34±0.06 to 25.67±0.13%. Furthermore, the Jewel variety demonstrated the highest moisture content in both items, whereas the Ejumla variety revealed the lowest moisture level. The results of the present study align with those of [17], indicating that the moisture content of orange-fleshed sweet potato porridge varied between 31.62% and 48.25%. However, these values are lower than those of Onyeso (2019), indicating a moisture content range of 49.25% to 83.10% for orange-fleshed sweet potatoes. On the other hand, findings from the present study are higher than those reported by [19], who found that the amount of water in orange-fleshed sweet potato flour ranged from 2.5% to 13.2%. This discrepancy is attributed to the variation in products examined since our study focuses on porridge and *Ugali* (stiff porridge), whereas [19] investigated orange sweet potato flour. Furthermore, our study indicates that porridge possesses a greater moisture content than stiff porridge, as it is prepared with a larger ratio of water to flour, whereas stiff porridge contains more flour concentration. The amount of water in orange-fleshed sweet potato flour is a quality that affects how long it can be stored since water can speed up chemical and microbiological activity [19]. Also, there was a significant difference ($p \leq 0.05$) in the amount of crude protein in the two products, porridge and *Ugali*. *Ugali* (stiff porridge) had the highest mean protein value compared to porridge. The protein content in both *Ugali* and porridge ranged from 4.07% to 5.80%. The Jewel cultivar exhibited the greatest crude protein concentrations in both porridge (5.35%) and *Ugali* (5.80%). Consistent with the findings of [19], orange-fleshed sweet potato flour exhibited a mean crude protein range of 3.14% to 6.57%. Our findings, however, exceeded those documented by [17, 18], who indicated that the protein level in OFSP flour ranged from 1.76 to 2.11%, and in orange-fleshed sweet potatoes, it ranged from 0.91 to 3.12%. This is because our study only utilized OFSP flour for both porridge and stiff porridge, in contrast to Haile’s study, which included bulla flour with OFSP flour. This indicates that an increase in OFSP flour correlates with a higher crude protein content in the product. The protein content of both the stiff porridge and the porridge met the daily requirements for a healthy individual, ranging from 0.80 to 1.52 g/kg/d [17]. Proteins are very important nutrients for structural, functional performers of different biomolecules in the human body, and they provide the essential amino acids required for metabolism [20].

Similarly, a significant difference ($p < 0.05$) was noted in the mean crude fat content between porridge and *Ugali*. The mean fat percentages ranged from 0.87% to 1.34% for porridge and 1.86% to 2.98% for *Ugali*. The processing method had no impact on the fat content in either product. The fat content in our findings was inferior to that reported by [18], who observed 0.96 to 6.01% fat in orange-fleshed sweet potatoes subjected to various treatments, and [19], who identified 13.94 to 25.66% fat in orange-fleshed sweet potato flour. The observed discrepancies may result from varying processing methods; for instance, [18] investigated fried orange-fleshed sweet potatoes, which absorbed oil and hence exhibited elevated fat content. A low-fat content might be attributed to fat oxidation during the products' drying period. Moreover, the difference in products and product varieties may result in different concentrations of fatty acids in the products.

Another critical component that was analyzed is the mean crude fiber. Fiber has various advantages, such as aiding digestion and preventing diseases such as irritable bowel syndrome, diabetes, and cancer. It also helps soften stools and lower plasma cholesterol levels in the body. In our study, crude fiber ranged from 1.06% to 2.84% and 1.89% to 3.23% in porridge and *Ugali*, respectively. Our findings were consistent with those of [19], whereby the fiber range of orange-fleshed sweet potato flour was 2.83 to 3.2%. The higher fiber content in stiff porridge is due to the concentrated nature of the product, as nutrients tend to be higher in concentrated products than in diluted ones. According to the FAO Food Standards Program, the RDA of fiber for a healthy person is set at 25 to 38 g/day [17]. Furthermore, the mean carbohydrates analyzed in the present study were 87.05-92.60% and 85.42-87.89%) in porridge and *Ugali*, respectively. The findings of this study were relatively higher than those reported by [17], who noted that the total carbohydrate content in porridge was 35% to 48.63%. This indicates that OFSP flour products can be consumed as a staple food because of the high concentration of carbohydrates [20]. Different food ingredient compositions and the use of OFSP cultivars may account for the difference. Moreover, ash is an inorganic residue in any food substance, which denotes the mineral content of the food [20]. It is a reflection of the mineral content of a food material. The mean total ash content of OFSP and *Ugali (*stiff porridge) in the current study was 2.90 - 4.67% and 3.89 - 5.23%, respectively. These results were relatively higher than those [17], which were 1.26 to 2.55% for flour and 2.39 to 2.78% for porridge, respectively. A high-fat content indicates that a food product is a good source of mineral elements in the body. Therefore, our study found that porridge and *Ugali* made from OFSP flour are good sources of mineral elements when consumed. The total energy in the current study ranged from 375.06 - 384.99 Kcal/100 g and 379.86-396.69 Kcal/100 g in porridge and *Ugali*, respectively. It has been found that OFSP is a good energy source that can supply 293 to 460 kJ per 100 g [1, 21]. This shows that both OFSP porridge and *Ugali* provide a good energy source to consumers.

3.2. Beta Carotene and Vitamin C Content of OFSP Porridge and *Ugali* (stiff porridge)

OFSP is known to have an excellent amount of β-carotene, which is highly bioavailable and converted into vitamin A (retinol) in the human body [1]. According to the [22], the prevalence of vitamin A deficiency among women of reproductive age is about 42%, while the recommended dietary allowance is 998.7 µg/100g. Likewise, [17] emphasizes that a healthy person's requirement of β-carotene ranges between 250 to 900 µg/100 g daily. The kind of processing methods impacted β-carotene content in the final products. There was a significant difference ($p \le 0.05$) between sun-dried and solar-dried products, whereby sun-dried products had a higher deterioration of β-carotene content. This is because β-carotene is a heat- and light-sensitive nutrient. β-carotene levels ranged from 21.24 mg/g to 25.61 mg/100 g for OFSP porridge and 21.20 to 28.79 mg/100 g for stiff porridge. This amount surpasses the range recommended by the [22], indicating that consumption of porridge and/or stiff porridge prepared from OFSP flour is good for obtaining sufficient amounts of vitamin A, especially for children, pregnant and lactating mothers. Moreover, the results of this study are greater than those reported by [17] for porridge prepared with a composite flour of orange-fleshed sweet potato and enset (bulla) flours. This discrepancy arises because, in our study, porridge and stiff porridge were solely made with OFSP flour, whereas in the previous study, OFSP flour was mixed with bulla flour, which possesses a relatively low β-carotene content. Likewise, the findings of the current study surpassed those of [23], which indicated levels of 3.02 mg/100 g in bread, 2.39 mg/100 g in OFSP biscuits, and 2.3 mg/100 g in OFSP cake. On the other hand, it is relatively lower than that reported by [24] which was found to range from 0.2469 mg/3.02 mg/100 g to 0.6704 mg/100 g in when researchers made the porridge from sorghum, chickpeas, and OFSP flour. Several factors, such as the kind of ingredients, cooking method used, and cooking duration, contribute to the differences in the beta-carotene content.

The amount of ascorbic acid in the different OFSP products dried in the sun and by other methods was statistically different ($p \le 0.05$). The average concentration of ascorbic acid varied between 3.48-9.31 mg/100 g and 3.29-10.45 mg/100 g, as indicated in Table 1. According to the [25], the recommended dietary allowance (RDA) for vitamin C in adults is 75mg/day for females and 90mg/day for males. The findings of this study are quite low, and therefore, it is recommended that consumers should not rely on OFSP flour and its products as a main source of vitamin C. Also, the results of this study were lower than those reported by [26], who found that the OFSP had an ascorbic content of 15.04 to 17.27 mg/100 g. The difference may be due to the application of heat during the preparation of porridge and stiff porridge, hence the significant reduction of ascorbic acid in the respective products. The retention was higher in solar-dried products as compared to sun-dried products because solar drying can be controlled to allow a measurable quantity of heat, while sun-drying occurs under uncontrolled conditions; ascorbic acid is heat-sensitive and a water-soluble nutrient; hence, under high heat treatments, considerable losses are encountered.

Table 1. *Nutrient content of OFSP porridge and Ugali (stiff porridge).*

Products	OFSP variety	Processing method	Proximate analysis								
			Moisture (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrates (%)	β-carotene (mg/100 g)	Ascorbic acid (mg/100 g)	Ash (%)	Total Energy (Kcal/100g)
Porridge	Ejumla	Sun	45.18 ± 0.03^{f}	4.78±1.54^{f}	1.19±0.07^{f}	1.06±0.0$03^{j}$	87.75 ± 0.43^{c}	21.24 ± 0.08^{l}	3.48 ±0.14^{i}	3.53 ± 0.02^{j}	381.63 ± 1.23^{c}
		Solar	45.43± 2.12^{e}	4.07±00.9^{j}	1.32 ± 0.02^{e}	2.47 ± 0.08^{d}	86.00 ± 0.11^{g}	22.35 ± 0.01^{g}	5.79 ±0.11^{f}	4.67 ± 0.24^{d}	376.16 ± 2.14^{g}
	Jewel	Sun	58.10± 0.01^{a}	4.70±06^{g}	1.12±002^{g}	2.43 ± 0.35^{d}	87.17 ± 1.43^{e}	23.43 ± 2.31^{d}	7.16 ±0.25^{d}	4.18 ±0.04^{g}	377.56 ± 3.12^{f}
		Solar	58.23± 0.32^{b}	5.35±0.04^{b}	1.34 ± 0.14^{e}	2.84 ± 0.37^{c}	85.40 ±3.65^{i}	25.61 ± 0.18^{c}	9.31 ±0.06^{c}	4.58 ± 0.16^{e}	375.06 ± 5.46^{h}
	Carrot Dar	Sun	47.86± 0.21^{c}	4.23±2.91^{i}	0.87 ± 0.03^{i}	1.93 ± 0.15^{h}	84.06 ± 0.04^{j}	21.74 ± 0.07^{i}	3.51 ±0.68^{h}	2.90 ± 0.01^{k}	384.99 ± 4.37^{c}
		Solar	47.32± 0.09^{d}	4.38 ± 0.55^{h}	0.97 ± 0.09^{h}	2.30 ± 0.61^{e}	87.23 ±3.16^{a}	22.31 ± 0.05^{h}	5.83 ±0.21^{f}	3.73 ± 0.21^{i}	379.17 ± 3.15^{e}
Ugali	Ejumla	Sun	21.34± 0.06^{k}	5.13 ± 0.38^{c}	1.98 ± 0.19^{c}	1.89 ± 0.04^{i}	87.89 ± 4.10^{b}	21.20 ± 0.071^{l}	3.29 ±0.08^{j}	3.89 ± 0.54^{h}	389.90 ± 3.97^{b}
		Solar	21.26 ± 0.04^{l}	5.76 ± 0.04^{a}	2.03 ± 0.35^{c}	2.29 ± 0.05^{e}	86.91 ± 0.02^{f}	22.43 ± 0.43^{f}	5.12 ±0.99^{g}	4.99 ± 0.72^{c}	388.98 ± 5.78^{b}
	Jewel	Sun	25.67 ±0.13^{h}	4.87 ± 0.75^{e}	2.76 ± 0.81^{b}	3.16 ± 0.01^{b}	87.45 ± 2.96^{d}	26.65 ± 0.06^{b}	9.42 ±1.39^{b}	5.23±0.003^{b}	394.12 ± 4.47^{a}
		Solar	25.65±	5.80 ±	2.98 ±	3.23 ±	85.51 ±	28.79 ±	10.45 ±	5.98 ±	396.06 ±

Products	OFSP variety	Processing method	Proximate analysis								
			Moisture (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrates (%)	β-carotene (mg/100 g)	Ascorbic acid (mg/100 g)	Ash (%)	Total Energy (Kcal/100g)
			0.65^{h}	0.01^{a}	0.56^{a}	0.65^{a}	0.09^{h}	1.14^{a}	0.18^{a}	0.05^{a}	2.57^{a}
	Carrot Dar	Sun	21.98 ± 0.98^{i}	4.67 ± 0.08^{g}	1.86 ± 0.34^{d}	2.16 ± 0.06^{f}	80.11 ± 0.45^{k}	21.67 ± 0.43^{j}	3.56 ± 0.03^{h}	4.12 ± 1.18^{g}	379.86 ± 7.79^{d}
		Solar	21.43 ± 0.001^{j}	4.98 ± 0.56^{d}	2.01 ± 0.04^{c}	2.08 ± 0.35^{g}	85.42 ± 0.21^{l}	22.87 ± 0.32^{e}	5.89 ± 0.26^{e}	4.43 ± 0.07^{f}	381.69 ± 1.84^{c}

Values are means ± SD, and values within the same column with different superscript letters are significantly different from each other at $p<0.05$.

3.3. Mineral Content of the Formulated OFSP Ready-to-serve Porridge and Stiff Porridge

Minerals are essential for maintaining a healthy body, facilitating the proper function of bones, muscles, the heart, and the brain, among other roles [26]. They contribute to the synthesis of enzymes and hormones. This study examined the mineral content (calcium, potassium, sodium, magnesium, zinc, and iron) in ready-to-serve and stiff porridge produced from OFSP flours processed using solar and sun methods. The results for mineral contents are presented in Table 2. There was a significant difference ($p<0.05$) between solar and sun-dried products in all tested essential minerals. Products that were dried in the sun had lower mineral content than products that were dried using solar energy. This may be attributed to solar driers operating under controlled circumstances, unlike sun drying, reducing the loss of essential minerals. Furthermore, stiff porridge underscored higher concentrations of all essential minerals than ready-to-serve porridge. This may be ascribed to the greater quantity of OFSP flour utilized in preparing stiff porridge than that employed for OFSP porridge. An increased amount of flour results in a higher concentration of micronutrients in the product. Moreover, the Jewel variety exhibited a notable abundance of essential minerals, including calcium (21.65 mg/100 g), iron (0.72 mg/100 g), zinc (0.51 mg/100 g), potassium (90.70 mg/100 g), sodium (169.98 mg/100 g), and magnesium (13.26 mg/100 g).

Calcium is the most abundant mineral in the body. It is essential for making strong bones and teeth. The body needs calcium for muscles to move and for nerves to carry messages between the brain and every body part [27]. The mean calcium in the present study ranged between 8.20-11.32 mg/100 g and 7.32-21.65 mg/100 g in porridge and *Ugali*, respectively. These results are relatively lower than [20] reported, who recorded a calcium level of 13.53 to 17.39 mg/100g in sorghum and OFSP flour porridge. This is because sorghum flour was incorporated into the mixture, and it is known to have a higher calcium content. Similarly, [24] recorded a higher calcium content of 99.91mg/100g in porridge made from OFSP flour, sorghum, and chickpea flour. Contrary to our findings, sorghum and chickpeas contribute to the observed high calcium levels. Potassium is an essential mineral for the body's functions. It helps the nerves and muscle heart to function well and move nutrients and waste products around the body's cells [27]. The present study's mean potassium ranged from 41.68 to 78.25 mg/100 g and 54.78 to 90.70 mg/100 g in porridge and stiff porridge, respectively. This amount was relatively higher than that reported by [20]. The mean sodium content in the present study ranged between 26.19-34.24 mg/100 g and 137.78-169.98 mg/100 g in porridge and stiff porridge, respectively. The recommended dietary sodium intake is 1500mg/100g [28]. Although sodium has a lower content in this study, it can be easily obtained from other foods and the daily habit of adding salt to foods during consumption. Magnesium helps to maintain normal nerve and muscle function, supports a healthy immune system, keeps the heartbeat steady, and helps bones remain strong [27]. In the present study, magnesium content ranged between 0.63-3.44 mg/100 g and 8.75-13.26 mg/100 g in porridge and *Ugali* (stiff porridge), respectively.

Zinc is a major player in the creation of DNA, the growth of cells, building proteins, the healing of damaged tissue, and supporting a healthy immune system [28]. Zinc in the current study ranged between 0.11-0.40 mg/100 g and 0.19-0.51 mg/100 g. These findings were lower than those of [24], which ranged from 2.12 to 2.66 mg/100 g. They incorporated chickpeas and sorghum in their study, which are known to be valuable sources of zinc.

Iron is an essential mineral for making hemoglobin, a protein in red blood cells in the body. These red blood cells help carry oxygen throughout the body. In the present study, iron content ranged between 0.13-0.35 mg/100 g and 0.41-0.72 mg/100 g in porridge and stiff porridge, respectively. The findings of our study were lower than those reported by [24], who recorded a good level of 4.28 to 7.65 mg/100 g. The difference is that sorghum was incorporated in the OFSP used to make porridge, and research activities have shown that sorghum is an excellent source of iron, unlike in this study where porridge and stiff porridge were made from OFSP flour only.

Table 2. *The mineral content of porridge and Ugali (stiff porridge) made from different varieties of OFSP flour under sun-dried and solar-dried treatments.*

Prod-ucts	OFSP variety	Pro-cessing method	Minerals (mg/100 g)					
			Ca	K	Na	Mg	Zn	Fe
Porridge	Ejumla	Sun	8. 20 ±0.03[f]	41.68 ±1.54[f]	27.19 ±0.08[f]	0.90 ±0.002[j]	0.11 ±0.45[c]	0.13 ±0.06[l]
		Solar	10.60 ±2.12[e]	73.17 ±00.9[j]	30.32 ±0.01[e]	0.60 ±0.77[d]	0.13 ±0.12[g]	0.35 ±0.02[g]
	Jewel	Sun	11.32 ±0.01[a]	50.60 ±0.06[g]	31.12 ±0.006[g]	2.13 ±0.34[d]	0.17 ±1.42[e]	0.18 ±2.32[d]
		Solar	13.27 ±0.32[b]	78.25 ±0.04[b]	34.24 ±0.15[e]	3.44 ±0.36[c]	0.40 ±3.64[i]	0.43 ±0.17[c]
	Carrot Dar	Sun	8.36 ±0.21[c]	45.43 ±2.91[i]	28.67 ±0.02[i]	0.93 ±0.14[h]	0.12 ±0.03[j]	0.14 ±0.06[i]
		Solar	10.21 ±0.09[d]	74.48 ±0.55[h]	31.97 ±0.06[h]	0.63 ±0.60[e]	0.14 ±3.15[a]	0.35 ±0.04[h]
Stiff porridge	Ejumla	Sun	17.33 ±0.06[k]	55.23 ±0.38[c]	131.78 ±0.19[c]	8.75 ±0.03[i]	0.19 ±4.14[b]	0.41 ±0.07[l]
		Solar	43.29 ±0.04[l]	85.66 ±0.04[a]	164.03 ±0.38[c]	12.45 ±0.04[e]	0.21 ±0.03[f]	0.59 ±0.42[f]
	Jewel	Sun	20.67 ±0.13[h]	64.67 ±0.75[e]	137.76 ±0.80[b]	10.36 ±0.02[b]	0.45 ±2.96[d]	0.65 ±0.05[b]
		Solar	21.65 ±0.65[h]	90.70 ±0.01[a]	169.98 ±0.55[a]	13.26 ±0.64[a]	0.51 ±0.07[h]	0.72 ±1.13[a]
	Carrot Dar	Sun	8.28 ±0.98[i]	73.57 ±0.08[g]	131.86 ±0.37[d]	8.86 ±0.05[f]	0.21 ±0.46[k]	0.43 ±0.42[j]
		Solar	10.36 ±0.01[j]	54.78 ±0.56[d]	162.01 ±0.02[c]	12.68 ±0.34[g]	0.22 ±0.23[l]	0.61 ±0.31[e]

3.4. Sensory Evaluation of OFSP Porridge and *Ugali* (stiff porridge)

The important sensory attributes, such as color, texture, taste, aroma, and overall acceptability, are summarized in Table 3. The cooking time was 15 and 20 minutes at 100 ℃ and 70-90 ℃ for porridge and *Ugali*, respectively. The data were presented as the mean consumer acceptance of the porridge and *Ugali* prepared from OFSP flour. The mean scores indicated the degree of liking (acceptability scores) for color, texture, taste, aroma, and overall acceptability. According to [17] it is essential to know the likely acceptability reaction to the characteristics of your product when offering a new product or changing the ingredients of food items. The organoleptic evaluation of the OFSP porridge and *Ugali* yielded sensory scores within the following ranges: color (3.2–4.5), texture (2.8–3.7), taste (2.7–4.0), aroma (3.0–3.7), and overall acceptability (3.0–3.9) for the ready-to-serve porridge; and color (3.0–3.9), texture (2.0–3.7), taste (2.1–3.4), aroma (2.1–3.2), and overall acceptability (2.4–3.4) for the stiff porridge, as detailed in Table 3. These findings indicate varying degrees of sensory acceptance, with the porridge generally receiving higher scores across all attributes than the *Ugali* (stiff porridge). Typically, solar-dried products exhibited a better color and texture acceptance score than sun-dried products. It was observed that porridge made from solar-dried OFSP flour had the highest overall acceptability of 3.9, and the least liked sample was stiff porridge made from sun-dried OFSP flour variety, with an overall acceptability of 2.4. Regarding OFSP varieties, the Ejumla variety was the most preferred by the panelists. In contrast, the least preferred was the Jewel variety, despite it having the highest concentrations of essential minerals, as demonstrated in this study. Similar findings were reported by [26].

Table 3. *Sensory evaluation scores of porridges and Ugali (stiff porridges) made from different varieties of OFSP flour.*

Products	Varieties	Processing methods	Sensory attributes				
			Color	Texture	Taste	Aroma	Overall acceptability
Porridge	Ejumla	Sun	3.7 ±0.01[a]	3.5 ±0.17[a]	3.8 ±0.09[a]	3.4 ±0.02b	3.6 ±0.17[a]
		Solar	3.9 ±0.05[a]	3.7 ±0.06[a]	4.0 ±0.03[a]	3.6 ±0.06b	3.9 ±0.06[a]

Products	Varieties	Processing methods	Sensory attributes				
			Color	Texture	Taste	Aroma	Overall acceptability
	Jewel	Sun	4.3 ±0.12[a]	2.8 ±0.03[d]	2.7 ±0.72[d]	3.0 ±0.09c	3.0 ±0.01[c]
		Solar	4.5 ±0.01[a]	3.0 ±0.01[c]	2.9 ±0.02[d]	3.4 ±0.16b	3.2 ±0.04[c]
	Carrot Dar	Sun	3.2 ±0.04[b]	3.1 ±0.15[c]	3.7 ±0.05[a]	3.5 ±0.05b	3.3 ±0.06[c]
		Solar	3.5 ±0.03[b]	3.2 ±0.05[c]	3.9 ±0.07[a]	3.7 ±0.01a	3.5 ±0.03[b]
	Ejumla	Sun	3.0 ±0.02[c]	3.7 ±0.72[a]	3.4 ±0.02[b]	3.1 ±0.14c	3.3 ±0.12[c]
		Solar	3.9 ±0.12[a]	3.5 ±0.16[b]	3.1 ±0.06[c]	3.0 ±0.27c	3.4 ±0.09[b]
Stiff porridge	Jewel	Sun	3.0 ±0.06[c]	2.0 ±0.04[d]	2.1 ±0.01[d]	2.3 ±0.11d	2.4 ±0.79[d]
		Solar	3.2 ±0.09[c]	2.5 ±0.04[d]	2.3±0.14[d]	2.1 ±0.05d	2.5 ±0.31[b]
	Carrot Dar	Sun	3.0 ±0.04[c]	2.8 ±0.07[d]	3.1 ±0.15[c]	3.2 ±0.04c	3.0 ±0.07[c]
		Solar	3.2 ±0.08[c]	3.1 ±0.13[c]	3.1 ±0.01[c]	3.0 ±0.08c	3.1 ±0.21[c]

4. Conclusion and Recommendation

This study found that both sun-drying and solar-drying procedures led to nutritional losses, especially in heat-sensitive compounds such as β-carotene and ascorbic acid. Nonetheless, solar-dried OFSP porridge and *Ugali* (stiff-porridge) retained more essential nutrients compared to sun-dried products comparison to sun-dried products. This highlights how controlled drying conditions are more effective for micronutrient preservation in foods. Furthermore, solar-dried products were rated higher in various sensorial attributes such as color, texture and overall acceptability. The Jewel variety exhibited the highest concentration of essential nutrients, although the Ejumla variety was more favored. This underscores the necessity of improving the sensory characteristics of the Jewel variety to boost consumer preference, thus enabling individuals to benefit from its micro-nutrient content. Advocating for solar drying instead of conventional sun-drying methods is beneficial for enhancing the nutritional advantages of OFSP.

Abbreviations

OFSP	Orange Fleshed Sweet Potato
VAD	Vitamin A Deficiency
SUA	Sokoine University of Agriculture
DPRTC	Directorate of Postgraduate Studies, Research, Technology Transfer and Consultancy

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Author Contributions

Caresma Chuwa: Conceptualization, Methodology, Data curation, Formal analysis, Investigation, Writing–original draft

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Data Availability Statement

Data supporting the findings of this study are available within the article.

Conflicts of Interest

The authors declare no conflicts of interest.

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