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A Comparative Evaluation of Orange-Fleshed Sweet Potato Varieties Grown in Burundi and Their Dehydration Methods in Terms of Residuals Beta-Carotene Content

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Abstract

During the drying and grinding processes, orange-fleshed sweet potatoes undergo various forms of degradation, including browning and a reduction in their residual beta-carotene content. In the present study residual of *β*-carotene content of four varieties of OFSP cultivated in Burundi (Irene, Naspot 9, Naspot 12 and Yanzovu) was assessed after being dried using both oven-drying and drying in sun. Naspot 12 variety exhibited the highest residual *β*-carotene content after being dried using both the two drying methods assessed. Residual *β*-carotene retention was however higher in the flour produced by oven-drying than that obtained by the sun-drying method. Naspot 12 is the ideal variety for retaining *β*-carotene after drying, whether in an oven-drying or in the sun. It is therefore the variety of choice for producing sweet potato flour with a high *β*-carotene content and could help prevent vitamin A deficiency, the one that produces flour with a high with a view to promoting its use to help prevent vitamin A deficiency-related diseases observed in households in Burundi.

Keywords

Orange-Fleshed Sweet Potato, Sun Drying, Oven-Drying, *β*-Carotene, Variety

1. Introduction

Sweet potatoes are the third most widely grown crop in Burundi, after cassava and bananas [1]. Rich in carbohydrates, sweet potato is a highly nutritious root crop. Among starchy staples, it is unique for its substantial content of β-carotene, particularly in the orange-fleshed varieties [2].

Previous study in Mexico, has shown that flour processed from orange-fleshed sweet potatoes is both industrially viable and economically viable, thus offering an option for the industrial marketing of sweet potatoes [3]. In China, research indicates that OFSP varieties contain high levels of β-carotene and are recommended for the production of flours and functional food ingredients [4]. In South Africa, research shows that incorporating orange-fleshed sweet potato flour into composite flours improves the nutritional value and increases the β-carotene content of food products [5].

Flours made from orange-fleshed sweet potatoes are used to produce nutrient-enriched foods designed to improve the nutritional quality of food products [6]. Sweet potato flour plays a vital role in the preparation of various foods, thereby helping to improve consumers' nutritional status and health [7]. OFSP flours can be incorporated into wheat flour for bread-making health [7] and improve the nutritional quality of other flours after blending [8]. This flour can be used to combat vitamin A deficiency [9], one of the major public health problems in low-income countries, particularly in Africa [10]. The processing of OFSP into flour by drying is practised in Africa to extend shelf life and to produce flours used in local food products [11]. Another method of processing into enriched flour is thermal drying in a drying oven [12].

In Burundi, a recent study shows that some rural households process orange-fleshed sweet potatoes into flour using the sun-drying method [13]. This flour could help prevent diseases and infant mortality linked to vitamin A deficiency [14], which continues to affect several African countries, including Burundi, with consequences in terms of nutritional morbidity. Currently, to prevent vitamin A deficiency, vitamin A supplementation campaigns are often organized by the Ministry of Public Health and the Fight against AIDS in Burundi in collaboration with its partners [15]. This is why diverse sources of vitamin A are necessary, including the processing of OFSP into flour that can be used to manufacture various products, such as porridge for children.

However, processing OFSP into flour through drying can result in a reduction in β-carotene levels, depending on the variety and the drying method [16] [17]. Indeed, although the sun drying was seen to be more detrimental to the residual β-carotene levels (27% - 56% retention) in cassava than shade (59%) or oven-drying (55% - 91%), Koua & Niamké *et al*. [9] stated that the pro-Vitamin A retention levels (66% - 96%) in sweet potato were not significantly different among the various drying methods. In fact:

The residual β-carotene content is the amount of β-carotene remaining in a foodstuff after processing (cooking, drying, storage, processing, etc.). It is expressed in mg of β-carotene per 100 g of foodstuff. In other words, the residual content = the amount of β-carotene measured after processing. β-carotene retention represents the percentage of β-carotene retained after processing, relative to the amount originally present in the food with,

$$\text{Retention}\left(\%\right)=\frac{\beta-\text{carotene content after processing}}{\beta-\text{carotene content before processing}}\times 100$$

The loss of beta-carotene corresponds to the percentage of beta-carotene content destroyed during processing where:

$$\text{Loss}\left(\%\right)=100-\text{Retention}\left(\%\right)$$

The aim of this research is to compare the β-carotene retention level of four OFSP largely cultivated in the plains along the shores of Lake Tanganyika in Burundi (Irene, Naspot 9, Naspot 12 or Yanzovu) at the end of two different drying processes (sun drying and oven-drying) and their conversion into flour.

2. Materials and Methods

2.1. Harvesting the Roots of Orange-Fleshed Sweet Potatoes

Four varieties (Irene, Naspot 9, Naspot 12 and Yanzovu) field grown in Rugombo, in the Cibitoke commune were harvested from smallholders' fields, following a four-month growing period. These varieties were chosen because they were recently introduced in this region between 2019 and 2023, making it easy to locate farmers growing them and thus enabling samples to be collected without difficulty. After being washed under running water to remove all traces of soil and other dirt [18], the roots were stored in refrigerated containers [19]. This was done to minimize the breakdown of β-carotene whilst they were being transported to the laboratory, a journey that took 45 minutes. Before the analysis, all the harvested roots were frozen at −20˚C for 5 days at National Food Technology Centre in Burundi.

2.2. Sample Preparation

For each OFSP variety studied, the roots were washed in tap water and peeled into small slices using a stainless steel knife [20]. After slicing, the OFSP slices were immediately dried to minimize air contact and prevent oxidation. The fresh OFSP roots and flour were not converted to dry weight in order to reflect their actual beta-carotene content. This approach allows for compliance with the moisture standards inherent to flour while avoiding overestimation of beta-carotene losses, which increase with heat intensity and drying time. The orange-fleshed sweet potato roots were divided into two batches of four varieties. For each variety, a 5 kg sample was peeled and then cut into small slices approximately 5 mm thick. The first batch was dried in a forced-air drying oven (Genlab Limited, N2005FTDIG/SS/FS, United Kingdom) at 45˚C [21] and the second batch in the sun on a rack placed on a table approximately one meter above the ground. Both drying methods were continued until a moisture content of less than 15.5%, the maximum threshold required for flour [22]. The moisture contents (percentage) found in the flour; for each variety, are shown in **Table 1**. This moisture content was achieved after 48 hours of exposure to the oven-drying, whereas sun drying took 72 hours. After drying, root slices were crushed and sieved to 300 µm [23] to obtain fine flour. The moisture content of the flour was measured using a pin-moisture meter following the protocol described by [24] and adapted as follows: the moisture meter was first fitted with its batteries, and its two metal probes were cleaned using a dry cloth. Once the device was switched on, a waiting period of a few seconds was observed until the display stabilized. At the same time, a sample of OFSP flour was homogenized by manual mixing, then transferred to a container. The device's probes were then inserted into the flour, taking care not to touch the bottom of the container. The moisture content value was displayed on the screen and recorded as soon as it stabilized. To ensure the reliability of the results, the procedure was repeated three times for each measurement and an average was calculated.

Table 1. Moisture content (%), by variety, of the flour obtained after drying.

Varieties	Moisture content of flour obtained by drying in an oven	Moisture content of flour obtained by sun-drying
Irene	13.3	13.5
Naspot 9	13.5	13.4
Naspot 12	13.9	13.8
Yanzovu	13.6	13.7

2.3. Determination of the Maximum Absorption Wavelength of *β*-Carotene

Measurements of *β*-carotene content of sample were performed using a UV-visible spectrophotometer (SHIMADZU, model UVMini-1240, Japan) at 460 nm according to the method established by [25].

2.4. Calibration Method

To calibrate this method standard solution of b-carotene (Sigma Aldrich) was prepared as described by [25] and adapted as follows: 0.1 g of standard *β*-carotene was weighed, dissolved in a chloroform/methanol solvent mixture (30:10) and the entire volume was poured into a 100 ml volumetric flask, to which the same solvent mixture was added until the flask was completely filled. Next, 10 ml of the prepared solution were taken and transferred to a 100 ml volumetric flask, then made up to the mark with the solvent mixture. From the previous solution, aliquots of 50 ml, 25 ml, 15 ml and 5 ml were taken respectively and transferred to 100 ml volumetric flasks, then topped up each time with a solvent mixture (chloroform/methanol) to the mark. A linear relationship between absorbance and *β*-carotene concentration was established. The linearity of the response was validated by a coefficient of determination (R^2) of 0.9967, thereby confirming the reliability of the measurements taken [26].

2.5. Determination of *β*-Carotene Content

β-carotene was extracted according to the protocol described by [25], with a few adjustments: 30 g of orange-fleshed sweet potato flour samples were placed in a separating funnel, followed by the addition of a chloroform/methanol mixture (30:10). After shaking the sealed flask for 30 minutes, the mixture was left to settle for two hours, resulting in a liquid and a semi-solid phase. The liquid phase thus isolated by decantation and by pipetting off the supernatant, was injected into the UV-visible spectrophotometer (SHIMADZU, model UVMini-1240, Japan) and the results were read at 460 nm. The *β*-carotene content was determined by calculating the average of three repeated measurements for each variety studied. The *β*-carotene content was calculated using the formula described by [27].

2.6. Statistical Analysis

The results were analysed using STATA software (version 17). The effect of the varieties of orange-fleshed sweet potatoes on *β*-carotene content was assessed using an analysis of variance (ANOVA) at the 5% significance level (**Table 3**). In addition, a Bonferroni test (**Table 4**) was carried out at the same significance level to compare the varieties as reported by [28]. Furthermore, a comparison of the drying methods (oven versus sun-drying) using a Student's t-test (**Table 5**) revealed a statistically significant difference.

3. Results and Discussion

Table 2 below shows, for each variety, the retention and loss of *β*-carotene content compared to the initial content after drying the flour in an oven and in the sun.

Table 2. Initial *β*-carotene content (mg/100g) and its loss following drying (%), by variety.

Varieties	*β*-carotene in fresh OFSP	*β*-carotene after oven drying	*β*-carotene after sun drying	Losses of *β*-carotene after oven drying	Losses of *β*-carotene after sun drying
Irene	14.70	13.96	9.85	5.05	32.97
Naspot 9	20.24	14.63	12.84	27.69	36.58
Naspot 12	20.41	17.83	16.24	12.66	20.41
Yanzovu	15.74	14.78	11.92	6.13	24.26

Figure 1 shows the percentage retention of *β*-carotene content after each drying method (oven-dried and sun-dried) as a function of the initial content of each variety. **Figure 2**, meanwhile, shows the initial and post-drying *β*-carotene contents (mg/100g) for each OFSP variety and each drying method.

Figure 1 shows that the *β*-carotene content of the "Irene" variety had decreased slightly from its initial value, after drying. In other words, Irene retains a significant amount of this element compared to other varieties.

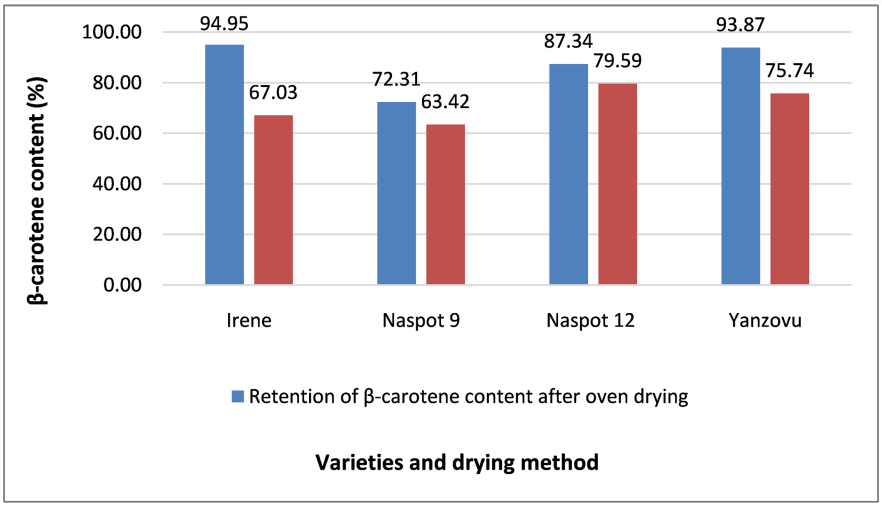

Figure 1. Comparison of β-carotene content retention in sweet potatoes of four varieties after drying.

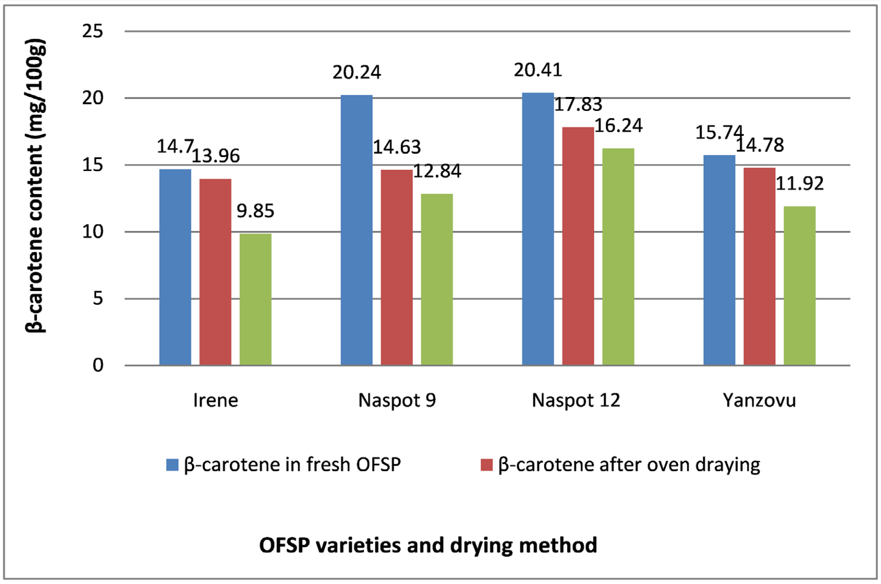

Figure 2. Comparison of β-carotene content (mg/100g) in sweet potatoes of the four varieties before and after drying.

Figure 2 shows that the Naspot 12 variety contains high levels of β-carotene for all drying methods.

According to **Table 2**, our study revealed β-carotene content ranging from 14.70 mg/100g to 20.41 mg/100g in the fresh OFSP root samples, This is consistent with the results find by [29], where the β-carotene content of orange-fleshed sweet potatoes ranged from 4.29 to 18.55 mg/100 g for orange-fleshed varieties in South Africa and the main American variety, Beauregard, had a value of 9.23 mg/100g [30]. Other results reported by [31] indicate that values in similar samples range from 5.85 to 13.63 mg/100g of β-carotene in fresh matter, depending on the variety. Conversely, other researchers have reported low β-carotene values compared to those obtained in our study, which are 0.254 ± 3.84 and 0.181 ± 2.64 mg/100g respectively for the Ejumula and Kakamega varieties [32]. This discrepancy may be explained by the considerable variability in *β*-carotene content depending on the variety [31]. The four varieties included in our study differ from those examined by these authors and significant differences may exist between varieties [16].

For oven-drying flour, the Irene variety had a high retention capacity (94.95%) compared to the other varieties, but its *β*-carotene content after drying remains lower than that of Naspot 12 (17.83 mg/100g versus 13.96 mg/100g) following a notable difference recorded in the fresh state (20.41 mg/100g) for Naspot 12 versus that of the Irene variety (14.70 mg/100g), which favours better preservation after processing (**Table 2**).

For the processing of orange-fleshed sweet potatoes into flour by sun-drying, Naspot 12 remains the variety retaining a high *β*-carotene content (79.59%) (**Table 2**).

Statistical analysis of the results, with a significance level of 5%, indicates a statistically significant difference between the varieties, as shown in **Table 3**. Indeed, the results show significant variation among the varieties studied. The highest average content was observed in the Naspot 12 variety (17.03 mg/100g), followed by Naspot 9 (13.74 mg/100g), Yanzovu (13.35 mg/100g), and finally Irene (11.91 mg/100g). Analysis of variance confirms that these differences are statistically significant ($p < 0.05$).

Table 3. Analysis of variance of *β*-carotene content according to the 4 varieties of OFSP.

Varieties	Average *β*-carotene content	p value of ANOVA
Irene	11.91	
Naspot 9	17.03	
Naspot 9	13.74	0.0002
Yanzovu	13.35	

Since ANOVA did not allow us to specify the nature of the differences between varieties, a Bonferroni multiple comparison test was applied to precisely identify the significant inter-varietal differences (**Table 4**).

Table 4. Comparison of *β*-carotene content of the 4 varieties by the Bonferroni test.

Values of the varieties to be subtracted from each other	Difference in *β*-carotene content between varieties	p-value
Naspot 12 minus Irene	5.13	0.001
Naspot 9 minus Irene	1.83	0.369
Yanzovu minus Irene	1.44	0.800
Naspot 9 minus Naspot 12	−3.30	0.011
Yanzovu minus Naspot 12	−3.68	0.004
Yanzovu minus Naspot 9	−0.38	1.000

The Bonferroni test reveals that Naspot 12 has a significantly higher β-carotene content than all other varieties ($p < 0.05$), highlighting its particular interest for programs to combat vitamin A deficiency.

To also verify whether drying methods influence beta-carotene content, a Student's t-test was applied at a significance level of 5% (**Table 5**).

Table 5. Determination of the effect of drying methods using the Student's t-test.

Drying method	Mean	confidence interval		Std. dev.	p-value
Oven drying	15.30	14.26	16.34	1.63	0.0030
Sun-dring	12.71	11.16	14.27	2.45	

Oven drying preserved an average content of 15.30 mg/100g, compared to 12.71 mg/100g for sun drying. The Student's t-test indicates that this difference is significant ($p < 0.05$). These results show that sun drying leads to greater degradation of β-carotene, while oven drying, allows for better preservation of nutritional value.

Our study indicates that processing sweet potatoes into flour by oven-drying and sun-drying reduces the β-carotene content compared to the initial amount. Sun-drying reduces β-carotene, with a greater loss than oven-drying. Indeed, β-carotene retention ranges from 72.31% to 94.95% when oven-dried at 45˚C for 48 hours, and from 63.42% to 79.59% when sun-dried for 72 hours. These results could be explained by the different working conditions for these two drying methods. Indeed:

In order to protect the drying products from nighttime weather, they were systematically transferred to a closed room each day after sunset. The processing and analysis of the samples were carried out in September 2026 in Bujumbura, an area with favorable solar potential for drying. During the month of September, the average solar radiation generally ranges between 5.0 and 5.5 kWh/m^2/day, with an average daily sunshine duration of 6.8 hours and a temperature of 29.93˚C [33]. Weather measurements taken outside the homes where sun-drying was carried out showed that the ambient temperature ranged from 27˚C to 33˚C, while the relative humidity was between 42% and 54% during the day. At night, the samples were stored in a room to protect them from nighttime weather. In this room, the temperature ranged from 18˚C to 24˚C and the relative humidity from 73% to 82%. These observations demonstrate that sun-drying is strongly influenced by weather conditions, particularly variations in temperature and relative humidity, which can affect the drying rate as well as the final quality of the products.

Oven drying is carried out at a predetermined temperature based on the experimental conditions. The oven is equipped with a ventilation system that ensures continuous circulation of hot air around the samples. This air renewal improves heat and mass transfer, thus promoting moisture removal. This results in faster, more uniform, and better-controlled drying than natural drying methods.

The ambient conditions inside the house housing the drying oven were characterized, during the day, by a temperature between 21˚C and 25˚C and a relative humidity of 41% to 50%. At night, the temperature was between 16˚C and 19˚C, while the relative humidity was 52% to 58%.

The results of our study are similar to those reported in [31], indicating that the type of drying influences *β*-carotene loss, with the highest retention observed during oven-drying, ranging from 89% to 96% over 48 hours and the lowest retention during sun-drying, ranging from 63% to 73% over 72 hours. In our study, the reduction in *β*-carotene ranged from 5.05% to 27.69% during oven-drying and from 20.41% to 36.58% during sun-drying (**Table 2**). Our results are similar to those of [16], who reported a reduction in *β*-carotene content, depending on the drying method, of 3.2% to 7.4% after oven-drying and 20.9% to 22.4% after sun drying. However, there are significant differences between these two studies due to *β*-carotene levels, which can be low or high depending on the variety [16].

The reduction in *β*-carotene content is significant after sun-drying for the following reasons: The first reason is that *β*-carotene is highly sensitive to light, particularly to UV rays, as direct exposure to sunlight causes photo-oxidation of *β*-carotene [34] and the breakdown of the pigment's double bonds [35]. In fact, *β*-carotene (C40H56) consists of a long chain of conjugated double bonds, making it unstable in the presence of oxygen and UV light; it absorbs visible light and promotes oxidation reactions during sun-drying [36]. The second reason is that oxygen promotes the oxidation of carotenoids [37]. Another argument is that sun-drying generally takes longer and depends on weather conditions (humidity, solar intensity); the longer the drying time, the more *β*-carotene degrades [35] and [38]. Furthermore, unstable environmental conditions lead to rapid degradation of carotenoids, including *β*-carotene [39] and [40]. When weather conditions are constantly changing (alternating sun and shade, clouds and temperature fluctuations), the activation and deactivation cycles of *β*-carotene become more frequent, which accelerates its breakdown.

Furthermore, the reduction in *β*-carotene content is minimal during flour processing by oven-drying because, with this method: i) exposure to light is low or non-existent, unlike in sun drying where radiation accelerates oxidation [41], ii) Controlling temperature and airflow [41], iii) The rapid inactivation of oxidative enzymes (enzymes that remain active for many hours catalyze the oxidation of carotenoids) [42], iv) Protection of the cell matrix (rapid drying in an oven causes a change in the cellular structure of the sweet potato which, in some cases, can form a protective micro-crust on the surface that limits the penetration of oxygen from the air into the center of the product, thereby reducing auto-oxidation) [38].

The results of our study are also similar to those reported by [17], which state that heat treatments cause variations in *β*-carotene content depending on the variety, with *β*-carotene retention after drying ranging from 200 µg/g to 1000 µg/g across the four varieties studied. Our study is also consistent with that of [16], which reports that the Kulfo variety decreased from 400 µg/g to 320 µg/g for sun-drying and from 400 μg/g to 372 μg/g for oven-drying, whilst for the Tulla variety, the values decreased from 335 μg/g of β-carotene to 260 μg/g for sun-drying and from 335 to 310 μg/g for oven-drying.

4. Conclusion

The aim of this study was to identify a variety that produces flour retaining a high β-carotene content after oven-drying and sun drying. It is important to note that the study was conducted in a single growing area and during a single harvest period. Orange-fleshed sweet potatoes were processed into flour by oven-drying and sun drying, followed by grinding and sieving to obtain a fine flour. The flour obtained from these two drying methods (oven-drying and sun drying) was analyzed to determine its β-carotene content. The results showed that the Naspot 12 variety retains a higher β-carotene content compared to the other varieties for both drying methods, with statistically significant differences ($p < 0.05$). The best method for preserving a high β-carotene content is oven-drying, but this one cannot be implemented immediately for rural households as the equipment requires electricity seeing that there is not by now. However, it can be recommended for farmers living in areas with access to electricity. Rural households that do not yet have electricity are advised to make do with using varieties that retain a high content after drying.

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Author Contributions

Concept and design of study: E.N., P.M. and V.N.; Data collection: E.N.; Analysis: E.N., P.M., S.S., A.N. and V.N.; Manuscript drafting: E.N., P.M., S.S, A.N. and V.N.; Significant revision of the manuscript and important intellectual content: E.N., P.M., S.S., A.N. and V.N.; Submission of the ready-to-print version of their manuscript: E.N., P.M., S.S., A.N. and V.N. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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