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Effects of drying methods on the qualities of beetroot flour

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ABSTRACT

The effects of drying methods on the qualities of beetroot flour were investigated. Fresh beetroot was purchased from a local market, peeled, washed and sliced into 3 mm, 5 mm, and 7 mm slice thickness. The sliced sample was divided into 3 groups for solar drying (Dehy-tray), sun drying, and oven drying, respectively. The oven dried sample was dried at 50 °C. The drying process was concluded when weight of samples remained constant at three consecutive reading. The dried sample were then milled, sieved and packaged for analysis. The proximate properties evaluated include; moisture content, ash content, fat content, crude fiber content, protein content, and carbohydrate content. Functional properties evaluated are swelling capacity, bulk density, water absorption capacity and oil absorption capacity. The data obtained from the results were statistically analyzed using SPSS 15 statistical package and the mean separated. The analysis of variance showed that there is a significant difference ($p < 0.05$) between all samples of beetroot flour in terms of proximate and functional properties. The results showed that 3 mm slice thickness of oven dried sample at 50 °C had the lowest moisture content of 6.10%, and the highest fiber content of 1.95%. The 7 mm slice thickness of solar dried sample had the highest protein content of 3.38%, and the 3 mm slice thickness of solar dried sample had the highest carbohydrate content of 76.66%. It is concluded that solar drying (Dehy-tray) method and 3 mm slice thickness should be used for drying beetroot as it retains the highest percentage of fat content, ash content, protein content, carbohydrate content and bulk density, and therefore recommended.

Keywords: drying methods, slice thickness, functional and proximate properties, beetroot flour, quality analysis

INTRODUCTION

The beet, *beta vulgaris* are herbaceous biennial root vegetables which belongs to the *chenopodiaceae* family. They are cultivated for their edible roots. Typically, they grow upright, with a rosette of leaves on stems and a lengthy primary root. The leaves are oval-shaped, reach lengths of 20-40 cm and are arranged alternately on the stem. The roots are predominantly red in color. The plant can grow to heights of 1-2 meters and produces sessile green flowers beetroot cool-season crop and grow well in the cool temperatures, beetroot requires 45 to 65 days to reach harvest (Plantvillage, 2022). Beetroot flour is suitable for enhancing the color of salad dressings, gravies, sauces, soups, and any recipe (Surti, 2021). Also, it can be mixed with water for smoothies and green drinks. Beetroot is also a rich source of diverse minerals such as potassium, sodium, phosphorous, calcium, magnesium, copper, iron, zinc and manganese. The beetroot, apart from consumption in its fresh form, it is also a valuable vegetable used in the food industry to produce dried and frozen food, non-concentrated and concentrated juices as well as natural colorants which is betalains (betacyanins and betaxanthins) used as additives in food manufacturing, flavonoids, polyphenols, saponins and inorganic nitrate, beetroot contains both betaine and nitrate. Betaine is a trimethyl derivative of amino acid glycine which promotes muscular endurance, strength, and power (Favero et al., 2012; Hoffman et al., 2009). The beetroot is an excellent source of a wide range of nutrients which include the carbohydrates, fibre, minerals (potassium, calcium, iron, phosphorus, and sodium) and vitamins (pro-vitamin A, niacin, and vitamin C). Across various food cultures, it is frequently consumed in the form of supplementary juice, powder, pickled, bread, gel, pureed, boiled or jam-processed foods. Beetroot peel contains higher antioxidant compounds thus promising a more intense utilization of the peels in food and nutraceuticals. Beetroot pigment is used commercially as a food dye. It can be used in ice cream, candy, and other confectionary due to it changes in color when heated. Also, beetroot is classified as one of the ten plants with the highest antioxidant activity. It is believed to be the primary commercial source of betalains, which are used in gelatins, confectionary, dairy, meat, and poultry-derived products as concentrated forms, powder, or natural color (Mirmiran et al., 2020).

Food preservation aims to extend the shelf life of food while preserving its nutrients and quality. Reducing the

Table 1. Production of beetroot in the world (Smrithi, 2021)

Country	Production (in million metric tons)	Percentage of the world (%)
France	29	11.98
Germany	25	10.33
USA	25	10.33
Russia	22	9.09
Ukraine	16	6.61
Turkey	14	5.79
Italy	12	4.96
Poland	11	4.55
Britain	8	3.31
Spain	7	2.89
World	242	100

moisture content of fruits and vegetables is important to extending their shelf life and promoting food security due to its high moisture content (Singh et al., 2013). Fruits and vegetables play a significant part in human diet and nutrition. The beetroot flour should be kept out of direct sunlight in an airtight container to prevent moisture buildup. Depending on how it is preserved, it can last for more than a year with minor color and nutritional changes (Merva, 2021). The two most widely utilized drying techniques for agricultural produce are sun and oven drying, sun drying is the most often utilized method (Matazu & Haroun, 2004). In order to maintain the quality of stored fruits and vegetables, it is normally kept in humid conditions. For most perishable crops, the higher the humidity the better it is in storage. However, if the humidity is too high, water may condense on top of the product thus increasing rotting (Sunmonu et al., 2012).

Beetroot Production Analysis

The total production of beetroot in the world is 242 million metric tons. Beetroot production is shown in **Table 1**.

Production of beetroot in the world are, as shown in **Table 1**, it was observed that most of the beetroot-producing countries are located in Europe, followed by USA and Russia. In fact, temperate climatic conditions of Europe, Russia and USA are most suitable for beetroot production.

The importance of the nutritional, sensory and functional quality of beetroot flour includes the following benefits:

1. It improves blood and cardiovascular health by supporting heart health, maintaining normal blood pressure, ensuring healthy circulation of blood and oxygen, and boosting energy, stamina, endurance, and athletic recovery.
2. It exhibits anti-inflammatory properties due to its contents of phytonutrients like *vulgaxanthin*, *betanin*, and *isobetanin*, which helps regulate the body's inflammatory responses.
3. It is sustainable, versatile and convenient. It is perfect for baking, sauces, oatmeal, smoothies, and many more.
4. It is incredibly nutrient-dense, i.e., it is a great source of foliate, manganese, potassium, iron, and vitamins.

Drying of Agricultural Product

Agricultural crops are important for human diet, depending upon its nature, including vitamins, mineral and fibers. Crops like beetroot are highly seasonal and are usually available in plenty. In the peak seasons, the selling price of crops becomes too low, leading to heavy losses for the grower and this leads to an unnecessary stock in the market, resulting in the spoilage of large quantities. Due to its seasonal nature, a need was felt to preserve crops over a period of time for use during off-seasons. Most of the post-harvest losses of agricultural product in developing countries like Nigeria are due to the lack of proper storage facilities (Adepoju & Osunde, 2017).

Preservation of crops can prevent the huge wastage and make them available in the off-season at remunerative prices. In addition, the seasonal nature of availability has led to efforts to extend the shelf life of crops by dehydration. Also, in order to reduce the post-harvest loss, the crops can be converted to stabilize products by drying so that it can be stored for extended periods of time. Various drying methods like sun-drying, oven-drying and many more have been practiced for dehydrating crops. Thus, it can be said that drying is the procedure used to remove excess moisture from the crop to reduce moisture levels to a level which is acceptable for safe storage. Dry air can absorb moisture faster and no cooling occurs in the extreme case of air that is totally saturated with water (Ajayi, 2011). The major reasons of drying of beetroot are; to reduce losses of beetroot, to use beetroot to make other things like sauce and wine and also, there is a growing need to optimize the process for achieving quality retention.

Drying is the oldest method of preserving food. It is a mass transfer process consisting of the removal of moisture from a solid, semi-solid or a liquid. It is also a method of food preservation that works by removing water from the food, which inhibits deterioration (Maxwell & Zantoph, 2002). Food can be dried in several ways. For example, it can be dried by sunlight if the air is hot and dry enough, in an oven if the climate is humid or in solar system if the climate is hot to about 30-40 °C (Zantoph & Schuster, 2004). Sun drying uses heat from the sun and natural movement of the air but exposes the food material to environmental factors such as dust, bacterial growth and excessive respiration. Drying involves the use of equipment (dryer). There are different types of mechanical dryers which include solar dryer, cabinet dryer, flash dryer (Agoreyo et al., 2011).

The selection of a drying method depends on the nature of the product, the situation, and provision of energy input (Gunathilake et al., 2018). The shelf life of agricultural products can also be enhanced by drying. These products are generally dried by hot air. Sun drying is the most common method to preserve the agricultural products in most of tropical countries. However, this technique is extremely weather dependent and has the problems of contamination with dust, soil, sand particles and insects. Also, the required drying time can be quite long (Mirmiran et al., 2020). Evaluating and choosing drying method that minimize environmental impact, increase resource efficiency, conserve energy, and retain nutrients are essential toward achieving sustainability in food production which promote food security. Drying operation should be done properly to remove dirt and prevent contamination. For effective and efficient drying, the steps to be carried out are listed below.

The main objectives of drying as reported by Fodor et al. (2006) are, as follows:

1. Extended storage life
2. Quality enhancement
3. Ease of handling
4. Further processing

Methods of Drying

Drying methods are the various techniques used to remove moisture from an agricultural product. Moisture removal is important to preserve and prepare produce for further use, as moisture can encourage the growth of microorganisms which causes spoilage, and lead to degradation of the produce (Ahmed et al., 2010). There are several drying methods available including sun drying, solar drying, and oven drying.

Sun drying

Sun drying is one of the most widespread and cheap methods practiced by most developing and underdeveloped countries, especially in tropics, where good sunshine hours available throughout the year. In this process, food commodities are laid on a platform in a thin layer for uniform drying. The heat of the sun does not only reduce the moisture level as desired, but also kills insects present in the food product. Sun drying has certain limitations as it is dependent on the weather and sunshine hours. During uncertain rain and precipitation, the materials are not dried properly, which causes microbial growth and other qualitative deteriorations. The drying process usually takes a long time, thus causing infestation from insects, birds, and animals. Also, this method of drying requires a large area. Despite these disadvantages, sun drying is still practiced in many parts of the world. The quality of sun dried foods can be improved by reducing the size of pieces to achieve faster drying on raised platforms, covered with cloth or net to prevent insects and animals (Ochimana, 2016).

The disadvantages of sun drying methods includes

1. Damage to the product by rodents, birds, and animals
2. Degradation through exposure
3. Contamination
4. Insect infestation
5. Growth of microorganisms
6. Insufficient or non-uniform drying losses > 30% (Kumpavat et al., 2019).

Solar drying

Solar drying systems have been developed as a successful and economical tool for drying agricultural product. Solar drying is achieved by direct sun radiation and greenhouse effect. The solar energy received by the drying chamber is dependent on the sunshine hours, climate, weather, atmospheric clearness, and location. According to Fodor (2006), on a clear day solar radiation available to any location is dependent on the angle of the sun relative to horizon. Solar energy is free, renewable, abundant, and an environment friendly energy source. This reduces drying time due to effective utilization of solar energy. It maintains the quality of the food products and acts as an ideal substitute for fossil fuel based dryers. The two basic limitations faced by the solar dryers are sunshine hours and weather change (Ochimana, 2016).

The various advantages associated with the use of solar dryers include:

1. The dryers can be connected in series and hence its capacity can be enhanced as per requirement, and it can be dismantled easily.
2. Solar dryer can save fuel and electricity, drying time in solar dryer is reduced in comparison to open drying method.
3. Products are protected against flies, rain and dust; product can be left in the dryer overnight during rain, since dryers are waterproof.
4. Fruits and vegetables dried in solar dryer are better in quality and hygienic than dried in sun.
5. It reduces losses and better market price to the products
6. Materials required for fabrication of solar dryer are locally available.
7. The use of solar dryer involves no fire risks (Lokesh et al., 2015)

Oven drying

Oven-drying is a method of drying agricultural produce that involves the use of an oven to remove moisture from the product. Oven-drying is a common method of drying agricultural produce due to its convenience, consistency, and ability to preserve the quality of the produce. However, the specific oven-drying conditions may vary depending on the type of produce being dried and the desired end-product characteristics. The process involves exposing the produce to a controlled temperature and air circulation inside an oven until the desired moisture content is reached.

The following are the basic steps involved in oven-drying of agricultural produce:

1. **Preparing the produce:** The agricultural produce is first cleaned, sorted, and sliced into uniform sizes to ensure even drying.
2. **Loading the produce in the oven:** The prepared produce is loaded onto trays and placed inside the oven. The trays are arranged in a single layer to ensure proper air circulation.
3. **Setting the temperature and time:** The oven temperature and drying time depend on the type of produce being dried and the desired moisture content. Generally, the oven temperature is set between 40°C to 70 °C, and the drying time can range from several hours to several days.
4. **Monitoring the drying process:** The drying process is monitored to ensure that the produce is drying properly and evenly. The trays may be rotated or shifted to ensure even drying and prevent sticking.
5. **Testing for dryness:** The produce is tested periodically to determine if it has reached the desired moisture content. This can be done by weighing the produce at a given time until a constant weight is attained.

6. **Cooling and storage:** Once the produce is dried, it is removed from the oven and allowed to cool. It can then be stored in airtight containers in a cool dry place until ready for use.

The heating time in oven drying procedures is relatively short, and moisture loss is minimal. Oven drying has the following advantages over other methods: faster heating (saving time), uniform volumetric heating, self-regulating and automatic system, higher efficiency, lowers processing costs (low energy consumption), and compatibility with traditional heating. Oven-drying is becoming more popular as the demand for plant-based foods in fast-dehydrated form grows (Singh et al., 2013).

Factors Affecting Drying of Agricultural Product

The following are the important factors that affects the rate of drying agricultural product, these include:

1. Initial moisture content of the raw material
2. Temperature, relative humidity and velocity of air used for drying (temperature between 49 °C to 60 °C is recommended for drying of fruits and vegetables).
3. Rate of heat transfer on the surface of the product
4. Composition of raw material
5. Initial load of the raw material
6. Size, shape and arrangement of stacking of the raw material
7. Pre-treatment of the raw material prior to drying (for example, peeling, blanching, sulphuring, etc.).

Aim of the Study

The aim of this study is to determine the effects of drying methods on the qualities of beetroot flour with a view to establish the most suitable drying methods in terms of retained proximate and functional qualities.

METHODOLOGY

This study was done in order to investigate the impact and effect of various drying method (sun, solar, and oven) on the proximate and functional quality of beetroot flour. Uniform and mature beetroot free from physical defects were purchased from Kure Market in Minna, Nigeria and then transported to the crop processing and storage laboratory of the department of agricultural and bioresources engineering, Federal University of Technology, Minna for analysis. They were carefully washed, peeled, sorted and sliced, ensuring consistency. The cleaned beetroot was sliced (3 mm, 5 mm, and 7 mm thick) and prepared into three samples; sample A, sample B, sample C which were then dried in an electric vacuum oven at 50 °C, solar drier (Dehy-tray) and sun, respectively. Oven was set at 50 °C, Dehy-tray was used for solar drying, and sun drying samples under direct sunlight. All samples were arranged in layers for 3 mm, 5 mm, and 7 mm thickness, respectively. These samples were monitored carefully and weighed regularly until moisture content reached constant weight. Each drying method was applied under controlled conditions to monitor changes in the properties.

Plate 1: Fresh beetroot vegetable Plate 2: Cleaned beetroot vegetable

Figure 1. Beetroot vegetables (Source: Authors' own elaboration)

For further analysis, all samples were milled, sieved, packaged and stored separately. The data was statistically evaluated to determine the analysis of variance (ANOVA) and the means were separated. The apparatus used for this paperwork are: VWR vacuum oven, Model 1410, solar dryer (Dehy-tray), borosil desiccator (200 mm), 1,100 °C muffle furnace with digital controller & venting port-KSL-1200X-L, Edamix series FRP fume cupboard, crucible (5 ml-10 ml), Kern analytical balance (220-4M), flat bottom silica dish, graduated cylinder (10 mL and 50 mL), beaker, glass petri dish, pyrex glass conical flask, magnetic stirrer hot plate 110V 85-2, test tube, vernier caliper 150 mm. **Figure 1** shows beetroot vegetables.

Proximate Properties

Moisture content

Moisture content was determined using the method of Association of Official Analytical Chemists (2005). The moisture cans were thoroughly washed and dried in the oven and weighed using analytical weighing balance as W1. 2 grams of the sample was put into the oven at 105 °C for about 3 hours. The samples were removed and placed in the desiccator to cool, and weighing was carried out afterwards. The sample was reheated and cooled intermittently until constant mass was obtained as W2. The difference in mass as percent moisture was then calculated as the percentage moisture content.

$$Moisture\ content\ (\%) = \frac{W1-W2}{W2} \times 100. \quad (1)$$

Crude fiber determination

Crude fiber was determined using the method of Association of Official Analytical Chemists (2005). About 5 g of each sample weighed and recorded W0 into a 500 ml conical flask and 100 ml of digestion reagent added. It was subjected to boiling for about 40 minutes counting from the start of boiling. The flask was removed from the heater, cooled a little and then filtered through a filter paper. The residue were washed with hot water, stirred once with a spatula and transferred to a porcelain dish. The sample was dried at 105 °C. After drying, it was then transferred to a desiccator and weighed as W1. It was burnt in a muffle furnace at 500°C for 6 hours, allowed to cool, and re-weighed as W_2.

$$Crude\ fiber\ (\%) = \frac{W1-W2}{W2} \times 100, \quad (2)$$

where, W1 is weight of crucible + fibre + ash, W2 is weight of crucible + ash, and W0 is dry weight of sample.

Crude protein determination

The Kjeldahl method was used for the determination of crude protein. 0.5 gram of each dry sample was weighed and put into a Kjedahl digestion flask. One tablet of catalyst was added into each of the flask moistened with distilled water and mixed with equal volume of 45% NaOH (sodium hydroxide) solution in a semi-micro Kjedahl distillation apparatus. The distilled mixture and the distillate was collected into 10ml of 4% boric solution containing 3 drops of mixed indicator (methyl-orange). A total of 50 ml distillate was collected and titrated against 0.02 ml of H_2SO_4 solution. A blank experiment was then set involving digestion of all the materials except the sample. The distillation was also carried out on the blank. The titre value of the blank was subtracted from that of the sample and the difference obtained was calculated using the formula below:

$$Nitrogen\ (\%) = Titre\ value \times morality\ of\ H_2SO_4 \times 0.0014 \times 50/5 \times 100. \quad (3)$$

Therefore, crude protein (%) = Nitrogen (%) × 6.25. $Crude\ protein\ \% = \%\ Nitrogen \times 6.25$

Ash content

Ash content was determined using the method of Association of Official Analytical Chemists (2005). About 5 g of each sample was weighed into crucibles in duplicate, the samples were further transferred into a muffle furnace using a pair of tongs and ashes at 550 °C for about 4 hours until white ash was obtained. The sample was then removed from the furnace and cooled in a desiccator to avoid absorption of moisture and weighed to obtain ash content. The percentage ash content was then calculated, as follows:

$$Ash\ content\ (\%) = \frac{Weight\ of\ ash}{Weight\ of\ sample} \times 100. \quad (4)$$

Fat content

Fat content was determined using the method of Association of Official Analytical Chemists (2005). About 10 g of sample was measured and wrapped in a filter paper which was then weighed using a chemical balance. It was placed in an extraction thimble of the Soxhlet setup after the sample was cleaned, dried in an oven, and cooled in a desiccator before weighing. Then, about 25 ml of solvent (n-hexane) was measured into the flask as it was kept at 60 °C. The process was carried out for a duration of 5 hours in order to enhance efficient fat extraction from the sample. After extraction, the solvent was evaporated by drying in the oven. The flask and its content was cooled in a desiccator and weighed. The percentage fat content was calculated, as follows:

$$Crude\ fat\ content\ (\%) = \frac{Weight\ of\ extracted\ fat}{Weight\ of\ sample} \times 100. \quad (5)$$

Carbohydrate

The carbohydrate was determined using the method of difference by which the mean values of other factors that were analyzed was subtracted from 100.

$$Carbohydrate = 100 - (moisture\ content\ [\%] + crude\ fiber\ [\%] + ash\ [\%]). \quad (6)$$

Functional Properties

Swelling capacity

The swelling capacity was determined using the method described by Shittu and Lawal (2007). The 50 ml measuring cylinder was filled up with sample to 10 ml mark. Distilled water was added up to 50 ml. The top of the cylinder was tightly covered, and the content was mixed by inverting the cylinder. After 2 minutes, the cylinder was inverted again. The cylinder was left to stand for 3 minutes, and the final volume occupied was then recorded. Swelling capacity was determined using Eq. (7):

$$Swelling\ capacity = \frac{Weight\ of\ sample\ in\ water}{Initial\ volume\ of\ sample}. \quad (7)$$

Bulk density

This was determined using the method described by Onwuka (2005). About 2.5 g of sample was weighed and filled in a 10 ml graduated cylinder and its bottom tapped on the laboratory bench until there was no decrease in volume of the sample, the volume of the sample was then recorded. Bulk density was determined using Eq. (8):

$$Bulk\ density = \frac{Weight\ of\ sample\ (g)}{Volume\ of\ sample\ (ml)}. \quad (8)$$

Water absorption capacity

Water absorption capacity was determined using the method of Adebowale et al. (2005). About 10 ml of distilled water were added to 1g of each sample in beakers. The suspension was stirred using a magnetic stirrer for 5 minutes. The suspension obtained was then centrifuged (Bosch Model No TDL-5 Germany) at 3555 revolution per minute for 30 minutes and the supernatant was measured in a 10ml graduated cylinder. The density of water was taken as 1 g/cm^3. Water absorbed was calculated as difference between the initial volume of water added to the sample and the volume of the supernatant.

Oil absorption capacity

Oil absorption capacity was determined using the method of Adebowale et al. (2005). Ten 10ml of oil were added to 1g of each sample in beakers. The suspension was stirred using a magnetic stirrer for 5 minutes. The suspension obtained was then centrifuged (Bosch Model No TDL-5 Germany) at 3555 revolution per minute for 30 minutes and the supernatant was measured in a 10 ml graduated cylinder. The density of oil was taken as 1 g/cm^3. Oil absorbed was calculated as difference between the initial volume of water added to the sample and the volume of the supernatant.

Table 2. The effects of drying methods on the proximate quality of beetroot flour

Drying method	Slicing thickness (mm)	Ashcontent (%)	Moisture content (%)	Fatcontent (%)	Crudefiber (%)	Crudeprotein (%)	Carbohydrate (%)
Fresh sample	--	1.70 ± 0.05^{d} (4)	87.90 ± 0.10 ^{d} (4)	0.68 ± 0.01^{d} (4)	2.10 ± 0.05^{d} (4)	1.72 ± 0.10^{d} (4)	8.00 ± 0.01^{d} (4)
Sun drying	3 mm	14.50 ± 0.10^{a} (1)	6.60 ± 0.05^{a} (1)	5.70 ± 0.02^{a} (2)	0.30 ± 0.10^{a} (1)	1.52 ± 0.10^{a} (1)	71.58 ± 0.11^{a} (1)
	5 mm	12.53 ± 0.06^{a} (2)	6.70 ± 0.05^{a} (2)	5.70 ± 0.02^{b} (2)	1.15 ± 0.02^{a} (2)	3.09 ± 0.10^{a} (2)	70.83 ± 0.01^{a} (2)
	7 mm	14.47 ± 0.06^{a} (1)	6.70 ± 0.10^{a} (2)	3.30 ± 0.02^{a} (3)	1.75 ± 0.20^{a} (3)	1.87 ± 0.10^{a} (3)	73.91 ± 0.05^{a} (3)
Solar drying	3 mm	10.00 ± 1.00^{b} (1)	6.90 ± 0.10^{b} (1)	2.30 ± 0.01^{b} (1)	1.40 ± 0.20^{b} (1)	2.74 ± 0.10^{b} (1)	76.66 ± 1.22^{b} (1)
	5 mm	13.33 ± 1.53^{b} (2)	7.50 ± 0.10^{b} (2)	3.90 ± 0.01^{b} (2)	0.25 ± 0.01^{b} (2)	2.05 ± 0.20^{b} (2)	72.97 ± 0.01^{b} (2)
	7 mm	11.47 ± 0.45^{b} (1)	7.80 ± 0.15^{b} (3)	3.40 ± 0.01^{b} (3)	0.70 ± 0.20^{b} (3)	3.38 ± 0.20^{b} (3)	73.25 ± 0.02^{b} (3)
Oven drying	3 mm	12.50 ± 0.50^{c} (1)	6.10 ± 0.10^{c} (1)	4.35 ± 0.01^{c} (1)	1.95 ± 0.01^{c} (1)	2.92 ± 0.10^{c} (1)	72.18 ± 0.56^{c} (1)
	5 mm	12.50 ± 0.20^{c} (2)	6.25 ± 0.05^{c} (2)	3.25 ± 0.10^{c} (2)	1.90 ± 0.01^{c} (2)	2.22 ± 0.10^{c} (2)	73.88 ± 0.01^{c} (2)
	7 mm	14.50 ± 0.50^{a} (1)	6.54 ± 0.02^{c} (3)	3.23 ± 0.03^{c} (2)	0.70 ± 0.20^{b} (3)	2.39 ± 0.10^{c} (3)	72.64 ± 0.01^{c} (3)

Note. Means followed by the same superscript of alphabets are not significantly different ($p > 0.05$) in drying method and means followed by the same subscript of numbers are not significantly different in slice thickness in a column by Duncan multiple range test at 5% level of probability & values are mean ± SEM of triplicate determination

Table 3. The effects of drying methods on the functional quality of beetroot flour

Drying methods	Slicing thickness (mm)	Bulk density (g/ml)	Water absorption capacity (%)	Oil absorption capacity (%)	Swelling capacity (%)
Sun drying	3 mm	0.58 ± 0.02^{a} (1)	200.00 ± 20.00^{a} (1)	83.33 ± 5.77^{a} (1)	3.85 ± 0.02^{a} (1)
	5 mm	0.61 ± 0.02^{a} (1)	240.00 ± 10.00^{a} (2)	120.00 ± 10.00^{a} (2)	3.84 ± 0.02^{a} (1)
	7 mm	0.62 ± 0.03^{a} (1)	244.44 ± 5.77^{a} (3)	103.33 ± 5.77^{a}1	3.70 ± 0.05^{a} (3)
Dehy-tray	3 mm	0.57 ± 0.01^{a} (1)	220.00 ± 10.00^{b} (1)	80.00 ± 10.00^{b} (1)	5.66 ± 0.01^{b} (1)
	5 mm	0.61 ± 0.01^{a} (1)	183.33 ± 5.77^{b} (2)	64.00 ± 5.77^{b} (2)	5.66 ± 0.01^{b} (1)
	7 mm	0.62 ± 0.03^{a} (1)	240.00 ± 20.00^{b} (3)	63.33 ± 15.28^{b} (1)	7.41 ± 0.01^{b} (3)
Oven drying	3 mm	0.54 ± 0.02^{a} (3)	183.00 ± 15.00^{c} (1)	60.00 ± 10.00^{a} (1)	10.71 ± 0.01^{c} (1)
	5 mm	0.48 ± 0.01^{c} (2)	248.33 ± 5.77^{c} (2)	123.33 ± 5.77^{a} (2)	3.85 ± 0.02^{c} (2)
	7 mm	0.60 ± 0.01^{a} (1)	160.00 ± 20.00^{c} (3)	103.33 ± 15.28^{c} (1)	13.80 ± 0.01^{c} (3)

Note. Means followed by the same superscript of alphabets are not significantly different ($p > 0.05$) in drying method and means followed by the same subscript of numbers are not significantly different in slice thickness in a column by Duncan multiple range test at 5% level of probability & values are mean ± SEM of triplicate determination

RESULTS AND DISCUSSION

Proximate Composition of Fresh Beetroot

The result of the proximate composition of the fresh beetroot showed that it contains 1.70% of ash content, 87.90% of moisture content, 0.68% of fat content, 2.10% of crude fibre, 1.72% of crude protein, and 8.00% of carbohydrates. The result obtained is similar to the values reported by Kale et al. (2018) on the evaluation of physical and chemical composition of beetroot (*beta vulgaris*). The effects of drying methods on the proximate and functional qualities of beetroot flour are as presented in **Table 2** and **Table 3**, respectively.

Effects of Drying Methods on the Ash Content of Beetroot Flour

The result obtained for the ash content ranges from 10.00% to 14.50% (**Figure 2**). The result of the ash content of dried samples showed that the sundried sample had the highest value of 14.5% at 3 mm slice thickness and 7 mm slice thickness of oven dried sample, the lowest value was obtained at 3 mm slice thickness of oven dried sample at 50 °C. However, statistical analysis showed that there is no significant difference ($p > 0.05$) between the 3 mm oven dried sample and 5 mm oven dried sample, and also, statistical analysis showed that the drying methods has significant effect on the ash content of beetroot flour with significant increase compared to the fresh beetroot. The high ash content indicates the presence of inorganic nutrients which implies that beetroot flour is rich in minerals. The ash content of the dried samples increased compared to the fresh sample irrespective of the drying methods used which may be due to the reduction of moisture in the dried sample that is left to dilute the amount of ash present in the sample.

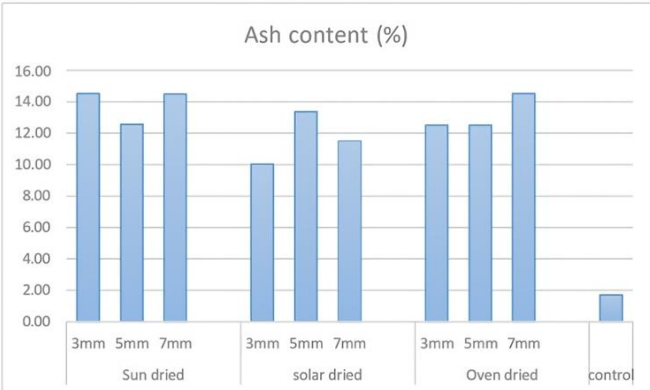

Figure 2. The effects of drying methods on the ash content of beetroot flour (Source: Authors' own elaboration)

Graphical representation of the compared analyzed at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 2**, respectively.

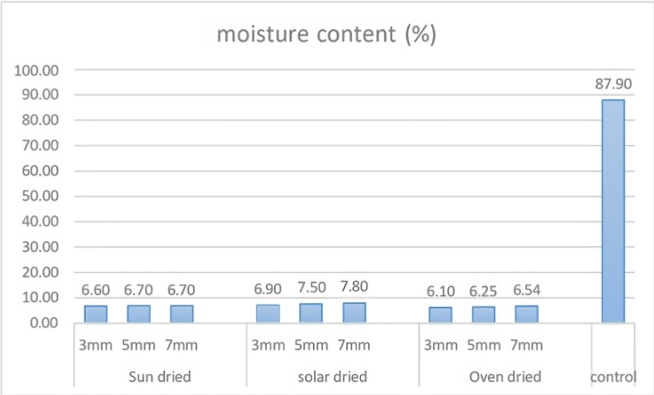

Figure 3. The effects of drying methods on the moisture content of beetroot flour (Source: Authors' own elaboration)

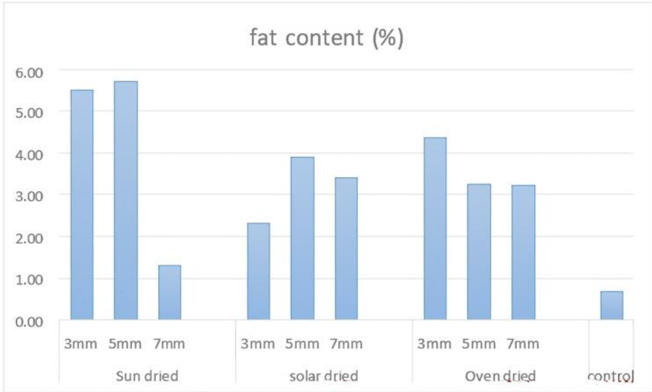

Figure 4. The effects of drying methods on the fat content of beetroot flour (Source: Authors' own elaboration)

Effects of Drying Methods on the Moisture Content of Beetroot Flour

Moisture content is the amount of water present in a product which is of great importance to agricultural industry as it can affect the properties, quality, and behavior of the product. Statistical analysis shows that the drying methods used have significant effects on the moisture content of beetroot flour (**Figure 3**). The moisture content of samples dried with sun, solar and oven ranges from 6.10% to 7.80%. There is similar trend on the moisture content of each drying method used based on the slice thickness. It was observed that increase in slice thickness leads to increase in the moisture content, this may be as a result of increase in surface area-to-volume ratio of the low slice thickness. The solar dried sample at 7 mm had the highest moisture content of 7.80%, and the oven dried sample at 3 mm had the least moisture content of 6.10% compared to the other drying methods, this observation agrees with Ogunlakin et al. (2012) who observed that oven dried sample had the least moisture content compared to sun and solar. This may be as a result of hot and dry environment created by the oven that encourages the rapid evaporation of moisture. The moisture content of the dried samples reduced significantly compared to the fresh beetroot regardless of the drying methods used, which may be due to evaporation of water vapor from the dried beetroot sample. High moisture can reduce the shelf life of a sample by increasing risk of spoilage. Therefore, it is essential to maintain proper moisture levels.

Effects of Drying Methods on the Fat Content of Beetroot Flour

Fat content refers to the amount of lipid present in a product, it is one of the three macronutrient required by the body along with carbohydrates and protein. The result obtained showed that sundried sample at 7 mm had the lowest value of 1.3% and sun dried sample at 5 mm had the highest fat content of 5.70%. Fat content of the dried samples ranges from 1.3%-5.7%. The sun dried sample has the highest fat content compared to the other drying methods. The fat content of the dried samples increased compared to the fresh sample regardless of the drying methods used. Statistical analysis showed that the drying methods (oven drying, sun drying and solar drying) used has significant effects on the fat content of beetroot flour with significant increase compared to the fresh beetroot. Low fat content can enhance the storage life of the beetroot flour due to the low chance of rancid flavor development. Graphical representation of the compared analyzed of fat content at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 4**, respectively.

Effects of Drying Methods on the Crude Fiber of Beetroot Flour

Fiber is a type of complex carbohydrate that cannot be digested by the human body's enzymes. The obtained result for the crude fiber showed that the highest value was 1.95% for oven dried sample of 3 mm slice thickness, and the lowest value had 0.25% for 5 mm solar dried sample. It was observed that fiber content of the sun dried sample increases with increase in slice thickness (0.30% of 3 mm, 1.15% of 5 mm, and 1.75% of 7 mm). The crude fiber of the dried samples reduced compared to the fresh sample irrespective of the drying methods used. However, the result obtained showed that the oven drying method has no significant difference between the 3 mm (1.95%) and 5 mm (1.90%) slice thickness. Statistical analysis showed that the drying methods used has significant effects on the crude fiber of beetroot flour with significant decrease compared to the fresh beetroot which may be as a result of changes in the composition of beetroot. Graphical representation of the compared analyzed crude fiber content at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 5**, respectively.

Effects of Drying Methods on the Crude Protein of Beetroot Flour

Proteins are complex molecules made up of long chains of amino acids. The crude protein had the highest value of 3.38% at 7 mm slice thickness of solar dried sample and had the lowest value of 1.52% at 3 mm sun dried sample. This can be as a result of exposure to elements like sunlight, wind, and dust, the high temperature of sun also can denature or break down proteins and can promote microorganism like bacteria which can lead to further degradation of proteins. From the statistical ANOVA, slice thickness (3 mm, 5 mm, and 7 mm) used has significant effects on the protein content of beetroot flour. However, statistical analysis showed that the drying methods used has significant effects on the crude protein of beetroot flour with significant increase compared to the fresh beetroot. This may be as a result of denaturation or

Figure 5. The effects of drying methods on the crude fiber content of beetroot flour (Source: Authors' own elaboration)

Figure 6. The effects of drying methods on the crude protein content of beetroot flour (Source: Authors' own elaboration)

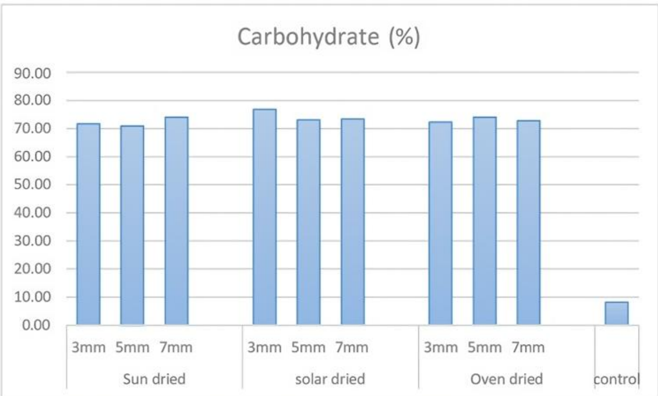

Figure 7. The effects of drying methods on the carbohydrate content of beetroot flour (Source: Authors' own elaboration)

concentrating effect as discovered by Gernah and Sengev 2011). Graphical representation of the compared analyzed at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 6**, respectively.

Effects of Drying Methods on the Carbohydrate of Beetroot Flour

The result obtained for the carbohydrate ranges from 70.83% to 76.66% (**Figure 7**), the carbohydrate content of solar dried sample at 3 mm had the highest value of 76.66%, and the lowest value of carbohydrate content was 70.83% for sun dried

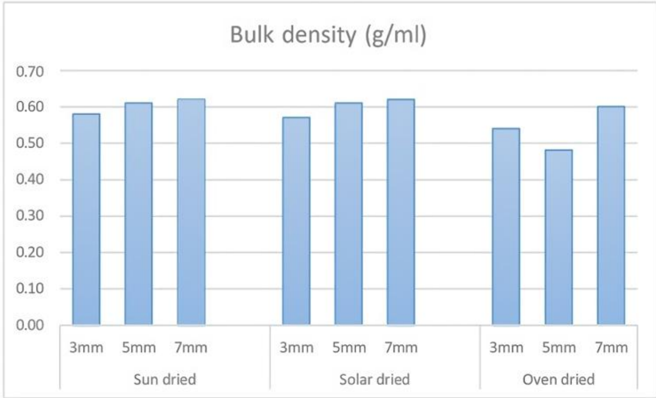

Figure 8. The effects of drying methods on the Bulk density of beetroot flour (Source: Authors' own elaboration)

sample at 5 mm. The carbohydrate content of the dried samples increased compared to the fresh sample irrespective of the drying methods used. Moreover, statistical analysis showed that the drying methods used has significant effects on the carbohydrate content of beetroot flour with significant increase compared to the fresh beetroot. This may be as the removal of water from the beetroot which makes it more concentrated in smaller volume, resulting in an increase in carbohydrate content. Carbohydrates in beetroot are mostly in form of sugars, such as sucrose, fructose, and glucose. According to Enwere (1998), the solid nutrients present in roots and tubers are predominantly made up of carbohydrates, which helps in fat metabolism and provide a rapid source of metabolizable energy.

Effects of Drying Methods on the Bulk Density of Beetroot Flour

The bulk density of the samples ranges from 0.48 g/ml to 0.62 g/ml (**Figure 8**), this is similar to the values reported by Singh et al. (2017) (0.53 g/ml to 0.74 g/ml) whose study on process optimization of spray drying of beetroot juice. The result obtained showed that the solar dried sample at 7 mm slice thickness and sun dried sample at 7 mm slice thickness had higher bulk density of 0.62 g/ml, the lowest value of beetroot was 0.48 g/ml for 5 mm slice thickness of oven dried sample. There is similar trend in the result of the slice thickness of each drying method on the bulk density of beetroot flour, which shows that the higher the slice thickness, the higher the bulk density of a sample. Statistical analysis shows that there is no significant difference between the sun dried samples and the solar dried samples and there is no significant difference between the 3 mm and 7 mm slice thickness of sun dried samples and oven dried sample on bulk density.

Hence, a lower bulk density may result in better quality beetroot with more desirable characteristics.

Effects of Drying Methods on the Water Absorption Capacity of Beetroot Flour

The result obtained for the water absorption capacity of beetroot flour ranges from 160% to 244%. The result obtained for the water absorption capacity showed that the lowest value was 160% for 7 mm oven dried samples and had the highest at 244% for 5 mm oven dried sample (**Figure 9**). It was observed

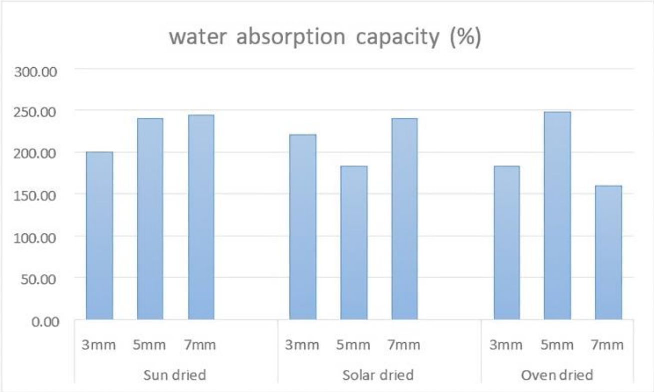

Figure 9. The effects of drying methods on the water absorption capacity of beetroot flour (Source: Authors' own elaboration)

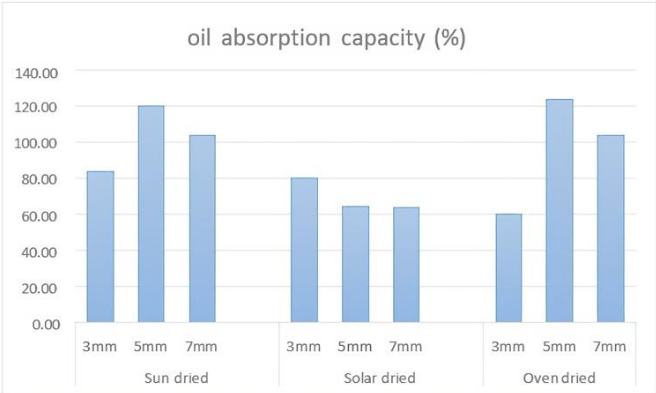

Figure 10. The effects of drying methods on the oil absorption capacity of beetroot flour (Source: Authors' own elaboration)

that the higher the slice thickness, the higher the water absorbed for sun dried samples. However, statistical analysis showed that the drying methods used has significant differences on the water absorption capacity of beetroot flour. Graphical representation of the compared analyzed at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 9**, respectively.

Effects of Drying Methods on the Oil Absorption Capacity of Beetroot Flour

Oil absorption capacity is the ability of a product to absorb oil, it is important because it can affect the quality and nutritional value of the final product. The result obtained in **Figure 10** showed that there is no significant difference ($p > 0.05$) between the sun dried sample and the oven dried sample. The value obtained ranges from 60.00% to 123.33%, the 5 mm slice thickness of oven dried sample had the highest percentage of 123.33% and the lowest value obtained was at 3 mm slice thickness of oven dried sample was 83.33%. Statistical analysis showed that the sun dried sample had similar trend on the slice thickness and there is no significant difference between the 5 mm solar dried sample (64.00%) and 7 mm solar dried sample (63.33%). The oven dried sample has the highest oil absorption capacity compared to the other drying methods. Graphical representation of the compared analyzed at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 10**, respectively.

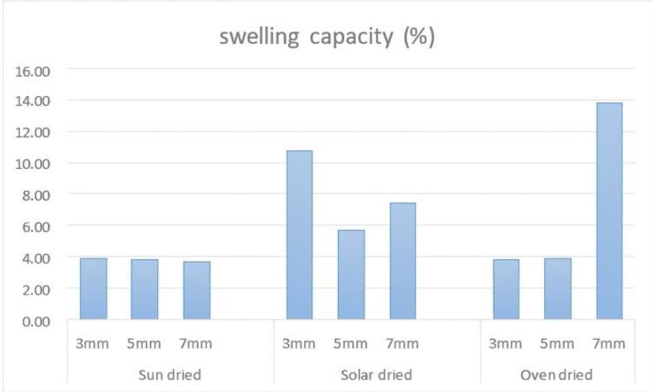

Figure 11. The effects of drying methods on the swelling capacity of beetroot flour (Source: Authors' own elaboration)

Effects of Drying Methods on the Swelling Capacity of Beetroot Flour

The swelling capacity of beetroot flour is its ability to absorb and retain water when hydrated. This property is significant in food applications, as it affects the texture, consistency, and overall quality of the end product. Higher swelling capacity indicates greater water absorption, which can contribute to improve moisture retention, thickening, and binding characteristics in food formulations. The swelling capacity of the flour obtained result ranges from 3.70% to 13.80%. The result showed that sun dried 7 mm slice thickness had the lowest value of dried samples of 3.70%, and the 7 mm of oven dried sample had the highest value of 13.8%. However, statistical analysis showed that that there is no significant difference on the slice thickness of sun dried samples (3.70 to 3.85%), and there is no significant difference on the slice thickness of 3 mm and 5 mm of oven dried samples (3.80 to 3.85%) on the swelling capacity of the sample. Graphical representation of the compared analyzed at 3 mm, 5 mm, and 7 mm for sundried, solar dried and oven dried samples is shown in **Figure 11**, respectively.

CONCLUSIONS

It was concluded in this study that drying method and slice thickness had significant effects on the proximate quality of beetroot flour. Ash content, crude protein, fat content, and carbohydrate increased significantly while the moisture content and crude fibre decreased significantly after the drying process. Drying method and slice thickness had significant effects on the functional quality of beetroot flour. The bulk density, water absorption capacity, and oil absorption capacity were significantly affected. The solar dryer should be used for drying beetroot as it retains the highest qualities similar to the fresh samples in terms of the fat content, ash content, protein content and carbohydrate content as well as the highest bulk density.

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Ethical statement: The authors stated that no ethics committee approval was required for the study. The study involves data acquisition from publicly available sources where data is not stored. Adherence to the ethical standard was followed throughout the study, guided by principles of integrity and responsibility in research conduct.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

REFERENCES

Adebowale, Y., Adeyemi, I. A., & Oshodi, A. (2005). Functional and physicochemical properties of flours of six mucuna species. *African Journal of Biotechnology, 4*(12).

Adejumo, B. A., Haruna, S. A., Chinma, C. E., Akanya, H. O., & Okolo, C. A. (2018). The influence of drying temperature on selected properties of flour produced from orange fleshed sweet potato tubers. *International Journal of Engineering Research & Technology, 7*(7), Article 339. https://doi.org/10.17577/IJERTV7IS070091

Adepoju, L., & Osunde, Z. (2017). Effect of pretreatments and drying methods on some qualities of dried mango (Mangifera indica) fruit. *Agricultural Engineering International: The CIGR E-Journal, 19*, 187-194.

Agoreyo, B., Akpiroroh, O., Orukpe., O. A., Osaweren, O., & Owabor, C., (2011). The effects of various drying methods on the nutritional composition of musa paradisiaca, Dioscorea rotundata and Colocasia esculenta. *Asian Journal of Biochemistry, 6*(6). https://doi.org/10.3923/ajb.2011.458.464

Ahmed, M., Sorifa, A. M., & Eun, J. B. (2010). Effect of pretreatments and drying temperatures on sweet potato flour. *International Journal of Food Science and Technology, 45*(4). https://doi.org/10.1111/j.1365-2621.2010.02191.x

Ajayi, O. A. (2011). *Modification and testing of an evaporative cooling facility for storing vegetables*. https://api.semanticscholar.org/CorpusID:109300928

Association of Official Analytical Chemists. (2005). *Official methods of analysis*. AOAC International.

Enwere, N. J. (1998). *Foods of plant origin*. Afro-Orbis Publications Ltd.

Favero, S., Roschel, H., Artioli, G., Ugrinowitsch, C., Tricoli, V., Costa, A., & Gualano, B. (2012). Creatine but not betaine supplementation increases muscle phosphoryl creatine content and strength performance. *Amino Acids, 42*, 2299-2305. https://doi.org/10.1007/s00726-011-0972-5

Fodor, E. V. (2006). *The solar food dryer: How to make and use your own low-cost, high performance, sun-powered food dehydrator*. New Society Publishers.

Gernah, D. I., & Sengev, A. I. (2011). Effects of processing on some chemical properties of the leaves of the drumstick tree (*Moringa oleifera*). *Nigerian Food Journal, 29*, 70-77.

Gunathilake, D. M., Senanayaka, D. P., Adiletta, G., & Senadeera, W. (2018). Drying of agricultural crops. In D. M. C. C. Gunathilake, D. P. Senanayaka, G. Adiletta, & Wiji Senadeera (Eds.), *Advances in agricultural machinery and technologies*. CRC Press. https://doi.org/10.1201/9781351132398-14

Hoffman, J. R., Ratamess, N. A., Kang, J., Rashti, S. L., & Faigenbaum, A. D. (2009). Effect of betanine supplementation on power performance and fatigue. *Journal of the International Society of Sports Nutrition, 6*(1), Article 7. https://doi.org/10.1186/1550-2783-6-7

Kale, R. G., Sawate, A. R., Kshirsagar, R. B., Patil, B. M., & Mane, R. P. (2018). Studies on evaluation of physical and chemical composition of beetroot (*beta vulgaris L.*). *International Journal of Chemical Studies, 6*(2), 2977-2979.

Kumpavat, M. T., & Sutar, P. P. (2019). Drying and storage engineering. *HZU*. https://www.hzu.edu.in/agriculture/Drying-and-Storage-Engineering.pdf

Lokesh, R. D., Vipin, H. B., & Jibhkate, Y. M. (2015). Solar dryers for drying Agricultural products. *International Journal of Engineering Research Online, 3*(2), Article 83.

Matazu, I. K., & Haroun, A. A., (2004). The effect of drying method on the nutrients and non-nutrients composition of the fruits of hibiscus esculentus (okra). *Nigeria Journal of Renewable Energy, 11*, 9-13.

Maxwell, E. O., & Zantoph, U. B. (2002). *Drying effect on food products*. CBS Publishers.

Merva, V. (2021). Beetroot powder recipe and its uses. *Simply Beyond Herbs*. https://simplybeyondherbs.com/beetroot-powder-recipe/#

Mirmiran, P., Houshialsadat, Z., Gaeini, Z., Bahadoran, Z., & Azizi, F. (2020). Functional properties of beetroot (*beta vulgaris*) in management of cardio-metabolic diseases. *Nutrition & Metabolism, 17*, Article 3. https://doi.org/10.1186/s12986-019-0421-0

Ochimana P. A. (2016). *Effect of drying methods on selected properties of cocoyam flour (colocasia esculenta)* [Mster's thesis, Federal University of Technology].

Ogunlakin, G. O., Oke, M. O., Babarinde, G. O., & Olatunbosun, D. G. (2012). Effect of drying methods on proximate composition and physio-chemical properties of cocoyam flour. *American Journal of Food Technology, 7*(4), 245-250. https://doi.org/10.3923/ajft.2012.245.250

Onwuka, G. I. (2005). *Food analysis and instrumentation: Theory and practice*. Naphtali Prints.

Plantvillage. (2022). *Beet diseases and pests, description, uses, propagation*. https://plantvillage.psu.edu/topics/beet/infos

Shittu, T. A., & Lawal, M. O. (2007). Factors affecting instant properties of powdered cocoa beverages. *Journal of Food Chemistry, 100*, 91-98. https://doi.org/10.1016/j.foodchem.2005.09.013

Singh, B., & Hathan, B. S. (2017). Process optimization of spray drying of beetroot juice. *Journal of Food Science and Technology, 54*(8), 2241-2250. https://doi.org/10.1007/s13197-017-2659-8

Singh, S., Gaikwad, K., More, P. K., & Kumbhar, B. K. (2013). Microwave convection drying characteristics of beet root (*beta vulgaris L.*) using modeling equations for drying. *Journal of Food Process Technology, 4*(7), 2-4. https://doi.org/10.4172/2157-7110.1000263

Smrithi, C. (2021). Country wise production and distribution of sugar beet around the world. *Your Article Library*. https://www.yourarticlelibrary.com/essay/country-wise-production-and-distribution-of-sugar-beet-around-the-world/25531

Sunmonu, M. O., Jimoh, M. O., & Olaniyan S. A. (2012). Comparative analysis of cooling efficiencies and nutritional variations of two different types of evaporative cooling structures. *Continental Journal Engineering Sciences, 7*(2), 1-5.

Surti, R. (2021). Is beet flour (powder) good for YOU? *Healthy Foods*. https://www.hearthyfoods.com/blogs/news/is-beet-flour-powder-good-for-you http://www.hearthyfoods.com/blogs/news/is-beet-flour-powder-good-for-you

Zantoph, B. C., & Schuster, U. N. (2004). Effects of colour drying on food products. *International Journal of Food Technology, 27*, 323-329.