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IMPACT OF DIFFERENT DRYING TREATMENTS ON THE BIOCHEMICAL AND ANTIOXIDANT ACTIVITY PROPERTIES OF EGYPTIAN RED BEETROOT

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KEY WORDS:
beetroots, betalains, phenolic compounds, antioxidant activity, freeze-drying

ABSTRACT

This paper aims to provide an overview of the main findings and conclusions of the research on freshly sliced Egyptian red beetroot (*Beta vulgaris*). Beetroot belongs to the botanical family of Chenopodiaceae and encompasses various variations with bulb hues that span the spectrum from yellow to crimson. It is known that the ethanolic extract from beet contains many health-beneficial and bioactive chemicals, such as alkaloids, carotenoids, phenols, tannins, and flavonoids; it also contains vitamins C, B3, B6, and B9. Hence, the beetroot extract exhibits both antioxidant and nutritional properties. The study was conducted to investigate the effects of two different drying processes, oven-drying (OD) and freeze-drying (FD), on the physicochemical qualities of betalain pigments and antioxidants. Overall, freeze-dried (FD) samples demonstrated superior retention of beetroots proximate composition when compared to those dried in the oven. This was observed in terms of minerals and antioxidants, with freeze-drying resulting in higher levels of these components compared to oven drying. On the other hand, reductions in some phenolic compounds were found in the samples treated with the freeze-drying method when compared with the oven-drying method. It was proven that red beets have a lot of phenolic compounds, including kaempferol, caffeic acid, vanillic acid, gallic acid, catechin acid, rutin, hesperidin, naringin, quercetin, and ferulic acid.

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ВЛИЯНИЕ РАЗЛИЧНЫХ СПОСОБОВ СУШКИ НА БИОХИМИЧЕСКИЕ И АНТИОКСИДАНТНЫЕ СВОЙСТВА ЕГИПЕТСКОЙ КРАСНОЙ СВЕКЛЫ

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КЛЮЧЕВЫЕ СЛОВА:
свекла, беталаины, феноловые соединения, антиоксидантная активность, сублимационная сушка

АННОТАЦИЯ

Цель данной статьи — представить обзор основных результатов исследования свеженарезанной египетской красной свеклы (*Beta vulgaris*). Свекла относится к ботаническому семейству *Chenopodiaceae* и включает в себя различные разновидности с луковичными оттенками, которые охватывают спектр от желтого до малинового. Известно, что этаноловый экстракт свеклы содержит много полезных для здоровья и биологически активных веществ, таких как алкалоиды, каротиноиды, фенолы, дубильные вещества и флавоноиды; он также содержит витамины С, В3, В6 и В9. Таким образом, экстракт свеклы обладает как антиоксидантными, так и питательными свойствами. Исследование было проведено с целью изучения влияния двух различных процессов сушки — сушки в духовом шкафу (OD) и сублимационной сушки (FD) — на физико-химические свойства пигментов беталаина и антиоксидантов. В целом, образцы свеклы, подвергнутые сублимационной сушке (FD), продемонстрировали лучшее сохранение исходного состава по сравнению с образцами, высушенными в духовке. Это было отмечено в отношении минералов и антиоксидантов, при этом сублимационная сушка привела к более высокому содержанию этих компонентов по сравнению с сушкой в духовом шкафу. С другой стороны, в образцах, обработанных методом сублимационной сушки, было обнаружено снижение содержания некоторых фенольных соединений по сравнению с методом сушки в печи. Было доказано, что в красной свекле содержится много фенольных соединений, в том числе кемпферол, кофейная кислота, ванильная кислота, галловая кислота, катехиновая кислота, рутин, гесперидин, нарингин, кверцетин и феруловая кислота.

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1. Introduction

The *Chenopodiaceae* family consists of the red beetroot (*Beta vulgaris*) [1]. The family *Dicotyledonous* and the genus *Chenopodiaceae* include approximately 1400 species that are classified into 105 genera [1]. The species belonging to the genus *Beta vulgaris* include *Beta vulgaris* ssp. *maritima*, *Beta vulgaris ssp. vulgaris*, and *Beta vulgaris* ssp. *adanensis* [2]. The beetroot is an edible root of robust or tapered structure. The roots exhibit a globular or cylindrical morphology and display a range of colors, including red-purple, golden yellow, or red-white, which is contingent upon the specific beet cultivar. Beets are readily available throughout the year, and the cold climate promotes the development of the vibrant red pigment in the beetroot. The harvesting period for beetroot in summer typically ranges from 75 to 90 days after planting, while in winter it extends to 100 to 120 days after planting. The availability of nitrogen controls the amount of beet sugar during the initial stages of development [3]. Beetroot has historically been used in traditional medicine for the treatment of several ailments, such as dandruff, stomach and joint discomfort, constipation, and other related conditions [4]. Recently, red beet extract has been used as a pharmacological intervention for hypertension, in addition to its recognized properties as an antioxidant and hypoglycemic

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agent [5]. Root vegetables, namely beets, include a variety of essential nutrients, including carotenoids, nitrates, flavonoids, vitamins, and minerals like calcium, magnesium, potassium, salt, phosphorus, copper, iron, zinc, and manganese. Betalains refer to a class of plant pigments that possess nitrogen and are capable of dissolving in water. The chemical structures and compositions of two betalains, namely betacyanin (a red pigment) and betaxanthin (a yellow pigment), have been ascertained. Beetroot is a highly abundant source of betanin pigment, which serves as a valuable component in dying various culinary products with visually appealing red or yellow hues. The determination of beetroot types and redness is contingent upon the proportion of betacyanin and betaxanthins, as established by [6]. According to [7] betaxanthin can be classified into two distinct varieties, namely vulgaxanthin-I and vulgaxanthin-II. The shell of beetroot was found to contain betacyanins, which include betanin, prebetanin, isobetanin, and neobetanin [8]. Betanin, an active component found in beetroot, comprises a significant proportion, ranging from 75% to 95%, of the total betacyanin content. The synthesis of betalain is initiated with the amino acid tyrosine.

There are a lot of phenolic compounds and phenolic acids in red beetroot [9]. These include catechin and epicatechin, as well as vanillic, p-coumaric, caffeic, protocatechuic, and ferulic acids. Previous studies have demonstrated that betalains exhibit favorable bioavailability and stability in the gastrointestinal tract, hence enhancing their potential as functional foods [10]. Numerous studies have indicated that beetroot is a significant source of phytochemicals that possess the ability to promote overall well-being. The antioxidant, anti-inflammatory, anticarcinogenic, and hepatoprotective properties of beetroot polyphenols, carotenoids, and vitamins contribute to the prevention of diabetes, reduction of blood pressure, mitigation of heart disease, and promotion of wound healing. Consequently, the inclusion of beetroot as an ingredient in many food products has been found to provide positive effects on human health, and it offers the potential for creating a wide range of nutritious food [11]. Using the red beetroot in human nutrition encompasses various applications. The use of this substance as a red food colorant is prevalent across a diverse range of applications, including tomato paste, sauces, sweets, jams and jellies, ice cream, candies, and cereals [12,13]. Additionally, it is added in dehydrated formats such as chips, tea, and powder in bakeries, as well as in food supplements and other related products. Numerous studies have shown that beetroot is a significant source of phytochemicals that possess the ability to promote overall well-being. The antioxidant, anti-inflammatory, anticarcinogenic, and hepatoprotective properties of beetroot polyphenols, carotenoids, and vitamins contribute to the prevention of diabetes, reduction of blood pressure, mitigation of heart disease, and promotion of wound healing. Consequently, the inclusion of beetroot as an ingredient in many food products has been found to provide positive effects on human health, and it offers the potential for creating a wide range of nutritious food [11].

The study's goal was to find out how different drying methods, such as oven-drying and freeze-drying, affect the physicochemical properties, antioxidant activity, and composition of phenolic and betalains compounds in beetroot that has been dried. The present study investigated the chemical composition and bioactive antioxidant properties of betalains in red beetroots. Additionally, the extraction and identification of phenolic compounds and flavonoids in beetroots were examined. Furthermore, the impact of thermal procedures on the antioxidant activity of red beetroots was assessed.

2. Objects and methods

2.1. Chemicals and reagents

(1) Sigma Aldrich, Germany, that supplied the DPPH (2, 2- diphenyl-1-picrylhydrazyl).
(2) El-Nasr Pharmaceutical Chemical Co., Egypt, that supplied ethanol alcohol 50%.
(3) Sigma-Aldrich Chemie provided the Folin-Ciocalteu reagents (Steinheim, Germany). All of the used reagents were of analytical grade.

2.2. Plant materials

The botanical sample used in the study was *Beta vulgaris*, commonly referred to as fresh beetroot or red beet. The product was cultivated in Egypt and subsequently purchased from a nearby marketplace. The red beets underwent a cleaning process with the running tap water and were thereafter sliced.

2.3. Preparation of fresh beetroots

A 30-kilogram batch of entire red beetroot was used for the experiment. A representative amount was taken from this batch to evaluate its composition. Subsequently, the newly harvested beetroot roots were split into two parts. One part was subjected to lyophilization, while the other was dried in an oven. The samples obtained were then crushed and stored at 20 °C until they were analyzed [14].

2.4. Drying process

2.4.1. Oven-drying

The drying method in an oven is utilized for a broad range of horticulture products, such as pumpkin, red beetroot, marrow squash, and onion, among others. In this study, the beetroot samples were dried in a convection air dryer (SHEL LAB, USA) for 390 minutes at 60 °C using natural convection. The drying process was carried out according to the described method in [15].

2.4.2. Freeze-drying

Initially, beetroot slices were subjected to a temperature of –20 °C for 12 hours before being placed in a freeze dryer. The freeze-drying procedure lasted for 48 hours using a vacuum freeze-dryer Advantage Plus (Virtis, Gardiner, NY, USA). The condenser temperature was set at –60 °C, and the vacuum pressure inside the dryer was 0.027 kPa. After completing the drying process, all samples were pulverized using an IKA A-11 analytical mill (Wilmington, USA) and then sifted through a No. 35-mesh sieve with a size of 500 µm (U. S. Standard Sieve Series, Dual Manufacturing Co., Illinois, USA). The powdered samples were hermetically packed in vacuum bags and kept at a temperature of 4 °C until they were ready for further analysis [16].

2.5. Chemical composition of raw beetroot

The chemical composition content was assessed using the methods recommended by AOAC [17], and carbohydrate was calculated by the difference.

2.6. Mineral content determination

The mineral composition of dried beetroot was analyzed using inductively coupled plasma-mass spectrometry (ICP-MS) (Agilent 7500, USA). A dried beetroot sample weighing 0.5 g was subjected to extraction in a heated digester using a mixture of 10 ml of 69% HNO3 and concentrated HCl in a 3:1 volume-to-volume ratio (DK 20, VELP Scientifica, Milan, Italy). The extract (DISMIC-25HP, Advantec, Tokyo, Japan) was filtered using 0.2 ml PTFE syringe filters. The reference materials obtained certification from Merck, a company based in Germany[18,19].

2.7. Extraction Techniques of Betalain

Betalains are a group of water-soluble compounds that include nitrogen and consist of over 55 ammonium derivatives of the chromophore betalamic acid. The experiment was conducted the methodology provided by [20,21], with the subsequent alterations: A total of 1 gram of each dehydrated substance was dissolved in 10 milliliters of an ethanol solution containing 50% ethanol. The solution was agitated at a speed of 800 rpm for 10 minutes, followed by centrifugation at a speed of 6,000 rpm for 10 minutes. To obtain the highest concentration of betalains, the liquid portion was collected in two portions using centrifugal force.

2.8. Betalain content

The quantification of betalain content was performed using a modified methodology as described in reference [22]. The homogenizer was employed to homogenize individual samples, each weighing 50 grams, in 150 milliliters of distilled water for 1 minute. The mixture was moved to a volumetric flask and strained through a glass funnel using Whatman No. 1 filter paper. The filter cake was rinsed with distilled water until the filtrate became devoid of color. The sample was thereafter subjected to centrifugation at a speed of 10,000 rpm using (Sigma 3K30, United Kingdom) for 15 minutes. A membrane filter with a diameter of 0.45 millimeters was used to separate the supernatant. The extracts were further diluted with a phosphate buffer solution (0.05 M, pH 6.5) until the absorbance reached a range of 0.4–0.5 AU. Ultimately, the process of betalain absorption was quantified by employing (T80 UV–VIS Spectrophotometer (PG Instruments, United Kingdom), which evaluated the absorption at two specific wavelengths (476 and 538 nm) [23].

2.9. Total phenolics determination

The quantification of total phenols was performed by combining 0.5 mL of an extract with 2.5 mL of a 10% folin-reagent of Ciocalteu's solution, followed by incubation at room temperature for 2 minutes. Next, the combination is subjected to the addition of 2 mL of sodium carbonate solution with a concentration of 7.5%. The resulting mixture is then maintained at a temperature of 50 °C for 15 minutes. The solution was cooled to room temperature before measuring its absorbance at 760 nm using a T80 UV–VIS Spectrophotometer (PG Instruments, United Kingdom), with distilled water as a reference sample. Gallic acid was used as a reference standard, and the results were calculated as the average of

three measurements expressed in milligrams of gallic acid equivalent (GAE) per milliliter of the extract [24].

2.10. Antioxidant capacity assay

The free radical scavenging activity was determined using a 2,2-diphenyl-1-picrylhydrazyl (DPPH) assay. In this test, the violet color of DPPH was diminished to a faint yellow shade as a result of the extraction of a hydrogen atom from the antioxidant molecule. An observation was made that enhancing the antioxidant activity resulted in a decrease in DPPH. The test reaction mixture consisted of 100 microliters of beetroot extract obtained from independent solvent extractions at different concentrations, which were prepared by diluting the extract with the extraction solvent. Additionally, 1 milliliter of a 0.1 millimolar solution of DPPH radical in methanol was added. Following intense agitation, the mixture was subjected to incubation at a temperature of 37 °C for 30 minutes. The absorbance was measured at a wavelength of 517 nm (Jenway 6305 Spectrophotometer, United Kingdom). As a means of comparison, ascorbic acid was used as a positive control reference. The free radical scavenging activity is inversely proportional to the absorbance of the reaction mixture, as expressed by the following equation:

$$\text{DPPH scavenging activity (\%)} = 100 \times \frac{A_0 - A_1}{A_0}$$

where A_0 and A_1 are the control and sample absorbance, respectively.

The findings are shown as the average of three replicate analyses, with the major values and standard deviations provided [25].

2.11. High-performance liquid chromatography (HPLC) analysis of phenolic acid and flavonoids in red beetroot

20 ml of a 2.0 M NaOH solution was added to 1 g of red beetroot in a quick-fit conical flask. Nitrogen gas (N2) was used to purge the flask, and the cork was subsequently reinserted. The material was subjected to magnetic stirring for four hours at ambient temperatures. The pH of the solution was subsequently modified to 2.0 by adding 6.0 M HCl. The mixture was subjected to centrifugation at a speed of 5000 rpm for 10 minutes, resulting in the recovery of the supernatant. The liquid component was extracted two times using 50 mL of a mixture consisting of equal parts of ethyl ether and ethyl acetate. The recovered solvents in the organic phases were evaporated completely at a temperature of 45 °C, resulting in a dry residue. This residue was then diluted again in 2 mL of methanol. An Agilent Technologies 1100 series liquid chromatography system with an autosampler and a diode array detector was used for the HPLC analysis. A Phenomenex Eclipse XDB-C18 analytical column of 150 mm in length and 4.6 mm in diameter, with a C18 guard column, was used in the experiment conducted in Torrance, CA. The mobile phase consisted of acetonitrile (solvent A) and a solution of 2% acetic acid in water (v/v) (solvent B) [26]. The flow rate was maintained at 0.8 ml/min during the whole 70-minute run, and the gradient program was as follows: the concentration of B decreases from 100% to 85% in 30 minutes, then from 85% to 50% in 20 minutes, then from 50% to 0% in 5 minutes, and finally increases from 0% to 100% in 5 minutes. The injection had a volume of 50 µl. The peaks corresponding to benzoic acid and cinnamic acid derivatives were simultaneously detected at the wavelengths of 280 nm and 320 nm, respectively. Before injection, all samples underwent filtration using a 0.45 ml Acrodisc syringe filter (Gelman Laboratory, MI). The retention times of the peaks were compared to those of standards and UV spectra [26].

2.11. Statistical analysis.

All results were expressed as mean values ± standard deviation (SD), and values are mean three replicate analyses. Comparisons were performed by analysis of variance (ANOVA). Statistical analyses were run using SAS software.

3. Results and discussion

3.1. Chemical properties and mineral composition of beetroot

The data about the chemical and mineral compositions, including the content of moisture, ether extract, ash, protein, crude fiber, and carbohydrate (calculated by difference), were analyzed and the findings are presented in Table 1 and Table 2.

Multiple studies indicate that the nutritional composition of fresh beetroots is affected by factors such as the variety of beetroot as well as the conditions in which it is grown and harvested [27]. Beetroot possesses a significant nutritional benefit due to its elevated sugar concentration [11]. According to the statistics from the United States Department of Agriculture, 100 g of raw beetroot has an average of 43 kcal of energy, 2.8 g of dietary fiber, 1.61 g of protein, 6.76 g of sugar, and 0.17 g of fat. Red beetroot can be consumed as a fresh vegetable or processed into frozen or dried food. Red beetroot possesses significant potential for utilization as a bio-functional meal with substantial added value [28]. The data shown in Table 1 indicates that beetroots are a valuable source of both carbs and protein. Due to its minimal fat content and complete absence of cholesterol, it leads to reduced consumption of calories. This is a key factor contributing to its suitability for inclusion in a weight-loss regimen. The body efficiently turns the easily metabolizable sugar content of this food into energy, regardless of its relatively high carbohydrate and sugar content. For athletes, it is advantageous to have a high sucrose content and low fructose concentration in their diet, as sucrose is more useful for them than fructose [29].

Table 1. **Proximate chemical composition of fresh red beetroot**

Таблица 1. **Приблизительный химический состав свежей красной свеклы**

Chemical composition	(g/100 g)
Moisture	84.95 ± 0.09
Ether extract	1.63 ± 0.03
Ash	1.49 ± 0.05
Crude fiber	2.50 ± 0.08
Crude protein	1.49 ± 0.04
Carbohydrate	7.94

Values are mean ± SD of three replicate analyses.

The mineral composition of the dehydrated beetroot was analyzed using inductively coupled plasma-mass spectrometry (ICP-MS). The data is displayed in Table 2.

Table 2. **Mineral content of red beetroot treated with different drying methods**

Таблица 2. **Минеральный состав красной свеклы, высушенной различными способами**

	mg/g (DW)	
Element	**Oven-dried**	**Freeze-dried**
Na	95.631 ± 0.005^b	138.623 ± 0.017^a
K	40.327 ± 0.015^b	54.672 ± 0.009^a
Mg	10.889 ± 0.016^b	13.388 ± 0.015^a
In	0.293 ± 0.005^b	2.815 ± 0.011^a
B	0.014 ± 0.005^a	0.014 ± 0.004^a
Li	0.004 ± 0.001^b	0.013 ± 0.001^a
Al	0.367 ± 0.001^b	0.869 ± 0.002^a
Ca	0.479 ± 0.002^b	0.539 ± 0.001^a
Ti	0.036 ± 0.002^a	0.034 ± 0.003^b
Cr	0.022 ± 0.002^b	0.067 ± 0.005^a
Mn	0.045 ± 0.001^b	0.072 ± 0.005^a
Fe	0.090 ± 0.001^b	0.102 ± 0.002^a
Co	0.003 ± 0.001^b	0.020 ± 0.001^a
N	0.003 ± 0.001^b	0.008 ± 0.001^a
Cu	0.078 ± 0.001^b	0.112 ± 0.002^a
Zn	0.093 ± 0.001^b	0.084 ± 0.003^a
Ga	0.019 ± 0.001^b	0.078 ± 0.002^a
Sr	0.142 ± 0.002^b	0.180 ± 0.004^a
Ag	0.037 ± 0.001^a	0.020 ± 0.001^b
Cd	0.001 ± 0.001^a	0.004 ± 0.002^a
Ba	0.010 ± 0.002^b	0.024 ± 0.003^a
Pb	0.031 ± 0.002^b	0.097 ± 0.004^a
Bi	0.124 ± 0.001^b	0.778 ± 0.003^a

* Values are mean ± SD of three replicate analyses, the letters (a, and b) represent the statistically significant differences between treatments ($p \leq 0.05$).

The current study is among the limited number of research publications investigating the mineral composition of freeze-dried and oven-dried beetroot powder. Table 2 displays the mineral composition (aluminum, calcium, iron, potassium, magnesium, sodium, lithium, zinc, lead, chromium, boron, and copper) of all red beetroot samples obtained using the chemical reference technique of ICP-MS. The freeze-dried and oven-dried powder contained significant amounts of nutritional components

such as sodium (Na), potassium (K), magnesium (Mg), and indium (In). The concentrations of these components amounted to 138.6, 54.67, 13.38, and 2.8 mg/g (dry weight) for the freeze-dried powder and 95.6, 40.3, 10.89, and 0.293 mg/g (dry weight) for the oven-dried powder respectively. The range of amounts of these four elements aligned with the reference value provided by the AIJN (Association of the Industry of Juices and Nectars) from the Fruits and Vegetables of the European Union [30]. Copper (Cu) and other harmful metals such as manganese (Mn), lead (Pb), and chromium (Cr) were detected in very small quantities (0.112, 0.072, 0.097, and 0.067 mg/g (DW), respectively) and (0.078, 0.045, 0.031, and 0.022 mg/g (DW), respectively). This indicates that red beetroot is safe for human consumption and that the levels of these metals are within the acceptable limit and do not pose a health risk [30].

3.2. Betalain content

The primary pigments found in beetroot are called betalains, and they are found in extremely high concentrations (greater than 99.0%) [31]. Data presented in Figure 1 illustrates the samples that were prepared by the freeze-drying method were found to have the highest concentration of betacyanin pigments in the current research.

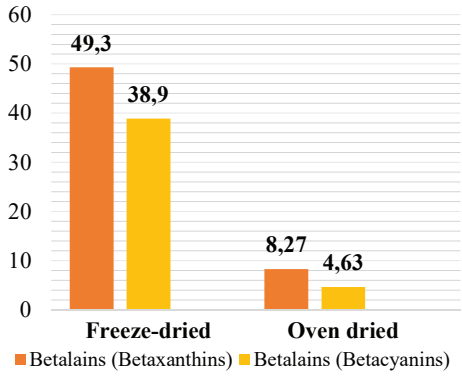

Figure 1. **Effect of the oven and freeze-drying process on betalain content of red beetroot**

Рисунок 1. **Влияние сушки в духовом шкафу и сублимационной сушки на содержание беталаина в красной свекле**

It is important to mention that the use of a temperature of 60 °C led to a decrease in the stability of betalain pigments. Compared to the freeze-dried samples, the betaxathin and betacyanin contents decreased by 83.22% and 88.09%, respectively. Three key factors could explain this decline: at a temperature of 60 °C, the presence of a relatively high amount of water in a dried sample can speed up the breakdown of betalains [27]. It has also been observed that freeze-drying can stop the activity of endogenous enzymes like glucosidase (BGL), polyphenol oxidases (PPO), and peroxidases (POX), and this can happen at both low and slightly high temperatures. However, these enzymes would remain functional at temperatures around 60 °C, thus leading to a significant increase in the degradation of betalain pigments [5,30]. Subjecting these pigments to prolonged heating at 60 °C (for 390 minutes) can cause their degradation when betacyanins convert into decarboxylated forms, leading to alterations in the hue of the product [14,23]. The levels of betalain pigment obtained in this experiment fell within the previously reported ranges [15,27,31].

3.3. Effect of oven-dryin1,5g and freeze-drying on total phenolic content and antioxidant capacity of red beetroot

Red beetroot's antioxidant properties. The impact of antioxidants on the scavenging of DPPH radicals was believed to stem from their capacity to donate hydrogen. DPPH is a persistent radical that can easily accept an electron or a hydrogen radical. This makes a stable diamagnetic molecule. We checked how well DPPH radicals could be reduced by looking at the drop in absorbance at 517 nm that antioxidants caused. The discoloration is visually visible, transitioning from purple to yellow. Additionally, phenolic compounds found in red beet have been shown to lower lipid oxidative damage, boost antioxidant status in humans, remove free radicals, reduce inflammation, fight cancer, and lower the risk of chronic diseases like cancer and heart disease [36]. For another thing, phenolic compounds are great antioxidants because of their redox potential, which lets them work as reducing agents, hydrogen donors, metal chelators, and singlet oxygen quenchers. The data in Table 3 illustrates the effect of oven-drying and freeze-drying on the total phenolic content and antioxidant capacity of the beetroot.

Table 3. **Effect of oven-drying and freeze-drying on total phenolic content and antioxidant capacity of red beetroot**

Таблица 3. **Влияние сушки в духовом шкафу и сублимационной сушки на общее содержание фенолов и антиоксидантные свойства красной свеклы**

	Drying methods	
	Oven-drying	Freeze-drying
Total phenolic acid mg/100 g dried sample	1.40 ± 0.02^{b}	2.19 ± 0.01^{a}
Antioxidant activity DPPH%	62.89 ± 0.22^{b}	69.05 ± 0.43^{a}

*Values are mean ± SD of three replicate analyses, the letters (a, and b) represent the statistically significant differences between treatments ($p \leq 0.05$).

Beetroot has several phenolic compounds that provide significant antioxidant properties. This analysis revealed the presence of betalain extracts with total phenolic content (TPC) and antioxidant properties. The freeze-dried beetroot features the highest total phenolic content (TPC). The oven-dried samples at 60 °C exhibited reduced levels of phenolic compounds, which contrasted with the results reported in [16]. Under these conditions, the TPC loss could be attributed to a range of reasons. Initially, exposure to the temperature of 60 °C for 390 minutes led to a decrease in TPC. It is worth noting that the DPPH result was identical to that stated in the referenced work [16].

3.4. The impact of oven-drying and freeze-drying on the overall phenolic content of red beetroot was assessed using high-performance liquid chromatography (HPLC)

Samples were put through an HPLC-DAD analysis to get a better representation of the specific phenolic compounds that were found in the betalain extracts. However, the data obtained from this analysis only provided identification of these compounds. Another extraction was performed using 50% ethanol to quantify the phenolic components in the samples. The summary results can be found in Table 4. Within this excerpt, a total of seventeen phenolic compounds were both qualitatively and quantitatively detected. Notably, pyrogallol emerged as the predominant phenol found in dehydrated beetroot.

Table 4. **The impact of oven-drying and freeze-drying on the overall phenolic content of red beetroot assessed using high-performance liquid chromatography (HPLC)**

Таблица 4. **Влияние сушки в духовом шкафу и сублимационной сушки на общее содержание фенолов в красной свекле, определенное с помощью высокоэффективной жидкостной хроматографии (ВЭЖХ)**

Total phenolics (mg/100 g)	Drying process	
	Oven-dried	Freeze-dried
Pyrogallol	37.79 ± 0.04^{a}	16.26 ± 0.06^{b}
Catechein	6.45 ± 0.02^{a}	2.36 ± 0.01^{b}
Protocatchoic	1.45 ± 0.01^{b}	4.89 ± 0.02^{a}
Catechol	4.61 ± 0.03^{a}	2.63 ± 0.01^{b}
chlorogenic	3.69 ± 0.05^{a}	0.39 ± 0.01^{b}
P-OH- benzoic	1.27 ± 0.02^{b}	3.37 ± 0.04^{a}
Benzoic	1.73 ± 0.02^{a}	1.12 ± 0.01^{b}
Gallic	1.26 ± 0.02^{a}	1.05 ± 0.01^{b}
4-aminobenzoic	0.62 ± 0.01^{a}	0.26 ± 0.02^{b}
Caffeic	0.54 ± 0.01^{a}	0.29 ± 0.01^{b}
Vanillic	0.97 ± 0.02^{a}	0.38 ± 0.01^{b}
P-coumaric	0.28 ± 0.03^{a}	0.22 ± 0.06^{a}
Ferulic	0.15 ± 0.03^{a}	0.18 ± 0.02^{a}
Iso-ferulic	0.26 ± 0.01^{b}	0.36 ± 0.01^{a}
α-coumaric	0.19 ± 0.03^{a}	0.22 ± 0.02^{a}
Coumarin	0.17 ± 0.01^{b}	0.92 ± 0.02^{a}
3,4,5-methoxy-cinnamic	0.72 ± 0.02^{a}	0.61 ± 0.01^{b}

*Values are mean ± SD of three replicate analyses, the letters (a, and b) represent the statistically significant differences between treatments ($p \leq 0.05$).

Table 4 illustrates the impact of processing methods on the content of phenolic acids in red beetroot. Uniform HPLC patterns of phenolic acid were observed in all processed samples, with varying amounts based on the method of treatment. Based on the information in the table, pyrogallol was the most common ingredient. Following it were catechin, protocatchoic, catechol, chlorogenic, P-OH-benzoic, benzoic, and gallic. Ferulic acid, vanillic acid, caffeic acid, coumarin, coumaric acids, and 4-aminobenzoic acid were detected in low concentrations. Beetroot exhibited

higher levels of phenolic acid in the oven-dried samples compared to the freeze-dried samples, as the drying process appears to induce the degradation of these compounds. Prior studies have shown significant reductions in phenolic compounds in the samples treated with the freeze-drying method. The authors hypothesized that the lyophilization-induced reduction in phenolics might be primarily due to structural damage to the sample cells caused by the formation of ice crystals, which could accelerate the oxidation of these chemicals [32,33,34].

The impact of oven-drying and freeze-drying on the flavonoid content of red beetroot was analyzed using high-performance liquid chromatography (HPLC). Data is presented in Table 5.

As an additional point of interest, the ethanolic extract of red beetroot contains a variety of flavonoid components, the most prevalent of which is hesperidin. Following this are naringin, rutin, rosmarinic acid, naringenin, quercetin, and apigenin. Nevertheless, traces of kaempferol, hesperetin, and quercetin were discovered in the sample. The results published in [32,35,36] were comparable. The fact that the freeze-dried samples had higher quantities of hesperidin and naringin than the dried powder in the oven suggests that the prolonged exposure to heat at those vacuum temperatures may have caused damage to the beets' cellular structure [35,36].

Table 5. **Impact of oven-drying and freeze-drying on the flavonoid content of red beetroot using high-performance liquid chromatography (HPLC)**

Таблица 5. **Влияние печной в духовом шкафу и сублимационной сушки на содержание флавоноидов в красной свекле, определенное при помощи высокоэффективной жидкостной хроматографии (ВЭЖХ)**

Flavonoids (mg/100 g)	Drying process	
	Oven-dried	Freeze-dried
Hesperidin	39.81 ± 0.01[b]	48.47 ± 0.03[a]
Naringin	1.45 ± 0.01[b]	1.61 ± 0.01[a]
Rosmarinic	0.32 ± 0.01[b]	0.72 ± 0.02[a]
Naringenin	0.27 ± 0.01[a]	0.17 ± 0.01[b]
Quercetrin	0.04 ± 0.01[b]	0.13 ± 0.01[a]
Quercetin	0.18 ± 0.01[a]	0.17 ± 0.01[a]
Hesperetin	0.03 ± 0.01[a]	0.02 ± 0.01[a]
Kaempferol	0.01 ± 0.01[a]	0.01 ± 0.01[a]
Apigenin	0.15 ± 0.01[a]	0.01 ± 0.01[b]
Rutin	1.01 ± 0.01[a]	ND

* Values are mean ± SD of three replicate analyses, the letters (a, and b) represent the statistically significant differences between treatments ($p \leq 0.05$).

4. Conclusion

Based on the research that was done and the information that was collected, the different ways of drying red beetroot, like oven-drying and freeze-drying, change its physicochemical properties, antioxidant activity, and the composition of phenolic and betalains compounds. Additionally, it is clear from this that the red beetroot (*Beta vulgaris*) has the potential to significantly increase the amount of nutrients consumed by both people and animals, regardless of its form. It is recommended to use the beetroot as a source of nutrients to supplement other significant sources of nutrients. Consuming vegetables throughout the year is recommended since they are becoming an increasingly significant component of the human diet. As a result of its low-fat content, *B. vulgaris* is advised for people who are obese or diabetic because it does not include a significant amount of carbohydrates compared to other foods. Due to the fact that it contains a substantial amount of minerals, it is recommended to consume beetroot in order to supplement the daily needs laid forth by the FAO and the WHO for sodium, potassium, and magnesium, respectively.

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