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Effect of Preparation and Drying Techniques on the Physicochemical, Functional and Nutritional Properties of products from Beetroot (*Beta Vulgaris L.*) varieties

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Drying techniques

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Iron retention

ABSTRACT

Beetroot (*Beta vulgaris* L.) is rich in biologically active compounds. This study aimed to assess how different methods of preparation and drying affect the physical, chemical, functional, and nutritional properties of iron-rich beetroot powder. Two beetroot varieties, Detroit Dark Red (DetR) and Crimson Globe (CrimG), were processed using three drying techniques: sun drying (SD), oven drying (OD), and freeze drying (FD), with both boiled and fresh beetroots. The properties evaluated in the study included water activity, color, total phenolics and flavonoids, oxalate content, and mineral content. The results showed significant ($p<0.05$) differences in these properties between the dried and fresh samples. Notably, drying increased calcium, zinc, and phosphorus levels while decreasing the iron content. Boiling followed by sun drying was the best method for retaining iron, particularly for the CrimG variety. The study suggests that drying can help preserve or even enhance the physicochemical properties and micronutrient content, especially iron while reducing phytochemical levels affecting iron absorption. These findings are important for developing iron-rich beetroot products to improve dietary iron intake, especially for adolescent children.

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1 Introduction

Beetroot (*Beta vulgaris* L.), known for its high fibre and sugar content, is also recognized for its moderate caloric value (Kovarovič et al. 2017). This vegetable, particularly the red beetroot variety (*Beta vulgaris* L. var. *vulgaris*), is appreciated worldwide for its rich composition and numerous health benefits (Székely and Máté 2023). The intense red coloration of beetroot is due to betalains, specifically betacyanins and betaxanthins, which offer significant antioxidant and anti-inflammatory properties (Șeremet and Oana-Viorela 2020). These compounds are noted for their health-promoting effects, such as inhibiting lipid peroxidation and enhancing low-density lipoprotein oxidation resistance (Șeremet and Oana-Viorela 2020).

Furthermore, consuming beetroot is linked to various health benefits, including improved blood circulation, respiratory health, skincare, and immune system support (Șeremet and Oana-Viorela 2020). Additionally, beetroot has shown potential in treating anemia by promoting red blood cell production and boosting hemoglobin levels (Ali and Bilal 2023). In today's market, which favors convenient and nutritious food options, beetroot powder has emerged as a promising product, especially for developing iron-rich supplements to enhance dietary iron intake among school-aged children (Șeremet and Oana-Viorela 2020). The drying techniques used in processing beetroot are crucial for preserving its nutrients, transforming it into powder form, and enhancing its functionality in food preparation or as a beverage ingredient (Șeremet and Oana-Viorela 2020).

However, the impact of these processing methods, including drying and thermal techniques, on the physicochemical, functional, and nutritional properties of beetroot powder needs careful consideration (Hamid and Mohamed Nour 2018). Previous research indicates that various drying techniques substantially influence the chemical composition, mineral content, bioactive compounds, and color characteristics of beetroot slices (Hamid and Mohamed Nour 2018). Various studies have assessed the effects of different drying conditions, such as traditional drying, swell drying, and blanching combined with drying, on the levels and activity of antioxidants in red beetroots (Alonzo-Macías et al. 2020). Moreover, the choice of drying method, including freeze-drying, microwave-assisted drying, or conductive hydro drying, affects the retention of bioactive compounds, phenolics, and antioxidant activity in beetroot products (Preethi et al. 2020; Liu et al. 2022). Drying is a common preservation method, but the effects of these methods on the phytochemicals and antioxidant properties of food products are necessary (Sarkar et al. 2021). Previous studies highlight the importance of evaluating different pre-treatments and temperatures to optimize the drying characteristics of beetroot slices (Mudgal 2023). Additionally, techniques like osmotic dehydration and ultrasound pre-treatments have been explored to enhance dried beetroot chips' nutritional quality and sensory attributes (Peters et al. 2021). Choosing the right preparation and drying techniques is vital for maintaining the quality, functionality, and nutritional value of beetroot products. Understanding how different processing methods impact the physicochemical properties of beetroot powder can facilitate the development of innovative and nutritious food products. This research aims to produce beetroot powder using various preparation and drying techniques and assess their effects on the physicochemical, functional, and nutritional attributes of dried beetroot products.

2 Materials and Methods

2.1 Raw materials and sample preparation

This study used two beetroot varieties, Crimson Globe (CrimG) and Detroit Dark Red (DetR). The mature, fresh beetroots were obtained directly from farmers in Kabale, Western Uganda, then transported to the laboratory in Kampala. Upon arrival, the beetroots were sorted, washed under running potable water, peeled using a ceramic knife, and placed in clean water to prevent discoloration.

2.2 Processing of samples into powder

The beetroots were peeled, cleaned, and sliced into 1-2 mm thick pieces. The slices were divided into two portions. One portion was boiled at 90°C for 30 minutes in a stainless-steel pan with distilled water, while the other was left unboiled. These portions were further divided into four sub-portions for different drying treatments: (i) Fresh Sample: grated into mash and used as a control, (ii) Oven Drying (OD): dried at 65°C for 48 hours, (iii) Sun Drying (SD): spread on raised plastic mesh using wooden stands, and (iv) Freeze Drying (FD): dried at -80°C for 48 hours. The dried samples were pulverized using a pestle and mortar, passed through a 60 mm plastic mesh sieve, and kept in dark, airtight plastic containers for further analysis.

2.3 Estimation of physicochemical and functional characteristics

2.3.1 Water activity

Measurements were conducted using an Aqua Lab water activity meter (Aqualab Series 3, Decagon Devices, Inc., Pullman, WA, USA) with temperature compensation. The measurements were performed in triplicate.

2.3.2 Color measurement

The color was determined using a Minolta CR-10 color reader (Minolta Co. Ltd, Japan), following the method of Youssef and Mokhtar (2014) with some modifications. The chroma meter was

calibrated using a white plate and light trap provided by the manufacturer. Color values were expressed using the CIE Lab* system.

2.3.3 Bulk density

Bulk density was determined using a graduated cylinder following the method described by Roongruangsri and Bronlund (2016).

2.3.4 Water solubility and water absorption

The parameters were determined using the methods outlined by Roongruangsri and Bronlund (2016) with necessary adjustments. One gram (1.0 g) of beetroot powder was mixed with 10 milliliters of distilled water and then placed in an incubator at 60°C for 20 minutes. Afterwards, the mixture was centrifuged at 3000 rpm for 15 minutes. The water solubility and absorption were then calculated based on the weights of the remaining solids and precipitates. The following formula was used for the calculation:

$$\text{Water solubility} = \frac{\text{Weight of residue}}{\text{Weight of beetroot powder}} \text{ x } 100$$

$$\text{Water absoprtion} = \frac{\text{Weight of centrifuged precipitate}}{\text{Weight of beetroot powder}}$$

2.4 Phytochemical analysis

2.4.1 Extraction of phenolic compounds

To extract phenolic compounds, the method described by Wang et al. (2020) and Serna-Vázquez et al. (2021) was followed with some minor adjustments. In summary, 100 mg beetroot sample was blended with a solution of 80% methanol and 2% formic acid (10 mL). This blend was homogenized at room temperature using a Poltroon PT 1200E handheld homogenizer. Next, we sonicated the homogenate for 30 minutes at room temperature using a Bandelin Electronic (Germany) sonicator with DT1028. After sonication, the mixture was centrifuged at 3000xg for 25 minutes using an MSE MSB080.CR2.K centrifuge (UK). The supernatant was carefully transferred to a separate container and stored at -18°C. We re-extracted the remaining pellet under the same conditions to ensure maximum extraction efficiency. The supernatants from both extractions were combined and stored in an airtight container in a Sanyo Biomedical Freezer MDF-U333 (Sanyo Electric Biomedical Co. Ltd, Japan) at -18°C. These extracts were subsequently used to determine the total phenolic content (TPC) and total flavonoid content (TFC).

2.4.2 Total phenolic content (TPC)

The total phenolic content of the samples was measured using the Folin-Ciocalteu reagent, following the method outlined by Özderin (2024). Briefly, 50.0 µL of beetroot powder extract was added to a 50.0 mL Falcon tube and diluted to 3.0 mL with distilled water. After this, 250 µL of Folin-Ciocalteu reagent (diluted 2-fold before use) was added to the mixture and allowed to react for 5 minutes. Subsequently, 250 µL of 7% (w/v) sodium carbonate solution was added, and the mixture was topped up to 5 mL with distilled water. This mixture was then incubated at ambient temperature for 90 minutes to develop the color. Absorbance was then measured at 765 nm using a UV/Vis spectrophotometer (Jenway 6405 UV/Vis, UK). A calibration curve with gallic acid standards (0, 20, 40, 60, 80, and 100 mg/mL) was used to quantify the total phenolic content. Results were expressed as milligrams of gallic acid equivalent (GAE) per 100 mL on a dry weight basis (DW).

2.4.3 Total flavonoid measurement

The total flavonoid content was measured using a method adapted from Sinurat et al. (2022). To summarize, 125 µL of either catechin standard solution or beetroot powder extract was placed in a 5 mL disposable test tube and mixed with 0.625 mL of deionized water and 37.5 µL of 5% (w/v) sodium nitrite solution. The reaction proceeded at room temperature for 6 minutes, after which 75 µL of 10% (w/v) aluminium chloride was added. The mixture was left to react for another 6 minutes before adding 0.25 mL of 4.0M sodium hydroxide. Finally, 0.4 mL of distilled water was added, and the absorbance was recorded at 510 nm using a UV/Vis spectrophotometer (Jenway 6405 UV/Vis, UK). A standard calibration curve was created using varying concentrations of catechin (ranging from 0.2 to 1.00 mg/mL). The total flavonoid content was expressed as milligrams of catechin equivalents per 100 mL of beetroot extract (mg CE/100 mL) on a dry weight basis (DW).

2.4.4 Measurement of Oxalates

The oxalate content of the samples was determined using a method similar to the classical titrimetric method described by Karamad et al. (2019). For one hour, 2.0 g of beetroot sample was digested with 10 mL of 6M hydrochloric acid. After cooling, the mixture was brought to a final volume of 250 mL with distilled water and filtered. Two portions of 125 mL were taken from this filtrate and placed in beakers. 3-4 drops of methyl red indicator were added to each portion. Concentrated ammonium hydroxide was added drop by drop until the solution changed from salmon pink to pale yellow, and the pH was recorded. Each portion was then heated to 90°C, cooled, and filtered to remove any precipitate. The filtrate was reheated to 90°C, and 10 mL of 5% calcium chloride solution was added while stirring continuously. The resulting solution was decanted, and the precipitate was dissolved entirely in 10 mL of 20% (v/v) sulfuric acid solution. This solution was then topped up to 300 mL with distilled water. An aliquot of 125 mL of this filtrate was heated until near boiling and titrated against 0.05 M standardized potassium permanganate until a pink color persisted

for 30 seconds at the endpoint. The oxalate content was calculated using a specific formula.

$$\text{Oxalate content} = \frac{\text{T X Vme X Df X 105}}{\text{ME X MF}}$$

Where: T = Titer value of Potassium permanganate, Vme= volume- mass equivalent (that is, 1 ml of 0.05 m Potassium permanganate, = 0.00228 g of anhydrous oxalic acid), Df= dilute factor (Vt/A that is, total volume of titrate/ Aliquot used), Mf= mass of sample used, ME = molar equivalence of Potassium permanganate in oxalate concentration in g/dm^3.

2.5 Nutritional analysis

2.5.1 Digestion and Mineral Content Analysis

The dried, ground beetroot sample underwent complete digestion using a solution composed of 50% nitric acid (HNO_3) and 30% hydrogen peroxide (H_2O_2), following a modified version of the method described by He et al. (2013). Briefly, 1.0 g of the ground sample was placed in a 50 mL grainer falcon tube. Approximately 0.5 mL of 50% HNO_3 and 0.2 mL of 30% H_2O_2 were added to the sample. The mixture was left overnight to allow for cold digestion. The next day, the samples were subjected to warm digestion on a heating block, initially at 80°C for 30 minutes, then increasing to 125°C for 2 hours. Once the solution became clear with a slightly yellowish tint, digestion was halted, and the volume was brought up to 25 mL with deionized water. The samples were then stored at room temperature in preparation for further analysis.

The digested samples were transferred into vials and placed in an autosampler (SPS 4 Autosampler, Agilent Technologies). Mineral content and control samples were analyzed using microwave plasma atomic emission spectroscopy (4200 MP-AES, Agilent Technologies). The concentration of each analyte was calculated in parts per million (PPM). The final concentration in mg/kg was determined using the formula:

$$\text{Final Concentration (mg/kg)} = \text{Sample Concentration (PPM) X } \frac{\text{Total Dilution}}{\text{Weight of Sample}}$$

2.6 Data analysis

Experimental data were presented as mean ± standard deviation of triplicate measurements and analyzed using IBM SPSS Statistics version 16 (IBM Corporation, New York, USA). Statistical significance was determined at $p \leq 0.05$ using Student's t-test and one-way ANOVA, followed by Fisher's Least Significant Difference test (LSD) for post hoc analysis.

3 Results and Discussion

3.1 Functional and physicochemical properties

Table 1 illustrates the significant influence of preparation and drying methods on beetroot powder's functional and physicochemical properties.

3.1.1 Water Activity

The water activity of beetroot samples decreased significantly ($p < 0.05$) with boiling and drying methods. The highest values were observed in boiled freeze-dried samples (0.54 ± 0.00 for Detroit Dark Red and 0.52 ± 0.00 for Crimson Globe). The lowest water activity values were reported in boiled sun-dried (0.25 ± 0.01) and sun-dried (0.23 ± 0.01) samples for the Crimson Globe variety. This reduction in water activity improves shelf-life stability by inhibiting microbial growth, which aligns with the findings of Stavropoulou and Bezirtzoglou (2019), who emphasized the importance of low water activity in food preservation.

3.1.2 Bulk Density

The bulk density varied significantly ($p < 0.05$) depending on the preparation and drying methods. The boiled oven-dried samples exhibited the highest bulk density (0.86 ± 0.01 for Detroit Dark

Table 1 Functional and physicochemical properties of crimson globe and detroit dark red beetroot powders

Treatment	Bulk Density(g/mL)		WaterAbsorptivity index		Water Solubility Index (%)		Water activity (a_w)	
	DetR	CrimG	DetR	CrimG	DetR	CrimG	DetR	CrimG
FDR	0.18 ± 0.03^{c}	0.22 ± 0.02^{d}	4.59 ± 0.08^{c}	5.09 ± 0.36^{c}	39.00 ± 8.00^{f}	41.00 ± 4.00^{d}	0.52 ± 0.02^{b}	0.52 ± 0.01^{b}
FDB	0.27 ± 0.01^{c}	0.26 ± 0.04^{d}	8.84 ± 0.50^{a}	8.40 ± 0.48^{a}	64.00 ± 10.00^{d}	44.00 ± 6.00^{d}	0.54 ± 0.03^{b}	0.52 ± 0.02^{b}
ODR	0.66 ± 0.02^{b}	0.69 ± 0.01^{c}	3.35 ± 0.07^{d}	6.49 ± 0.57^{b}	77.00 ± 6.00^{b}	78.00 ± 5.00^{a}	0.29 ± 0.01^{cd}	0.31 ± 0.03^{c}
ODB	0.86 ± 0.02^{a}	0.79 ± 0.02^{b}	4.73 ± 0.17^{c}	4.74 ± 0.08^{d}	67.00 ± 11.00^{d}	72.00 ± 4.00^{b}	0.33 ± 0.02^{c}	0.37 ± 0.02^{c}
SDR	0.68 ± 0.01^{b}	0.74 ± 0.01^{b}	5.34 ± 0.12^{b}	5.44 ± 0.10^{c}	78.00 ± 5.00^{a}	75.00 ± 4.00^{b}	0.26 ± 0.01^{d}	0.23 ± 0.01^{d}
SDB	0.82 ± 0.02^{a}	0.90 ± 0.02^{a}	5.26 ± 0.19^{b}	4.03 ± 0.03^{f}	71,00 ± 8.00^{c}	60.00 ± 6.00^{c}	0.25 ± 0.01^{d}	0.26 ± 0.02^{f}

Values represent means ± standard deviation from three separate experiments, different superscript letters in the same column indicate significant differences ($P < 0.05$); here DetR (Detroit Dark Red), CrimG (Crimson Globe), FDR (Freeze-Dried Raw), FDB (Freeze-Dried Boiled), ODR (Oven-Dried Raw), ODB (Oven-Dried Boiled), SDB (Sun-Dried Boiled), SDR (Sun-Dried Raw)

Red and 0.90 ± 0.02 for Crimson Globe), while the boiled freeze-dried samples had lower bulk densities. The higher bulk densities in the boiled samples indicate a more compact structure, which is in line with the findings of Hamid and Mohamed Nour (2018), who observed that drying methods significantly impact the physical properties of beetroot slices.

3.1.3 Water Absorption and Solubility

The highest water absorption index was found in the boiled freeze-dried samples for both varieties, while the lowest was observed in the oven-dried Detroit Dark Red and boiled sun-dried Crimson Globe samples. On the other hand, the water solubility index was highest in the sun-dried Detroit Dark Red and oven-dried Crimson Globe samples, with the lowest values in freeze-dried samples. The porous structure of freeze-dried products allows for higher water uptake, which is beneficial for rehydration (Razzak 2024). This is crucial due to the impact of the speed at which a powder dissolves in water on its rehydration properties and the quality of the finished product (Grabowski et al. 2006; Kim et al. 2012).

3.2 Color

Table 2 shows the color characteristics of beetroot powders based on different processing methods. The lightness (L) values increased when the beetroot was boiled and dried, with the highest values reported in oven-dried and freeze-dried boiled samples. The redness (a) values were highest in the freeze-dried samples, while sun-dried and oven-dried samples showed a significant reduction. The yellowness (b) values increased significantly with sun and oven drying, indicating a relationship with drying temperature. The pigment analysis revealed that the betacyanin content in freeze-dried samples was similar to that of fresh samples but decreased as the temperature increased. Conversely, the betaxanthin content increased with higher drying temperatures. This suggests that betacyanin, the red pigment, is sensitive to heat and degrades with increased temperature, possibly converting into betaxanthin (Gokhale and Lele 2011). The increase in yellow betaxanthin could be due to the chemical transformation of betacyanin or enhanced extractability at higher temperatures. These findings are consistent with the observation that freeze-drying preserves texture and minimizes shrinkage, unlike sun and oven drying, which cause considerable shrinkage (Hamid and Mohamed Nour 2018).

3.3 Nutritional Characteristics

The assessed nutrients included mineral levels, oxalates, and the total contents of phenolics and flavonoids in various dried samples of beetroots. The results of these analyses are presented in Tables 3, 4, and 5.

3.3.1 Mineral Content

Table 3 shows the mineral content of fresh and dried beetroot samples (calcium, iron, magnesium, zinc, and phosphorus). The study found a significant increase ($p < 0.05$) in the calcium content after drying, with the highest level of calcium reported in oven-dried boiled Crimson Globe and sun-dried boiled Detroit Dark Red samples. These results are supported by Asante et al. (2024), who found that boiling before drying enhanced calcium content. Iron also significantly increased ($p < 0.05$) in boiled-dried samples, with the highest levels in boiled and sun-dried samples, consistent with the findings of Joshi and Mehta (2010). Additionally, there was a significant increase in the levels of magnesium and zinc in boiled dried samples, particularly in oven-dried boiled samples, which aligns with the results of Alassane et al. (2022). Furthermore, fresh samples had higher phosphorus content than dried samples ($p < 0.05$), contrary to the findings of Asante et al. (2024).

Table 2 Colour characteristics of the crimson globe and detroit dark red beetroot varieties

Treatment	L* (Lightness)		a* (Redness)		b* (Yellowness)	
	DetR	CrimG	DetR	CrimG	DetR	CrimG
FB	34.55±0.07 [b]	35.65±0.35[b]	7.0±0.42 [c]	8.55±0.42[b]	8.2±0.14[c]	9.25±0.70[b]
FDR	35.40±0.40 [a]	38.10±0.20[a]	11.50±0.40[b]	12.40±0.00[a]	7.80±0.10[f]	8.85±0.10 [c]
FDB	34.40±0.20 [b]	38.70±0.20 [a]	15.10±0.40 [a]	14.80±0.10[a]	7.65±0.10[f]	9.15±0.10 [b]
ODR	36.00±0.11 [a]	38.60±0.20 [a]	6.50±0.00 [c]	6.20±0.30[c]	10.30±0.00[a]	11.65±0.20[a]
ODB	34.60±0.20 [b]	37.40±0.10 [a]	2.70±0.10 [f]	2.70±0.20[g]	8.60±0.00[c]	11.40±0.00[a]
SDR	35.60±0.10 [a]	35.50±0.10 [b]	7.20±0.40 [c]	6.90±0.30[c]	9.70±0.00[b]	10.30±0.10[a]
SDB	32.50±0.20 [c]	32.80±0.08[c]	4.70±0.20 [d]	4.40±0.00[f]	8.05±0.10[c]	8.30±0.00[c]

Values are presented as means ± standard deviation from three independent experiments, different superscript letters in the same column denote significant differences ($p < 0.05$), here DetR (Detroit Dark Red), CrimG (Crimson Globe), FDR (Freeze-Dried Raw), FDB (Freeze-Dried Boiled), ODR (Oven-Dried Raw), ODB (Oven-Dried Boiled), SDB (Sun-Dried Boiled), SDR (Sun-Dried Raw), FB (Fresh Beetroot)

Table 3 Mineral content of the processed crimson globe and Detroit dark red beetroot products

Treatment	Ca mg/100gDW		Fe mg/100gDW		Mg mg/100gDW		Zn mg/100gDW		P mg/100gDW	
	DetR	CrimG	DetR	CrimG	DetR	CrimG	DetR	CrimG	DetR	CrimG
FDR	72.65±2.55^{f}	103.89±6.5^{d}	2.94±0.9^{d}	5.71±0.5^{d}	144.36±2.8^{c}	130.23±10.8^{d}	4.62±0.92^{c}	6.63±0.4^{b}	146.02±1.9^{f}	105.56±4.5^{f}
FDB	117.97±1.3^{c}	105.31±5.9^{d}	5.72±0.6^{b}	5.10±1.0^{f}	171.35±27.4^{b}	147.96±5.28^{c}	6.21±0.2^{b}	5.90±0.1^{c}	167.68±4.8^{c}	149.92±1.6^{d}
F	100.74±3.3^{d}	124.24±1.4^{a}	4.19±0.2^{c}	7.23±0.8^{b}	183.03±17.8^{a}	183.73±11.9^{a}	3.83±0.7^{d}	4.58±0.2^{d}	213.24±5.1^{a}	240.69±13.9^{a}
FB	118.74±9.9^{c}	110.52±5.1^{c}	6.36±2.0^{b}	5.47±0.3^{d}	154.12±1.4^{c}	143.72±2.7^{c}	6.26±0.4^{b}	4.35±0.6^{d}	217.09±1.7^{a}	184.92±6.4^{b}
ODR	117.35±2.4^{c}	98.81±3.6^{f}	4.55±0.3^{c}	5.72±0.4^{d}	166.31±21.4^{b}	154.43±23.2^{b}	5.23±0.1^{b}	5.77±0.1^{c}	211.19±4.4^{a}	148.37±1.2^{a}
ODB	143.89±4.1^{a}	227.25±8.5^{a}	6.10±0.1^{b}	6.68±0.7^{c}	195.50±18.9^{a}	190.10±29.3^{a}	6.83±0.3^{a}	8.72±0.3^{a}	192.55±4.58^{b}	197.72±9.46^{b}
SDR	126.10±4.8^{b}	118.64±7.5^{b}	8.49±0.3^{a}	7.54±0.3^{b}	131.58±22.8^{d}	113.10±6.9^{f}	6.14±0.3^{b}	5.35±0.2^{c}	168.97±7.85^{c}	153.01±0.4^{c}
SDB	165.19±3.8^{a}	128.10±8.4^{a}	9.25±0.7^{a}	9.51±0.7^{a}	153.17±18.1^{c}	129.63±20.1^{d}	5.95±0.1^{b}	4.61±0.1^{d}	166.80±5.6^{c}	158.86±2.7^{c}

Values are presented as means ± standard deviation from three independent experiments, different superscript letters in the same column denote significant differences ($p < 0.05$), DetR (Detroit Dark Red), CrimG (Crimson Globe), FDR (Freeze-Dried Raw), FDB (Freeze-Dried Boiled), ODR (Oven-Dried Raw), ODB (Oven-Dried Boiled), SDB (Sun-Dried Boiled), SDR (Sun-Dried Raw), F (Fresh Non-Boiled Beetroot), FB (Fresh Boiled Beetroot)

Table 4 Total phenolic and flavonoid content of the crimson globe and detroit dark red beetroot powder

Treatment	Total phenolic content mg GAE 100mg^{-1}) DW		Flavonoid content (mg CE 100 mg^{-1}) DW	
	DetR	CrimG	DetR	CrimG
FDR	0.53±0.00^{b}	0.41± 0.01^{d}	0.46±0.01^{g}	0.42±0.01^{f}
FDB	0.74±0.08^{a}	0.68±0.02^{b}	1.84±0.02^{a}	1.00±0.02^{a}
ODR	0.78±0.01^{a}	0.56±0.02^{c}	0.98±0.02^{c}	0.75±0.02^{d}
ODB	0.55±0.02^{b}	0.48±0.01^{d}	0.56±0.01^{d}	0.88±0.01^{c}
SDR	0.50±0.03^{b}	0.35±0.03^{f}	0.57±0.04^{d}	0.45±0.03^{f}
SDB	0.51±0.02^{b}	0.80±0.04^{a}	0.63±0.03^{f}	1.01±0.02^{a}

Values are presented as means ± standard deviation from three independent experiments, different superscript letters in the same column denote significant differences ($p < 0.05$), here DetR (Detroit Dark Red), CrimG (Crimson Globe), FDR (Freeze-Dried Raw), FDB (Freeze-Dried Boiled), ODR (Oven-Dried Raw), ODB (Oven-Dried Boiled), SDB (Sun-Dried Boiled), SDR (Sun-Dried Raw), F (Fresh Non-Boiled Beetroot)

Table 5 Oxalate content of the crimson globe and detroit dark red beetroot powder

Treatment	Oxalate content (calcium oxalate) mg/100g					
	Insoluble		Soluble		Total	
	DetR	CrimG	DetR	CrimG	DetR	CrimG
FDR	13333.30±721.70[a]	9583.30±721.70[a]	5833.30±721.70[a]	5416.70±721,70[a]	19166.70±721.70[a]	15000.00±1250.00[a]
FDB	10833.30±721.70[b]	5416.70±721.70[g]	4166.70±721.70[b]	5416.70±721.70[a]	15000.00±1250.00[b]	10833.30±721.70[b]
F	7083.33±721.70[c]	7500±721.00[b]	2500±0.7210[c]	1666.67±721.70[c]	9583.33±721.69[c]	9166.67±721.69[c]
FB	5000±721.70[g]	4166.67±721.67[d]	1666.67±721.70[f]	1250.00±721.00[b]	6666.67±721.67[f]	5416.67±721.69[f]
ODR	6666.70±721.70[d]	4583.30±721.70[f]	1666.70±721.70[f]	1666.70±721.70[c]	8333.30±1443.40[d]	6250.00±721.70[d]
ODB	7083.30±721.70[c]	6666.70±721.70[c]	2500.00±0.00[c]	2500.00±721.70[b]	9583.30±721.70[c]	9166.70±721.70[c]
SDR	7083.30±721.70[c]	7500.00±721700[b]	2083.30±721.70[d]	1666.70±721.70[c]	9166.70±721.70[c]	9166.70±721.70[c]
SDB	5416.70±721.70[f]	5000.00 ±721.70[h]	2500.00±721.60[c]	1666.7±721.70[c]	7916.70±721.70[h]	6666.70±721.70[g]

Values are presented as means ± standard deviation from three independent experiments, different superscript letters in the same column denote significant differences ($p < 0.05$), here DetR (Detroit Dark Red), CrimG (Crimson Globe), FDR (Freeze-Dried Raw), FDB (Freeze-Dried Boiled), ODR (Oven-Dried Raw), ODB (Oven-Dried Boiled), SDB (Sun-Dried Boiled), SDR (Sun-Dried Raw), F (Fresh Non-Boiled Beetroot), FB (Fresh Boiled Beetroot)

3.3.2 Total Phenolic Content (TPC)

The processing methods significantly impacted the total phenolic content (TPC), with the highest levels of TPC reported in raw oven-dried beetroot powder for dark red and boiled sun-dried samples for light red beetroot powder (Table 4). These findings are consistent with those of Guldiken et al. (2016), who observed a 36% increase in TPC in dried red beetroot compared to fresh samples. However, it differs from the results of Youssef and Mokhtar (2014), who noted a reduction in TPC during drying.

3.3.3 Total Flavonoid Content (TFC)

The treatment methods significantly affected TF content ($p < 0.05$). The highest TF content was found in boiled freeze-dried dark red samples and boiled sun-dried crimson globe samples (Table 4). The influence of drying methods on flavonoid content has been extensively researched. Mandale et al. (2023) underscored the importance of drying methods in preserving nutritional quality; these findings are also consistent with those of Liu et al. (2021).

3.3.4 Oxalates

Table 5 displays the oxalate content of beetroot powders. The total oxalate content varied significantly among treatments and varieties, with the highest levels found in raw freeze-dried samples. Oxalic acid, known to chelate metal cations, can contribute to the formation of kidney stones (Holmes and Assimos 2004; Weaver et al. 2006). The observed oxalate levels are higher than those reported by Wruss et al. (2015), which aligns with the typically high oxalic acid content found in beetroots (Duke 2001).

Conclusion

The study showed that beetroot is a rich source of essential minerals such as iron, zinc, phosphorus, magnesium, calcium, phenolic compounds, and flavonoids. These nutrients are important for physiological functions and overall health. The research also found that how beetroot powder is prepared and dried significantly affects these properties. Specifically, the treatment methods can protect or enhance the physical and micronutrient properties, especially iron, while potentially reducing phytochemicals affecting iron bioavailability. This understanding is crucial for developing iron-rich beetroot products that can effectively supplement dietary iron intake, especially for adolescent school children.

Conflict of interest

The authors declare that there is no conflict of interest concerning the publication of this research.

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