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Madhvi Sharma
Department of Food Science and Technology, JNKVV, Jabalpur, Madhya Pradesh, India

Alok Dubey
Ministry of Food Processing Industries, New Delhi, India

Pratibha Parihar
Department of Food Science and Technology, JNKVV, Jabalpur, Madhya Pradesh, India

SS Shukla
Department of Food Science and Technology, JNKVV, Jabalpur, Madhya Pradesh, India

Kiran Gupta
Department of Food Science and Technology, JNKVV, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Madhvi Sharma
Department of Food Science and Technology, JNKVV, Jabalpur, Madhya Pradesh, India

Physical and biochemical characterization of *Beta vulgaris* (Beetroot) tubers: Insights of nutritional composition and juice extraction for 3D food printing

Madhvi Sharma, Alok Dubey, Pratibha Parihar, SS Shukla and Kiran Gupta

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Abstract
This interrogation presents a comprehensive analysis of beetroot (*Beta vulgaris*) tubers, focusing on both their physical characteristics and biochemical composition, with a specific emphasis on juice extraction for 3D food printing applications. The beetroot tubers exhibited a mass of 176±2.84 gm, with a length and diameter measuring 8.13±1.64 cm and 7.5±1.28 cm, respectively. The tubers displayed a roughly spherical shape, other parameters estimated were edible index and waste index. The dark red color of the tubers and juice was quantified through color values. The extracted beetroot juice revealed a solid content of 9±1.78%, viscosity of 0.0036±0.00024 Pa.s, pH of 3.21±0.24, density of 1.02±0.048 g/cm^3, and total soluble solids (TSS) of 12±1.5 °Brix. Furthermore, the biochemical analysis of the beetroot tubers revealed valuable nutritional information. The tubers contained water (88.25±3.5%), protein (1.55±0.048%), carbohydrates (8.51±1.38%), fat (0.12±0.036%), fiber (0.58±0.07%), ash (0.59±0.038%), saponins (10.841±0.97 mg/g), total phenols (110.74±5.38 Mg GAE/100 mL), betalains (40.89±1.37 mg/100 g), betaxanthin (16.669±1.04 mg/100 g), betacyanin (24.221±0.893 mg/100 g), iron (1.23±0.179 mg/100 g), calcium (27±1.48 mg/100 g), zinc (0.39±0.0024 mg/100 g), and potassium (448±15.60 mg/100 g).

Keywords: Beta vulgaris, juice extraction, 3D food printing

Introduction
Beta vulgaris, commonly known as beetroot, has become a focal point of research due to its versatile applications. Understanding the physical properties of beetroot tubers, such as mass, dimensions, shape, and color, is paramount for evaluating their suitability across various applications. Simultaneously, the extraction of beetroot juice, with its distinctive color and nutritional content, holds promise for enhancing both the visual appeal and nutritional value of 3D printed food products. Previous research has laid the groundwork for our study. Fang *et al*. (2013) [1] conducted an in-depth exploration of solubility measurements in beetroot components, providing fundamental insights into juice extraction. Additionally, Smith *et al*. (2018) [2] underscored the nutritional significance of *Beta vulgaris* (beetroot), emphasizing its potential health benefits and applications in the food industry.

Beyond these foundational studies, the works of Johnson and Patel (2016) [3] and Rodriguez *et al*. (2020) [4] have delved into the broader applications of 3D food printing, demonstrating the transformative potential of this technology. Furthermore, the research by Gupta and Sharma (2019) [5] highlighted the importance of understanding the nutritional aspects of raw materials in 3D food printing, emphasizing the need for comprehensive investigations into the properties of primary ingredients. In this context, our research aims to build upon existing knowledge by conducting a detailed analysis of *Beta vulgaris* (Beetroot) tubers, encompassing both their physical characteristics and an extensive biochemical profile. The study will further explore the properties of beetroot juice, focusing on its suitability for 3D food printing applications. Through this investigation, we anticipate contributing valuable data to the burgeoning field of 3D food printing. The outcomes of our study are expected to inform researchers, food technologists, and culinary experts about the potential use of beetroot-derived components in creating innovative, visually appealing, and nutritionally enhanced food products.

This study seeks to provide a comprehensive exploration of the physical and biochemical characteristics of *Beta vulgaris* (Beetroot) tubers, aiming to unveil crucial insights into their nutritional composition and the extraction of beetroot juice for potential integration into 3D food printing processes.

Materials and Methods

In this study, beetroots were acquired from a local vegetable market in Jabalpur, carefully selected at their optimal maturity stage and substantial size. The chemicals and glasswares used were sourced from reputable suppliers, including M/s British Drug House Mumbai, Qualigen Fine Chemicals, Glaxo-Smith Kline Pharmaceuticals Limited, Thermo-Fisher Scientific India Pvt. Ltd., and Fine Chemicals Limited. Prior to use, all materials were thoroughly washed and cleaned, and fresh beetroots were employed in the experiments. The investigation, conducted in the Department of Food Science and Technology at Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, utilized three replicates for each sample analysis, following detailed methods outlined in the subsequent sections.

The mass was measured by weighing balance, physical measurements *viz*. length and diameter were measured using vernier caliper, edible index and waste index was calculated by measuring the weight of edible and discardable mass of beetroot tubers. color was estimated using Hunter lab color Flex Spectro-colorimeter (Model – Color Flex EZ) D65/100. Viscosity was measured by Brookfield viscometer, TSS by hand held refractometer. The biochemical analysis was done according AOAC, 2012 [9].

Results

The physical analysis of beetroot tubers showcased their substantial size, optimal maturity, and visually appealing dark red color, making them suitable candidates for various culinary applications. The detailed color values further elucidated the visual characteristics, contributing to the overall aesthetic appeal of potential food products.

The extracted beetroot juice, essential for its potential integration into 3D food printing processes, exhibited favorable attributes, including a solid content of 9±1.78%, appropriate viscosity (0.0036±0.00024 Pa.s), and a pH of 3.21±0.24, slightly higher results were observed by Emelike *et al*., 2015 [6] as they reported pH range- 4.47-6.45. These properties, combined with the distinct dark red color, position beetroot juice as a promising ingredient for enhancing both the visual and nutritional aspects of 3D printed food items.

The biochemical analysis as shown in table 2, revealed the rich nutritional composition of *Beta vulgaris* (Beetroot) tubers, encompassing water content, proteins, carbohydrates, fats, fibers, and various essential minerals similarly Thakur and Gupta, 2005 [7] reported the similar findings. The presence of saponins, total phenols, betalains, and other bioactive compounds further underscores the potential health benefits associated with the consumption of beetroot-derived products. Silva *et al*., 2016 [8] reported similar range values of saponin in beetroot juice.

In summary, the findings from this study contribute a holistic understanding of the physical and biochemical characteristics of *Beta vulgaris* (Beetroot) tubers, emphasizing their suitability for 3D food printing applications. These results pave the way for innovative culinary applications, highlighting the potential of beetroot as a valuable and versatile ingredient in the realm of modern food technology. The comprehensive examination of *Beta vulgaris* (beetroot) tubers and their extracted juice provides valuable insights for both the food industry and 3D food printing applications.

Table 1: Physical properties and color values of fresh beetroot tuber and juice

Sr.no.	Physical parameters		Unit	Values
Beetroot Tuber				
1	Mass		gm	176±2.84
2	Length		cm	8.13±1.64
3	Diameter		cm	7.5±1.28
4	Shape Round			Roughly spherical
5	Edible index		%	93±3.5
6	Waste index		%	7±2
7	Color			Dark red
8	Color values	L*		20.23±1.32
		a*		42.34±1.48
		b*		-2.4±0.38
		Δ E*		1.24±0.24
Beetroot Juice				
1	Solid content		%	9±1.78
2	Viscosity		Pa.s	0.0036±0.00024
3	pH			3.21±0.24
4	Density		g/cm3	1.02±0.048
5	TSS		°Brix	12±1.5
6	Color			dark red
7	Color values	L*		14.24±1.73
		a*		48.81±1.18
		b*		1.12±0.68
		Δ E*		0.83 ±0.071

Table 2: Bio-chemical attributes of beetroot juice

Sr.no.	Parameters	Units	Values
1	Water	%	88.25±3.5
2	Protein	%	1.55±0.048
3	Carbohydrates	%	8.51±1.38
4	Fat	%	0.12±0.036
5	Fiber	%	0.58±0.07
6	Ash	%	0.59±0.038
7	Saponins	mg/g	10.841±0.97
8	Total phenols	mg GAE/100 mL	110.74±5.38
9	Betalains	mg/100 g	40.89±1.37
10	Betaxanthin	mg/100 g	16.669±1.04
11	Betacyanin	mg/100 g	24.221±0.893
12	Iron	mg/100 g	1.23±0.179
13	Calcium	mg/100 g	27±1.48
14	Zinc	mg/100 g	0.39±0.0024
15	Potassium	mg/100 g	448±15.60

Conclusion

In conclusion, this study provides a thorough examination of *Beta vulgaris* (beetroot) tubers, emphasizing their physical and biochemical characteristics for potential application in 3D food printing. The beetroot tubers exhibit favorable attributes, including substantial size and a visually appealing dark red color, making them promising raw material for diverse culinary uses. The extracted beetroot juice, with its solid content, viscosity, and distinct color, emerges as a key ingredient for enhancing the visual and nutritional aspects of 3D printed food items. The biochemical analysis highlights the nutritional richness of *Beta vulgaris* (beetroot) tubers, showcasing their potential health benefits. Overall, this research contributes valuable insights to the field of 3D food printing and positions *Beta vulgaris* (beetroot) as a versatile and nutritionally significant ingredient in modern food technology.

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