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INTENFICATION OF THE DRYING PROCESS OF BEET (BETA VULGARIS L.) WITH THE HELP OF ULTRASOUND-CONVECTIVE METHODS

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Abstract: This paper deals with the process of intensification of table beet (Beta vulgaris L.) drying using ultrasonic-convective method. Beetroot is rich in bioactive substances such as betalains, flavonoids, phenols, ascorbic acid and carotenoids which have antioxidant, anticancer, antihypertensive and other beneficial properties. The paper describes the advantages of modern processing methods aimed at preserving nutrients in the product. Experimental studies of the influence of drying parameters: temperature (45 °C), air speed (0.75-1 m/s), ultrasound frequency (20, 30, 40 kHz) and drying duration (up to 480 minutes) were carried out. The most effective was drying at a frequency of 30 kHz for 240 minutes, with a final product moisture content of 15-17%. It was found that ultrasound promotes accelerated evaporation of moisture and improves the quality of the finished product. The obtained results demonstrate the feasibility of ultrasound application in the technology of vegetable processing. Thus, the proposed method allows to intensify drying, minimising losses of bioactive substances and improving the technological characteristics of the final product.

Аннотация: В данной статье рассмотрен процесс интенсификации сушки столовой свёклы (Beta vulgaris L.) с использованием ультразвуково-конвективного метода. Свёкла богата биоактивными веществами, такими как беталаины, флавоноиды, фенолы, аскорбиновая кислота и каротиноиды, которые обладают антиоксидантными, противораковыми, антигипертензивными и другими полезными свойствами. В работе описаны преимущества современных методов обработки, направленных на сохранение питательных веществ в продукте. Проведены экспериментальные исследования влияния параметров сушки: температуры (45 °C), скорости воздуха (0,75–1 м/с), частоты ультразвука (20, 30, 40 кГц) и продолжительности сушки (до 480 минут). Наиболее эффективной оказалась сушка при частоте 30 кГц в течение 240 минут, при этом конечная влажность продукта составила 15–17%. Установлено, что ультразвук способствует ускоренному испарению влаги и улучшению качества готового продукта. Полученные результаты демонстрируют целесообразность применения ультразвука в технологии переработки овощей. Таким образом, предложенный метод позволяет интенсифицировать сушку, минимизируя потери биоактивных веществ и улучшая технологические характеристики конечного продукта.

Keywords: beetroot, ultrasound, convective drying, bioactive substances, betalains, nutritional value, innovative technologies, functional products, drying speed, preservation of nutrients

Ключевые слова: свёкла, ультразвук, конвективная сушка, биоактивные вещества, беталаины, пищевая ценность, инновационные технологии, функциональные продукты, скорость сушки, сохранение питательных веществ

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INTRODUCTION

Processing beetroot into various innovative value-added products such as yoghurt, candy, snacks, ice cream, jelly, cream cheese, etc., can help consumers get the therapeutic benefits of beetroot in different forms. Juice can be prepared by processing beetroot using centrifuge blender, powder using spray dyeing machine, chips using freeze dryer and cooked beetroot by boiling [1-2].

The demand for a healthy diet that includes the consumption of "functional foods" is increasing worldwide, and people are trying to improve their overall health and quality of life. Some fruits and vegetables fulfil the role of functional foods due to the presence of various components such as betalains, carotenoids, vitamins, dietary fibre and other phytochemicals that play a role in protecting against cardiovascular disease, cancer, diabetes, age-related disorders and liver disease [3-4].

MATERIALS AND METHODS

Beetroot is one of the recognised functional foods that are consumed in both raw and processed form all over the world because of its taste, nutritional and medicinal properties. According to studies, the nutritional composition of fresh beetroot varies according to different varieties, genetics, environmental factors and harvesting conditions. Macronutrients found in beetroot include starch, fructose, sucrose, glucose, protein, fat and fibre (Table 1) [5-7].

Table 1

Nutritional value of beetroot [1]

Nutrients	**Table of Contents (per 100 g beetroot)**
Macronutrients	
Water, g	87,58
Energy, kcal	43
Carbohydrates, g	9,56-9,96
Sugar, g	7,96
Dietary fibre, g	2-2,8
Proteins	1,61-1,68
Fats, g	0,17-0,18
Saturated fatty acids, g	0,027
Phytosterols, mg	25
Cholesterol, mg	0
Indispensable and substituted amino acids	
Tryptophan, g	0,019
Isoleucine, g	0,048
Leucine, g	0,068
Lysine, g	0,058
Threonine, g	0,047
Methionine, g	0,018
Phenylalanine, g	0,046
Tyrosine, g	0,038
Valine, g	0,056

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Cystine, g	0,019
Arginine, g	0,042
Histidine, g	0,021
Alanine, g	0,060
Glutamic acid, g	0,428
Glycine, g	0,031
Proline, g	0,042
Asparagic acid, g	0,116
Serine, g	0,059
Micronutrients Vitamins	
Vitamin A, mcg	2
Thiamine, mg	0,031
Riboflavin, mg	0,27
Niacin, mg	0,331
Pantothenic acid, mg	0,145
Vitamin B6, mg	0,067
Ascorbic acid, mg	3,6
Folate, mcg	80
Minerals	
Na, mg	77
Ca, mg	16
Fe, mg	0,79
P, mg	38
K, mg	305
Mg, mg	23
Zn, mg	0,35
Mn, mg	0,329

In addition, beetroot is also an important source of bioactive compounds such as carotenoids, ascorbic acid, flavonoids, polyphenols, saponins, nitrates, triterpenes and betalains, as well as lower levels of folate, betaine and glycine [6]. Betalains as dietary antioxidants are extremely useful due to their higher bioavailability than other flavonoids and have superior stabilisation compared to anthocyanins [1].

Beetroot has been shown in various in vivo and clinical studies to have pharmacological activities such as anti-anemic, antipyretic, anticarcinogenic, antihypertensive, antimutagenic, anti-inflammatory, antioxidant, antidiabetic, anti-fat, and lipid-lowering and blood pressure-lowering effects due to the bioactive substances present in it. Beetroot has a high content of phenolic compounds and flavonoids. The total phenolic content of beetroot is estimated to be 50-60 μmol/g dry weight [7]. In addition, beetroot rind has the second highest concentration of total phenolics on a dry weight basis [1].

Physical methods such as canning, drying and cooling are widely used to preserve and process food products to inactivate enzymes and microbes and extend the shelf life of the product. New food technologies such as high-pressure processing, ultrasonic processing, irradiation, microwaves, heating, pulsed light, etc., have great potential for use on an industrial scale because of their advantages over thermal and conventional processing methods [1, 8-9].

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Currently, unconventional techniques such as pulsed electric field, gamma irradiation, microwave and ultrasonic extraction reduce drying time, energy consumption, solvent consumption and post-treatment wastewater [10-12]. These new technologies applied to beetroot to inactivate microbes and enzymes and to facilitate other processing steps such as extraction and drying [1].

RESULTS AND DISCUSSION

Beetroot is nutritionally and therapeutically important with health benefits such as anti-carcinogenic, anti-hypertensive, antioxidant, antidiabetic, anti-fat etc. due to the presence of bioactive substances such as betalains, phenols, flavonoids, ascorbic acid, triterpenes, saponins and carotenoids etc. in it. Heat treatment successfully inactivates microbes and enzymes in beetroot, but it can degrade betalains. Mild heat treatment increased the bioactive availability to some extent by destroying the vegetative cell wall [1].

An experimental study on the qualitative drying of table beetroot in an ultrasonic convective dryer was carried out. The experiment was conducted on table beet pulp with different parameters affecting the drying in the test process.

Table 2

Results of table beet pulp drying at 45 °C, air velocity 0.75 m/s and ultrasonic exposure

№	Time, min	Temperature, °C	Air velocity, m/s	Change of product weight under the influence of ultrasound during drying, g			
				0 kHz	20 kHz	30 kHz	40 kHz
1	0	45	0,75	1000	1000	1000	1000
2	30	45	0,75	912,13	880,64	780,11	746,54
3	60	45	0,75	859,21	801,64	650,34	623,45
4	90	45	0,75	720,09	670,06	530,20	509,30
5	120	45	0,75	616,31	560,84	440,41	411,63
6	150	45	0,75	523,64	460,54	380,66	349,64
7	180	45	0,75	450,00	403,64	320,23	304,56
8	210	45	0,75	390,54	340,94	270,31	246,54
9	240	45	0,75	342,64	296,45	240,56	223,21
10	270	45	0,75	301,23	260,97	210,08	191,09
11	300	45	0,75	276,45	230,91	190,94	176,31
12	330	45	0,75	250,06	210,49	180,33	159,06
13	360	45	0,75	215,36	195,52	169,36	
14	390	45	0,75	199,06	180,61		
15	420	45	0,75	188,64	170,02		
16	450	45	0,75	169,06			
17	480	45	0,75	154,21			

The optimal parameters of qualitative drying were determined and the following results were obtained: initial moisture content of table beet pulp was 86-89%, final moisture content 15-17%, thickness 7-8 mm, air velocity 1 m/s, exposure to ultrasound 30 kHz, cooking temperature 55 ^{0} C, drying time 240 minutes. Drying is recommended based on these parameters.

CONCLUSION

Thus, the conducted research confirms the high efficiency of ultrasonic-convective method for drying table beetroot. The use of ultrasound with a frequency of 30 kHz at a temperature of 45 °C and air velocity of 0.75-1 m/s allowed to significantly accelerate the dehydration process and to reach the optimum level of final moisture content (15-17 %). This favours the preservation of bioactive compounds such as betalains, phenols and vitamins, which have important antioxidant and therapeutic properties. Unlike traditional thermal methods, ultrasound provides a more gentle treatment, preventing the destruction of valuable components. The presented method can be recommended for industrial application in the production of functional beetroot products with increased nutritional and therapeutic value. The results obtained demonstrate the importance of introducing modern non-destructive technologies in the food industry to improve the quality and safety of finished products. The study also highlights the importance of an integrated approach in the development and optimisation of drying processes for plant raw materials. The introduction of such methods opens up new opportunities for deep processing of vegetables while preserving their natural benefits.

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