MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
SUMY NATIONAL AGRARIAN UNIVERSITY

Qualifying scientific work on the rights of the manuscript

Liu Yan

UDC: 635.11:664.834.1:637.52:664.681

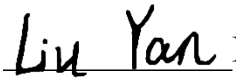
DISSERTATION

TECHNOLOGY OF SEMI-FINISHED PRODUCT FROM DRIED BEETROOT, PRETREATED BY FREEZE-THAW METHOD AND FOOD PRODUCTS USING IT

Specialty 181 – Food Technology

Field of study 18 – "Production and Technology"

Submitted for a scientific degree of Doctor of Philosophy. The dissertation contains the results of own research. The use of ideas, results and texts of other authors have references to the relevant source


Liu Yan

Scientific supervisor: Helikh Anna, PhD, Associate Professor

A copy of the dissertation identical in content with other copies

Sumy-2023

ANNOTATION

Liu Yan. Technology of semi-finished product from dried beetroot, pretreated by freeze-thaw method and food products using it – Qualifying scientific work on the rights of manuscript. Dissertation for the degree of the Doctor of Philosophy in the specialty 181 − «Food technologies» − Sumy National Agrarian University, Sumy, 2023.

The use of natural ingredients as preventative or therapeutic agents has drawn considerable attention on a global scale in recent years. Beetroot is a root vegetable containing betalain, ascorbic acid, polyphenols, flavonoids, saponins, carotenoids and a high content of nitrates. Beetroot provides a number of health benefits and can help prevent or be therapeutic for a variety of disorders and diseases due to its bioactive components. Meanwhile, due to its wide range of phytochemicals, beetroot is a potential source of nutraceutical substances that can be employed to create functional foods. In terms of pharmacology, beetroot has the potential to act as a powerful antioxidant, antimicrobial, anticancerous, hypocholesterolemic, and anti-inflammatory agent. Due to its growing popularity as a source of natural antioxidants, beetroot is increasingly being processed and used in products. Beetroot is intended for the food business and is used as a food coloring or additive in food products such as meat products, confectionery, bakery products, dairy products and other products. The beetroot extract is used to enhance the color in tomato pastes, soups, sauces, desserts, jams, jellies, candies and breakfast cereals.

Fresh beetroot is exposed to spoilage due to its high moisture content. Drying is one of the oldest, widely-applied food preservation operations, which consists of the reduction in the water content slowing down microbial or enzymatic degradation oxidation. Drying methods applied may affect the color, shape, structure, nutritional and nutraceutical compounds in all kinds of ways. As a consequence, it is crucial to choose an optimal drying method. The optimization of the drying procedure is a critical step toward obtaining dehydrated beetroots with the lowest loss of the nutrients and maximum potential activities. The quality of the product obtained depends largely on the methodology used. The use of pre-treatments prior to drying is an alternative for better preserving fresh food attributes and reducing energy requirements. The results vary widely depending on the type of pre-treatments used and the product in question, although in some instances, an increase in drying rate and a greater retention of quality can be noted.

The introduction and the first section presented the application of drying methods and pretreatments in beetroot processing, and application of beetroots in food industry and the development prospect of beetroots. Based on the review of literature sources, specific tasks and issues for further research are identified. Beetroot is a powerful dietary source of health-promoting substances with the potential to treat a variety of pathological conditions, and dried beetroot is promising as an economical, practical and, importantly, natural dietary product.

In the second section, we introduced the experimental protocol in the study, defined the research topic and materials, described all the determination methods, and analyzed and processed the experimental data. The research was carried out at Hezhou University in China, Sumy National Agricultural University in Ukraine, the results of experiments are confirmed by relevant research protocols.

In the third section, the scientific problem of different drying conditions on the physicochemical properties and antioxidant activity of beetroots have been discussed. For heat pump drying, the best drying process parameters were beetroot slices with thickness of 5 mm, drying temperature of 65 °C, and loading density of 2.0 kg/m^2. Moreover, the most favorable conditions for vacuum microwave drying of beetroots were microwave power of 500 W, vacuum degree of –90 kPa, and sample thickness of 2 mm. Influence of different drying methods on quality parameters of beetroots were investigated. Different microwave-assisted drying methods, namely high-power microwave drying followed by low-power microwave drying (HMD+LMD), high-power microwave drying (HMD), low-power microwave drying (LMD), high-power microwave drying followed by hot air drying (HMD+HAD), hot air drying followed by low-power microwave drying (HAD+LMD), high-power microwave drying followed by vacuum drying

(HMD+VD) and vacuum drying followed by low-power microwave drying (VD+LMD), on the quality characteristics of dehydrated beetroots were studied. According to the results, it was demonstrated that VD+LMD was the optimal microwave-assisted method for beetroot drying. Influence of different drying methods, namely heat pump drying (HPD), vacuum drying (VD), freeze drying (FD), microwave drying (MD), microwave vacuum drying (MVD) on the physical properties, bioactive compounds and antioxidant capacity of dehydrated beetroots were also investigated. Considering the quality attributes and drying time, the combined drying methods (HPD+MVD) may guarantee high quality of beetroots and a short drying time. In this section, freeze-thaw cycles such as freeze-thaw once (FT1), freeze-thaw two times (FT2), freeze-thaw three times (FT3), and without freeze-thaw pretreatment (FT0), different freezing temperatures (–4, –20, –50, and –80 °C), and different thawing methods (microwave thawing, water thawing, air thawing, refrigerator thawing, and ultrasonic thawing) on the physical properties, bioactive compounds and antioxidant capacity of dehydrated beetroots were studied. The results demonstrated that freeze thaw once (FT1) was the best number of freeze-thaw cycles, and the optimal freezing temperature was –20 °C, and water thawing was a more suitable way to thaw the frozen beetroots.

In the fourth section presented the results of dried beetroot, pretreated by freeze-thaw method used in meat product and biscuits. Beetroot powder can improve the quality properties of the meat product, not only by increasing the sensory evaluation and increasing the protein content, but also by inhibiting the lipid oxidation of the meat product due to the presence of betalain. Also, betalain of beetroot powder is an effective antioxidant and food coloring in meat products and sausage products. It was revealed that the beetroot powder addition of 2.0% resulted in improve physicochemical properties of meat product. The results showed that the addition of dried beetroot, pretreated by freeze-thaw method to biscuits provides better sensory properties (color, taste and smell) and increases the nutritional value of biscuits. It was concluded that the substitution of low-gluten wheat flour with dried beetroot, pretreated by freeze-thaw method up to 10% into the formulation of biscuits could enhance the organoleptic properties and nutritional value of biscuits. This study can provide important information for the further use of Beetroot powder in the technology of minced meat products such as sausages and meet-containing breads.

Degustation of biscuits and meat products with the addition of beetroot powder was carried out at Hezhou University in China. Degustation results were recorded in the relevant degustation protocols.

In the fifth section, practical implementation of dried beetroot, pretreated by freeze-thaw method and food products using it were introduce. Determination of the socio-economic effect of the introduction of the semi-finished beetroot production technology. To calculate the full cost of production, we took into account the cost of all costs for the production and sale of manufactured products as of 2023 in Ukraine. Based on the implementation of the results of the innovative strategy of developing new products, conducted theoretical and experimental research, the technology of semi-finished beetroot and culinary products using it has been tested and implemented in the food industry. The profitability of the products from the sale of the research and industrial batch in the amount of 30 kg of finished products is at a high level.

Keywords: vegetables, powders, dried beetroot, freeze-thaw pretreatment, drying, dehydration, microwave vacuum drying, food coloring, bioactive compounds, confectionery, minced meat products, meat-containing bread, dietary food, quality characteristics, technological indicators.

АНОТАЦІЯ

Лю Янь. Технологія напівфабрикату з буряку заморожено-розмороженого сушеного та харчових продуктів з його використанням. – Кваліфікаційна наукова праця на правах рукопису. Дисертація на здобуття наукового ступеня доктора філософії за спеціальністю 181 «Харчові технології». – Сумський національний аграрний університет, Суми, 2023.

Використання натуральних інгредієнтів як профілактичних або терапевтичних засобів останніми роками привернуло значну увагу в глобальному масштабі. Буряк - це коренеплід, що містить беталаїн, аскорбінову кислоту, поліфеноли, флавоноїди, сапоніни, каротиноїди та високий вміст нітратів. Буряк забезпечує низку переваг для здоров'я та може допомогти запобігти або бути терапевтичним засобом при різноманітних розладах та захворюваннях завдяки біоактивним компонентам. Тим часом, завдяки широкому спектру фітохімічних речовин, буряк є потенційним джерелом нутрицевтичних речовин, які можна використовувати для створення функціональних продуктів харчування. З точки зору фармакології, буряк може діяти як потужний антиоксидант, протимікробний, протипухлинний, гіпохолестеринемічний і протизапальний засіб. Завдяки зростаючій популярності, як джерела природних антиоксидантів, буряк все частіше переробляється та використовується в продуктах. Буряк призначений для харчового бізнесу, і його використовують як харчовий барвник або добавку до харчових продуктів, таких як м'ясні продукти, кондитерські вироби, хлібобулочні вироби, молочні та інші продукти. Екстракт буряка використовується для підсилення кольору томатних паст, супів, соусів, десертів, джемів, желе, цукерок і сухих сніданків.

Свіжий буряк піддається псуванню через високий вміст вологи. Сушка є однією з найдавніших, широко застосовуваних операцій консервування харчових продуктів, яка полягає у зменшенні вмісту води, що сповільнює мікробні або ферментативні реакції окислення. Застосовувані методи сушіння можуть впливати на колір, форму, структуру, поживні та нутрицевтичні сполуки різними способами. Тому дуже важливо вибрати оптимальний метод сушіння. Оптимізація процедури сушіння є критичним кроком до отримання зневодненого буряка з найменшою втратою поживних речовин і максимальною потенційною активністю. Якість отриманого продукту багато в чому залежить від використовуваної методики. Використання попередньої обробки перед сушінням є альтернативою для кращого збереження харчових властивостей і зниження потреби в енергії. Результати значно відрізняються залежно від типу використовуваної попередньої обробки та відповідного продукту, хоча в деяких випадках можна відзначити збільшення швидкості сушіння та краще збереження якості.

У вступі та першому розділі представлено застосування методів сушіння та попередньої обробки при переробці буряків, застосування буряків у харчовій промисловості та перспективи розвитку буряківництва. На основі огляду літературних джерел визначено конкретні завдання та проблеми подальших досліджень. Буряк є потужним дієтичним джерелом речовин, що сприяють здоров’ю, з потенціалом для лікування різноманітних патологічних станів, а сушений буряк є перспективною як економічний, практичний і, що важливо, натуральний дієтичний продукт.

У другому розділі ми представили експериментальний протокол дослідження, визначили тему дослідження та матеріали, описали всі методи визначення, а також проаналізували та обробили експериментальні дані. Дослідження проводились в Університеті Хечжоу в Китаї, Сумському національному аграрному університеті в Україні, результати експериментів підтверджені відповідними протоколами досліджень.

У третьому розділі обговорено наукову проблему впливу різних умов сушіння на фізико-хімічні властивості та антиоксидантну активність буряку. Для сушіння за допомогою теплового насоса найкращими параметрами процесу сушіння були скибочки буряка товщиною 5 мм, температура сушіння 65 °C, щільність завантаження 2,0 кг/м2. Крім того, найбільш сприятливими умовами для вакуумного мікрохвильового сушіння буряків були потужність НВЧ 500 Вт, ступінь вакууму –90 кПа та товщина зразка 2 мм. Досліджено вплив різних способів сушіння на показники якості буряків. Різні методи сушіння за допомогою мікрохвильової печі, а саме сушіння в мікрохвильовій печі високої потужності з подальшим сушінням у мікрохвильовій печі низької потужності (МВП+МНП), сушіння в мікрохвильовій печі високої потужності (МВП), сушіння в мікрохвильовій печі низької потужності (МНП), сушіння в мікрохвильовій печі високої потужності шляхом сушіння гарячим повітрям (МВП+ГП), сушіння гарячим повітрям з подальшим сушінням у мікрохвильовій печі низької потужності (ГП+МНП), сушіння у мікрохвильовій печі високої потужності з наступним сушінням у вакуумі (МВП+ВС) і сушіння у вакуумі з подальшим сушінням у мікрохвильовій печі низької потужності (ВС+МНП), досліджено якісні характеристики зневоднених буряків. Відповідно до результатів було продемонстровано, що ВС+МНП є оптимальним мікрохвильовим методом сушіння буряка. Досліджено вплив різних методів сушіння, а саме сушіння тепловим насосом (ТП), вакуумного сушіння (ВС), сублімаційного сушіння (СС), мікрохвильового сушіння (МС), мікрохвильового вакуумного сушіння (МВС) на фізичні властивості, біоактивні сполуки та антиоксидантну здатність сушеного буряку. Враховуючи якісні показники та час сушіння, комбіновані способи сушіння (ВС+МНП) можуть гарантувати високу якість буряків та короткий час сушіння. У цьому розділі були вивчені різні цикли заморожування-розморожування, такі як один раз заморожування-розморожування (T_1), заморожування-розморожування два рази (T_2), заморожування-розморожування три рази (T_3) і без попередньої обробки заморожування-розморожування (T_0), різні температури заморожування (–4, –20, –50 і –80 °C), а також різні методи розморожування (мікрохвильове розморожування, розморожування у воді, розморожування на повітрі, розморожування в холодильнику та ультразвукове розморожування) на фізичні властивості, біоактивні сполуки та антиоксидантну здатність сушеного буряка. Результати показали, що одноразове заморожування та розморожування (T_1) було найкращою кількістю циклів заморожування-розморожування, а оптимальна температура заморожування становила

- 20 °C, а розморожування у воді було більш прийнятним способом розморожування замороженого буряка.

У четвертому розділі представлені результати використання сухого заморожено-розмороженого бурякового порошку в м'ясному продукті і печиві. Буряковий порошок може покращити якісні властивості м'ясного продукту, не тільки підвищуючи сенсорну оцінку і збільшуючи вміст білка, але також завдяки наявності беталаїну пригнічуючи окислення ліпідів м'ясного продукту. Також беталаїн бурякового порошку є ефективним антиоксидантом та харчовим барвником у м'ясних продуктах та ковбасних виробах. Встановлено, що додавання бурякового порошку 2,0 % покращує фізико-хімічні властивості м'ясного продукту. Результати показали, що додавання заморожено-розмороженого бурякового порошку у печиво забезпечує кращі сенсорні властивості (колір, смак і запах) і збільшує поживну цінність печива. Зроблено висновок, що заміна в рецептурі печива пшеничного борошна з низьким вмістом клейковини заморожено-розмороженим буряковим порошком до 10% може підвищити органолептичні властивості та харчову цінність печива. Це дослідження може дати важливу інформацію щодо подальшого використання заморожено-розмороженого порошку буряка у технології фаршевих виробів, таких як ковбаси та м'ясні хліби.

Дегустація бісквітів та м'ясних продуктів з додаванням порошку буряку проводились в Університеті Хечжоу в Китаї. Результати дегустації зафіксовані відповідними протоколами дегустації.

У п'ятому розділі представлено практичне впровадження сушеного буряка, попередньо обробленого методом заморожування-розморожування, та харчових продуктів з його використанням. Визначення соціально-економічного ефекту від впровадження технології виробництва бурякових напівфабрикатів. Для розрахунку повної собівартості продукції ми врахували вартість усіх витрат на виробництво та реалізацію виробленої продукції станом на 2023 рік в Україні. На основі реалізації результатів інноваційної стратегії розробки нової продукції, проведених теоретичних та експериментальних досліджень апробовано та впроваджено в харчову промисловість технологію бурякових напівфабрикатів та кулінарних виробів з її використанням. Рентабельність продукції від реалізації дослідно-промислової партії в кількості 30 кг готової продукції знаходиться на високому рівні.

Ключові слова: овочі, порошки, буряк сушений, попередня обробка заморожуванням-розморожуванням, сушіння, дегідратація, мікрохвильова вакуумна сушка, харчовий барвник, біологічно активні речовини, кондитерські вироби, фаршеві вироби, м'ясний хліб, дієтичне харчування, якісні характеристики, технологічні показники.

LIST OF PUBLISHED PAPERS ON THE TOPIC OF THE DISSERTATION

SCOPUS / Web of Science publications

1. Liu, Y., Helikh, A., Filon, A., & Duan, Z. (2023). Sausage technology for food sustainability: recipe, color, nutrition, structure. *Eastern-European Journal of Enterprise Technologies, 4*(11(124), 47-58. DOI: https://doi.org/10.15587/1729-4061.2023.286323 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

2. Shang F., Kryzhska T., Liu Y., Duan Z., Danylenko S., Stepanova T., Koshel O. (2022). Effects of different natural food coloring additions on the quality of chicken sausage. *Journal of Chemistry and Technologies, 30*(2), 265-274. DOI: https://doi.org/10.15421/jchemtech.v30i2.244538 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

3. Liu, Y., Sabadash, S., Duan, Z., & Gao, D. (2022). Influence of different microwave-assisted drying methods on the physical properties, bioactive compounds and antioxidant activity of beetroots. *Eastern-European Journal of Enterprise Technologies, 1*(11(115), 15-25. DOI: https://doi.org/10.15587/1729-

4061.2022.251942 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

4. Liu, Y., Sabadash, S. M., & Duan, Z. (2021). Effect of heat pump temperature on the physical properties, bioactive compounds and antioxidant capacity of beetroots. *Journal of Chemistry and Technologies, 29*(4), 589-598. DOI: http://doi.org/10.15421/jchemtech.v29i4.240470 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

5. Liu, Y., Sabadash, S., Duan, Z., & Deng, C. (2022). The influence of different drying methods on the quality attributes of beetroots. *Eastern-European Journal of Enterprise Technologies, 3*(11(117), 60-68. DOI: https://doi.org/10.15587/1729-4061.2022.258049 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

Articles in scientific professional publications of Ukraine

6. Liu, Y., Sabadash, S., & Duan, Z. (2021). Effects of intermittent microwave drying conditions on characteristics and physical properties of beetroots. *Ukrainian Journal of Food Science, 9*(1), 30-47. DOI: http://doi.org/10.24263/2310-1008-2021-9-1-5 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

7. Liu, Y., Sabadash, S., & Duan, Z. (2021). Research of physicochemical properties and antioxidant activity of beetroots as affected by vacuum microwave drying conditions. *Technology Audit and Production Reserves, 5*(3(61), 40-45. DOI: https://doi.org/10.15587/2706-5448.2021.243069 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*).

8. Liu, Y., Sabadash, S., Gao, D., Shang, F., & Duan, Z. (2021). Influence of vacuum microwave drying parameters on the physicochemical properties of red beetroots. *Scientific Messenger of LNU of Veterinary Medicine and Biotechnologies. Series: Food Technologies, 23*(96), 8-14. DOI:

https://doi.org/10.32718/nvlvet-f9602 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

9. Liu, Y., Duan, Z., & Sabadash, S. (2021). Bioactive compounds and antioxidant activity of beetroots prepared by different drying methods. *Ukrainian Journal of Food Science, 9*(2), 246-258. DOI: http://doi.org/10.24263/2310-1008-2021-9-2-11 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

10. Liu, Y., Duan, Z., Sabadash, S., & Shang, F. (2022). Study on the effect of intermittent microwave drying conditions on the bioactive compounds and antioxidant capacity of beetroots. *Technology Audit and Production Reserves, 1*(3(63), 6-13. DOI: http://doi.org/10.15587/2706-5448.2022.251351 (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

Conference papers

11. Liu Yan, Anna Helikh, Duan Zhenhua. Food safety of dried beetroot, pretreated by freeze-thaw method. *Technical sciences theoretical foundations of scientists and modern opinions regarding the implementation of modern trends,* 434-438. XXV International Scientific and Practical Conference. (June 27-30, 2023, San Francisco, USA) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

12. Liu Yan, Duan Zhenhua, Sabadash Serghii, Gao Dan, Shang Feifei. (2020). Drying characteristics and mathematical modeling of heat pump drying of beetroot slices. *The 4th International Conference on Processing & Preserving of Fresh Foods,* 51-52. (August 15-17, 2020, Hezhou, China) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

13. Liu Yan, Zhenhua Duan, Sabadash Sergey. (2020). Effect of hot air drying temperatures on drying characteristics and physicochemical properties of beetroot (*Beta vulgaris*) slices. *2020 International Conference on Green Development and Environmental Science and Technology, IOP Conference*

Series: Earth and Environmental Science, 615, 012099 DOI: https://doi.org/10.1088/1755-1315/615/1/012099 (September 18-20, 2020, Changsha, China) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

14. Liu Yan, Sabadash Serghii, Duan Zhenhua. (2020). Comparison of different heat pump drying conditions on drying characteristics and physical properties of beetroot slices. *The world of science and innovation. Abstracts of the 2nd International scientific and practical conference. Cognum Publishing House,* 221- 228. (October 14-16, 2020, London, United Kingdom) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

15. Liu Yan, Sabadash Sergey, Duan Zhenhua. (2021). Effect of microwave-assisted drying methods on the physicochemical properties of beetroots. *2nd International Conference on Agricultural Science and Technology and Food Engineering, IOP Conference Series: Earth and Environmental Science,* 792, 012012. DOI: https://doi.org/10.1088/1755-1315/792/1/012012 (May 28-30, 2021, Qingdao, China) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

16. Liu Yan, Sabadash Sergey, Duan Zhenhua. (2022). Effects of different types of drying on quality of beetroot slices. *Proceedings of VIII International Scientific and Practical Conference,* 19-25. (February 26-28, 2022, Kharkiv, Ukraine) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

17. Liu Yan, Sabadash Sergey. (2022). Influence of different drying methods on physical properties of beetroots. *International Scientific Conference «Global and national trends in life sciences»,* 204-206. (May 12, 2022, Zoom on line, Ukraine) (*PhD participant in carrying out of experimental research, processing of results, and writing the article*)

18. Liu Yan, Duan Zhenhua, Sabadash Sergei, Tang Xiaoxian. (2022). Effects of freeze-thaw pretreatment on the physicochemical properties of

microwave dried beetroots. *Advances in Food Safety and Environmental Engineering. 4th International Conference Food Safety and Environmental Engineering,* 55-61. DOI: https://doi.org/10.1201/9781003318514-10 (February 25-27, 2022, Xiamen, China) *PhD participant in carrying out of experimental research, processing of results, and writing the article*)

INTRODUCTION

Relevance of the topic.

Fresh beetroot becomes spoiled easily due to its high moisture content, and food industry is seeking to use various food preservation methods to preserve beetroot or its phytochemicals. Drying is one of the most effective methods to preserve food because it reduces the amount of water available for chemical, enzymatic, and microbiological reactions as well as minimizes physical and chemical reactions during storage. This makes the product more stable for storage and transportation.

The drying technique used may have a variety of effects on the color, shape, structure, nutritional and nutraceutical components. As a consequence, it is crucial to choose the best drying technique. The optimization of the drying procedure is a critical step toward obtaining dehydrated beetroot with the lowest nutrient loss and maximum potential activities.

The application of pretreatment can not only reduce drying time, boost drying rate, improve moisture distribution, and minimize energy consumption, but they can also improve the functional and nutritional quality features of dried products over untreated samples. It has been proved that the use of pretreatment ahead of drying is beneficial for improving the drying process efficiency and enhancing the quality of fruits and vegetables. However, there have been few reports on the connections between pretreatment microstructure alterations and the evolution of physicochemical attributes (texture, color, and rehydration ratio) of foods. As a result, more investigation is required to investigate the links between pretreatments, microstructure, and physicochemical aspects of products in order to improve structure formation and change functional qualities of food by selecting appropriate pretreatment methods.

There has been an increasing interest in the biological activity of beetroot and its potential use as a functional food for health promotion and disease prevention. Beetroot contains a huge number of bioactive compounds that can be used as a functional food source to treat a variety of disease.

In this context, rationalization of the drying process can be solved in two main ways: improvement of drying methods and development of pretreatment. Pretreatment significantly reduces energy consumption, affects physical properties, retention of bioactive compounds and antioxidant capacity of products.

The choice of drying and pre-treatment methods has recently become more and more active. Therefore, an urgent task is to develop methods of drying and pre-treatment of beets to substantiate the technology of semi-finished products from dried beetroot, pretreated by freeze-thaw method, as well as to study its effect on the organoleptic, physico-chemical and safety indicators of meat products and biscuits.

Connection of work with scientific programs, plans, topics.

The dissertation work was developed in accordance with the research plans of the Sumy National Agrarian University, according to research topics of the Department of Technology and Food Safety 0119U101237 "Innovative technological solutions in the production of food products" and 0122U201635 “Development of technical documentation for semi-finished products from vegetable raw materials with increased biological value for dual purposes”. Scientific research of the dissertation work was carried out on the basis of the School of Food Sciences of the Henan Institute of Science and Technology, China.

The aim and objectives of the study. The purpose of the work is research and substantiation of the method of obtaining a semi-finished product from dried beetroot, pretreated by freeze-thaw method for further use in the technology of meat products and biscuits.

To achieve the goal, it is necessary to solve the following tasks:

1. To study the influence of different drying conditions and methods on the physical properties, bioactive compounds and antioxidant activity of beets:

- to study different conditions of heat pump drying for physico-chemical properties and antioxidant activity of beets;

- to study the conditions of vacuum microwave drying for quality characteristics of beets;

- to study the influence of different methods of drying with the help of microwaves on the physical properties, bioactive compounds and antioxidant capacity of beets;

- to study the effect of different drying methods (heat pump, vacuum, sublimation, microwave and vacuum microwave drying) on the quality characteristics of beets.

2. To investigate the influence of different methods of pre-treatment by freezing-thawing on the quality characteristics of beets, as well as different drying methods on the quality characteristics of pre-treated beets by freezing-thawing.

3. To study the effect of freeze-thaw cycles on the physical properties, bioactive compounds, and antioxidant activity of microwave dried beets:

- to study the effect of different freezing temperatures on the physical properties, biologically active compounds and antioxidant capacity of beets dried by a heat pump;

- to study the influence of different methods of defrosting on the physical properties, biologically active compounds and antioxidant activity of beets dried in a microwave oven;

- to study the effect of different drying methods (sun, hot air, freezing, vacuum, microwave and vacuum microwave drying) on the quality characteristics of beets pretreated by freezing-thawing.

4. To develop the technology of semi-finished products from dried beetroot, pretreated by freeze-thaw method.

5. To study the effect of semi-finished products from dried beetroot, pretreated by freeze-thaw method on organoleptic, physico-chemical and safety parameters of meat products and biscuits.

6. To justify the optimal recipe and rational parameters of the process of making meat products and biscuits using semi-finished products from dried beetroot, pretreated by freeze-thaw method.

7. To determine the economic efficiency of the implementation of the technology of research results in practical production.

8. To develop regulatory documentation for a new type of semi-finished products from dried beetroot, pretreated by freeze-thaw method and food products with its use and to carry out industrial approval of the developed technology in production.

The object of the study - fresh beetroots, dried beetroots and dried beetroot, pretreated by freeze-thaw method, beetroot powder.

The subject of this study - the impact of drying conditions, drying methods and different freeze-thaw pretreatments on the physico-chemical and antioxidant properties of beetroots. Food quality indicators, produced by the addition of dried beetroot, pretreated by freeze-thaw method: nutritional and biological values, and organoleptic properties of products.

Research methods. The methodology of the research is based on analysis and synthesis as well as information already known about the research problem, as well as new data collected in the course of the work. The results of the analysis available in the new literature form a scientific hypothesis based on the theoretical part of the study and confirmed in experimental studies.

The scientific hypothesis and its theoretical basis will be formulated in Ukraine (Sumy National Agrarian University). Some of the experimental studies related to the determination of optimal parameters for prior processing and drying and its impact on the physicochemical properties and antioxidant activities of beetroots, the influence of different freeze-thaw pretreatments on the quality attributes of dried beetroots, as well as the addition of dried beetroot, pretreated by freeze-thaw method to the production of food products and the study of their quality indicators will be carried out at the Hezhou University in China with the participation of the head of School of Food and Bioengineering. The discussion, analysis and generalization of the results of the experiments will be done using the Internet. Dissertation work will be formulated and discussed at different levels in Ukraine.

Part of the Normal Technical Documentation, the manufacturing implementing acts will be approved in Ukraine, part in China. Ukraine's patent will be issued, developed and validated in Ukraine.

The studies will use modern methods of analysis of the subject: physical and chemical methods, methods of experiment planning and optimization, organic and biological methods, and mathematical processing of experimental data computer programs.

Research materials and results will develop and scientifically-based optimal pretreatment and a new combination will be based the drying method and its impact on the physico-chemical and antioxidant properties of the dried beetroots, as well as food technology with the addition of dried beetroot, pretreated by freeze-thaw method. Normal Technical Documentation validated, practically implemented, new production based on manufacturing implementing acts and scientific and protective documentation validated. It's Ukraine's patent.

Scientific novelty of the obtained results. On the basis of analytical, scientific and experimental research and trends in the dissertation for the first time:

- experimentally obtained a complex of data on the influence of different methods of drying on beet quality indicators;

- the effect of various drying methods, namely heat pump drying (HPD), vacuum drying (VD), freeze drying (FD), microwave drying (MD), microwave vacuum drying (MVD) on the physical properties, bioactive compounds and antioxidant capacity of dried beet;

- it was established that microwave vacuum drying is the optimal microwave method of drying beets. Considering the quality indicators and drying time, microwave vacuum drying can guarantee high quality beets and short drying time;

- it was established that the best parameters of the microwave vacuum drying process were beet slices 5 mm thick, drying temperature 65 °C, loading density 2.0 kg/m2. In addition, the most favorable conditions for vacuum microwave drying of beets were the microwave power of 500 W, the degree of vacuum -90 kPa, and the sample thickness of 2 mm;

- different freeze-thaw cycles were studied, such as freeze-thaw once (T1), freeze-thaw twice (T2), freeze-thaw three times (T3) and without pretreatment freeze-thaw (T0), different freezing temperatures (–4, –20, –50 and –80 °C);

- different methods of defrosting (microwave defrosting, water defrosting, air defrosting, refrigerator defrosting and ultrasonic defrosting) were studied for the physical properties, bioactive compounds and antioxidant capacity of dried beets;

- it was found that single freeze-thaw (T1) was the best number of freeze-thaw cycles and the optimum freezing temperature was –20 °C, and water thawing was the more acceptable way to thaw frozen beets.

- the possibility of using dried beetroot, pretreated by freeze-thaw method in meat products and biscuits was studied;

- optimization of the recipe of meat products and biscuits using semi-finished products from dried beetroot, pretreated by freeze-thaw method;

- a complex of new data characterizing the chemical composition, organoleptic, microbiological and toxicological indicators, nutritional value was obtained, and the conditions and terms of storage of meat products and biscuits using semi-finished products from dried beetroot, pretreated by freeze-thaw method were scientifically substantiated;

- it was found that beetroot powder can improve the physicochemical properties of meat products, not only improving the sensory quality and increasing the protein content, but also inhibiting the lipid oxidation of meat products. It was established that the addition of 2.0% beetroot powder improves the physical and chemical properties of meat products.

- results showed that dried beetroot, pretreated by freeze-thaw method in biscuits provides better sensory properties (color, taste, smell and taste). and increased the nutritional content (fat and protein) of the biscuits. It was concluded that replacing wheat flour with a low gluten content in the cookie recipe with dried beetroot, pretreated by freeze-thaw method up to 10% can increase the organoleptic properties and nutritional value of biscuits.

- acquired further development and generalization:

- ways of using semi-finished products from dried beetroot, pretreated by freeze-thaw method in food products of different groups.

Practical significance of the obtained results. On the basis of fundamental and applied research, a semi-finished products from dried beetroot, pretreated by freeze-thaw method with a high content of bioactive compounds, antioxidant activity and improved physico-chemical properties was developed for its further use in the technology of meat products and biscuits, as a semi-finished product that increases food and biological value, and also has a positive effect on the physico-chemical, structural-mechanical and organoleptic characteristics of these products. The results of the dissertation work can be used in the learning process for the "Food technology", "Nutritiology", "Food quality and safety" disciplines, "Processes and appliances of food production". At the same time, the results of the studies can be used in fundamental and detailed studies into food technology. Technical documentation has been developed and approved (TS 10.3-04718013-007:2022 "Dried beetroot"; TS 10.3-04718013-008:2022 "Concentrated and dried taro products"; Q/YTBG-0004S-2023 "Tough biscuits fortified with beetroot powder"; Q/YTBG-0005S-2023 "Chicken sausages fortified with beetroot powder"), which regulates the technical requirements and technological process for the production of semi-finished products from dried beetroot, pretreated by freeze-thaw method and food products using it. A Ukrainian patent for an invention (a202204792 "Dried beetroot, pretreated by freeze-thaw method" and a utility model (u202204698 "Method for obtaining dried beetroot, pretreated by freeze-thaw method") has been submitted. The semi-finished product made from dried beetroot, pretreated by freeze-thaw method (beetroot powder) was introduced at the specialized enterprises: Individual entrepreneur "Filon A.M.", Shenzhen Wah Tai Xing Foods Co., Ltd., Individual entrepreneur "Klymenko L.O.".

The applicant's personal contribution. The applicant's personal contribution is to plan and carry out experimental research under laboratory conditions, conduct mathematical processing and scientific analysis, form conclusions and suggestions, prepare materials for publication, as well as introduce new technologies into production.

The dissertation work was carried out with the methodological and scientific support of **Ph.D., Associate Professor Anna Helikh.**

Approbation of dissertation results. The main results of the dissertation work were reported discussed and endorsed the following conferences: XXV International Scientific and Practical Conference. June 27-30, 2023. San Francisco, USA. The 4 International Conference on Processing & Preserving of Fresh Food. August 15-17, 2020. Hezhou, China. II International Scientific and Practical Conference. September 16-18, 2020. London, United Kingdom. 2nd International Conference on Agricultural Science, Technology and Ecological Engineering. September 18-20, 2020. Changsha, China. 6th Food Drying Conference & 7th Symposium for Space Nutrition and Food Engineering. October 28-30, 2020. Wuxi, China. 2nd International Conference on Agricultural Science and Technology and Food Engineering. May 28-30, 2021. Qingdao, China. 4th International Conference on Food Safety and Environmental Engineering. February 25-27, 2022. Xiamen, China. VII International Scientific and Practical Conference "Topical issues of modern science, society and education". February 26-28, 2022. Kharkiv, Ukraine. International Scientific Conference «Global and national trends in life sciences». May 14, 2022. Online conference at Zoom.

Publications. The results of the dissertation are reflected in 18 printed works, including: 5 articles in scientific publications by specialty, included on the date of publication in the list of scientific specialized publications of Ukraine, 5 articles in periodical scientific publications, which are indexed in the Scopus/Web of Science Core Collection database, 3 of which is in the journal of the 3rd quartile (Q3), 2 of which is in the journal of the 4th quartile (Q4), 8 abstracts of reports at scientific, scientific-practical and international conferences, 2 of which are indexed in the Scopus/Web of Science Core Collection database.

Structure and volume of dissertation. The thesis consists of an introduction, five sections and conclusions, 191 references, which are all from far abroad and 16 additions. The full text of the paper is 224 pages, with 64 tables and 37 figures.

TABLE OF CONTENTS | P.

Addition K. Certificate of implementation "Tough Biscuits Fortified With Beetroot Powder"

Addition L. Certificate of implementation "Chicken Sausages Fortified With Beetroot Powder"

Addition M. Certificate of implementation "Sausage technology using freeze-thaw dried beetroot"

Addition N. Certificate of implementation "Biscuit technology using freeze-thaw dried beetroot"

Addition O. Certificate of implementation "Technology of sausage products using dried beetroot"

Addition P. Certificate of implementation "Technology of chicken sausages using concentrated taro products"

THE LIST OF SYMBOLS

RR	Rehydration ratio
PR	Pulse ratio
C	Chroma
H°	Hue angle
ΔE	Total color change
TPC	Total phenolic content
TFC	Total flavonoids content
GAE	Gallic acid equivalent
TE	Trolox equivalent
RE	Rutin equivalent
TPA	Texture profile analysis
FRAP	Ferric reducing antioxidant power
ABTS	2,2'-Azino-bis(3-ethylbenzothiazoline-6-sulfonic acid)
DPPH	1,1-Diphenyl-2-picrylhydrazyl radical
SEM	Scanning electron microscope
HAD	Hot air drying
MD	Microwave drying
VD	Vacuum drying
MVD	Microwave vacuum drying
FD	Freeze drying
HPD	Heat pump drying
SD	Sun drying
ANOVA	One-way analysis of variance
L^*	Lightness
a^*	Redness
b^*	Yellowness

SECTION 1
LITERATURE REVIEW ON THE TOPIC AND CHOICE OF RESEARCH DIRECTIONS

1.1 An introduction to beetroot

1.1.1 Basic information of beetroot

Beetroot (*Beta vulgaris* L.) is botanically classified as a biennial herb of the *Chenopodiaceae* family [1], which is originated from Eastern Europe, Southern Europe, and Northern Africa [2]. Beetroot is an annual or biennial crop that has become widely farmed from the Americas through Europe and Asia[3], which is mostly grown in temperate areas. The four basic beetroot varieties are Detroit Dark Red, Crosby Egyptian, Early Wonder and Crimson Globe [4]. The edible part of beetroot is the root, which is long, tapered, and stout. Beetroot is generally globe or cylindrical shaped with red-purple/golden yellow/red-white in color, depending on its variety [5].

According to studies, the nutritional composition of fresh beetroot varies with varieties, ecological factors, genetics, and harvesting conditions [6]. Macronutrients found in beetroot are carbohydrates (starch, fructose, sucrose, glucose and fibre), protein, and fat. According to USDA [7], the macronutrients of raw beetroot (100 g) contain an average energy of 43 kcal, water of 87.58 g, total sugar of 6.76 g, total dietary fiber of 2.8 g, proteins of 1.61 g, and fats of 0.17 g. Beetroot contains a large number of essential and non-essential amino acids, such as methionine, leucine, threonine, tryptophan, lysine, isoleucine, serine, tyrosine, proline and aspartic acid [8].

Beetroot is frequently consumed both raw and cooked, pickled or canned [9], and it is notably famous in Eastern Europe as the major ingredient of the sour soup known as borsch, which is prominent in the cuisines of Ukraine, Romania, Moldavia, Latvia, Lithuania, and Poland [10].

1.1.2 Bioactive compounds of beetroot

Beetroot is a vital source of bioactive compounds, such as betalains, carotenoids, ascorbic acid, flavonoids, polyphenols, nitrates, triterpenes, and saponins [6].

Research on beetroots have increased rapidly due to the presence of brightly colored water-soluble pigments that give the red hue, as well as due to other phytochemicals which function as antioxidants, antimicrobials, and anticancer agents. These pigments were wrongly considered earlier as anthocyanins, but later identified as betalains, which possess typical chemical structures and physiological properties. However, betalains is restricted to a minimum number of varieties in nature when compared to anthocyanins [11]. Betalains are water-soluble nitrogen-containing pigments, which can be divided into betacyanins (red–violet) and betaxanthins (betaxanthins) pigments (yellow–orange) [6].

Betalains as major bioactive compounds which are naturally present in beetroot, with betanin, isobetanin, betanidin and vulgaxanthin I predominating among twenty two pigments identified [12]. Five red beet varieties (Bonel, Nero, Favorit, Rubin, and Detroit) for their pigment composition was analyzed in [13]. It was found that in all cases, the major red violet pigments were betanin, isobetanin, betanidin and isobetanidin, and betanin was found to be the main component in all varieties. Vulgaxanthin I and vulgaxanthin II were the major yellow components. The research in [14], showed that each of the beetroot products possessed its own unique profile of betalain compounds and the total betalains content differed significantly between individual beetroot products. It was reported that the concentrations of betacyanins and betraxanthins in beetroots were between 0.4 and 2.1 mg/g of fresh weight and between 0.2 and 1.4 mg/g of fresh weight, respectively [15].

1.1.3 Functional properties and biological value of beetroot

In addition to being a great source of nutrients, vitamins, minerals, vitamin B complex, and folic acid, beetroots also contain a significant amount of unique bioactive compounds with numerous medical and therapeutic benefits. The medical benefits of beetroots include antioxidant, analgesic, hepatoprotective, anti-inflammatory, antihypertension, antimicrobial, antimigraine, antihypertension, antihyperglycemic, anti-progestogenic, antiviral, anti-anaemic, antipyretic, anti-mutagenic, anti-obesity, antiallergic, anti-tumorigenic, antithrombotic, and prevents hepatic damage and neurodegeneration [16–17].

Beetoots are a rich source of antioxidant compounds, with one study ranked beetroots as the tenth-highest antioxidant content of vegetables [18]. It has been reported that betalains had antioxidant and anticancer activity, which can be a promising source of natural antioxidant and anticancer agent and definitely provide an alternative towards synthetic antioxidant [19]. Betalains are hydrophilic nitrogenous pigments that are widely used in the food industry as natural colorants for products such as processed meat, ice creams or baked goods [20]. Despite the fact that betalains are water soluble stable between pH 3 to pH 7, betalains are less frequently utilized in food processing than anthocyanins and carotenoids [21]. As the major bioactive compound presented in beetroot, nitrate is known to have bioactivity in the cardiovascular system [22], which has effects on antihypertension and cognitive function [23]. Nitrate can produce NO enhancement, in which affects muscle function, resulting in the improvement of exercise performance [24].

The authors of [25] investigated the antimicrobial potential of beetroot extract in the current research. Beetroot extracts were found to have antibacterial action against a variety of gram-positive and gram-negative bacteria, but no inhibitory activity against fungi and yeasts. It has been reported that beetroot extract had antibacterial activity against *L. monocytogenes* in [26]. The cancer-preventive properties of red beetroot and the water-soluble betalains derived from the plant were reviewed in [27]. Due to its bioactive components, beetroot and the value-added products offer a range of health advantages and aid in preventing and treating a number of conditions.

Beetroot is a potential source of nutraceutical compounds that can be used to build functional foods due to the variety of phytochemicals it contains. In terms of pharmacology, beetroot offers a great deal of potential as an anti-inflammatory, anti-cancer, hypocholesterolemic, antioxidant, and antibacterial agent [28]. However, few studies have shown that beetroot has the activities of anti-HIV, fibrinogenolytic, anti-tyrosinase, vasorelaxant, antihypertension, and antiarthritis. It can be said that further research is of great significance for developing these activities so as to improve the applicability of beetroot in food industry [28]. Furthermore, the significant biological activities of beetroot aid in the exploration of a number of previously unknown areas where dietary supplements can be beneficial for health.

1.2 Application of drying methods in beetroot processing

As fresh beetroot becomes spoiled easily due to its high moisture content, and food industry is seeking to use various food preservation methods to preserve beetroot or its phytochemicals. The removal of water reduces the volume of the final product, lowers the amount of water available for chemical, enzymatic, and microbiological reactions, and minimizes physical and chemical reactions during storage, making drying one of the most effective ways for food preservation.

Drying is one of the most effective methods to preserve preservation because it reduces the amount of water available for chemical, enzymatic, and microbiological reactions as well as minimizes physical and chemical reactions during storage. This makes the product more stable for storage and transportation [29-30]. The drying process can be challenging because it leads to the loss of various thermosensitive compounds. According to the literature, there are various kinds of drying methods for beetroots.

As the best dehydration method for heat-sensible food, freeze drying (FD) is the process of removing water from a previously frozen product owing to the sublimation process, which involves three phases of freezing, sublimation, and desorption, and is carried out at a very low pressure and low temperature [31]. Usually, FD produces good-quality food with well-retained flavor and nutritional quality, and maintains the material volume with porous structures and good rehydration ability [32].

One of the most popular drying techniques is hot air drying (HAD), which has the benefits of great drying effectiveness, easy operation, low cost, and minimal environmental impact. However, there are also some disadvantages, such as relatively long drying time, high temperature, degradation of important nutritional substances [33], color change and shrinkage [34]. Convective drying (at 60 °C and 2 m/s; CD) and freeze drying (at -50 °C and 30 Pa; FD) were used to dry beetroot. It was shown that the CD sample displayed both a larger loss of phenolic compounds and a higher gain of these compounds in gastric juice, implying that CD is more conducive to releasing phenolic compounds from beetroots than FD samples [35].

Heat pump drying (HPD) is based on the inverse Carnot cycle principle, which allows it to recover energy from the exhaust, increase energy efficiency and independently control the drying temperature and air humidity [36]. This makes it particularly suitable for the retention of bioactive compounds in thermosensitive vegetables and fruits as drying can occur at low temperatures. Impact of different heat pump drying temperatures (45 to 65 °C) on the physical properties, bioactive compounds and antioxidant capacity of dried beetroots was investigated in [37]. The results exhibited that 65 °C was the optimal drying temperature for heat pump drying of beetroots. Various investigations have found that agricultural products dried by HPD have better color and flavor qualities than those dried by the conventional hot air dryer.

Microwave drying (MD), either alone or in combination with other drying methods, is the most quick and effective processing method in laboratory and industrial applications for food preservation. MD has various advantages, including quick processing (short time), uniform volumetric heating, high efficiency, low cost (low energy consumption), and automatic and self-regulating system, which is compatible with other processing technologies [6].

Vacuum drying (VD), a successful and practical process that has been employed in food industry, is based on the evaporation of moisture under reduced pressure, in which the wet material is spread out in thin layers on trays and water is evacuated by a vacuum pump and condensed in a condenser [38]. The vacuum produced by vacuum drying allows for the quick and homogeneous evaporation of water from the material [39]. It has been confirmed that vacuum drying is a conceptually suitable method for heat-sensitive and oxygen-sensitive materials because it minimizes the possibility of oxidation reactions. Mella et al.[40] studied whether vacuum drying (VD) could be a proper alternative to freeze-drying (FD). The resulted indicated that VD samples retained the proximate composition content of beetroot, and the total polyphenol content and oxygen radical absorption capacity of VD (50 °C) were higher than those of FD sample, thus vacuum drying at 50 °C can be a suitable drying temperature instead of FD. Székely et al. [41] confirmed that VD is a more favourable method to preserve the nutritional characteristics of beetroots. In the study [42], beetroot powders were prepared by tray drying, drum drying, freeze-drying, and continuous vacuum-belt drying. Research has found that vacuum-belt drying could produce continuous beetroot powder, with a good color and betalain content similar to freeze-dried products.

Microwave vacuum drying (MVD) or vacuum microwave drying (VMD) using microwaves under vacuum, and its main advantage is to achieve the required drying at lower temperatures, thereby retaining bioactive compounds. During the MVD process, microwave energy is absorbed by water located throughout the entire volume of the dried material [34], and a large vapor pressure is generated at the center of the material, which quickly transfers water to the surrounding vacuum and prevents structural collapse [43]. In addition, with the expansion phenomenon during the rapid dehydration process, a porous structure of the food is formed, which helps to obtain a crisp and delicate structure [44], as well as reduces the density and shrinkage of the product [34]. In the study [45], beetroot slices were pretreated in 40 °Bx chokeberry juice at 50 °C for 2 h, and then carried to MVD at different microwave power levels. The results indicated that as the microwave power increased, the bioactive potential decreased for untreated samples, while the bioactive potential of pretreated samples increased.

For osmotically pretreated beetroot slices with a specific surface area of 827 ± 18 m^2m^{-3}, and VMD at 240 W was recommended to obtain high quality beetroot snacks. Under vacuum microwave drying, the total drying time and drying shrinkage decreased significantly compared with conventional drying. VMD led to lower compressive strength, better rehydration capacity and higher antioxidant activity than conventional drying [34]. The paper [46] displayed the effects of atmospheric, vacuum and microwave vacuum drying methods on the quality of dried beetroots, and it demonstrated that MVD reduced total drying time and decreased shrinkage compared to other drying methods, and the combined method (hot-air at 60 °C followed by microwave vacuum finish drying) was the most appropriate method to preserve the investigated parameters of dried beetroots in the highest amount.

Foam mat drying consists of the conversion of liquid or semiliquid foods into stable foams via intense agitation and insertion of air, along with using foaming agents or stabilizing agents, and conducts at lower temperatures and shorter drying times which helps to maintain nutrient in vegetables [47]. The foam mat process of drying usually refers to dehydration of the thin layer of foam by hot air [48]. In the study [47], hot air dried beetroot pulp at 50 °C for 6 h in cabinet dryer, then successfully foamed using egg albumen and fish gelatine as foaming agents, and further hot air dried and grinded into powder. The results showed that beetroot with fish gelatine had good foam expansion, foam density, hygroscopicity and red color's powder.

Sun drying (35-45 °C), tray drying (40, 50 and 60 °C) and lyophilizer drying (–40°C) were used to drying beetroots in [49]. The results showed that the chemical composition and organoleptic quality of different beetroot powders were significantly different, and the powder prepared by lyophilizer had better texture, color retention and flavor, and higher total phenolic content, betalain content, antioxidant activity and overall quality than other drying methods used. The evacuated tube solar dryer (ETSD) was used to dry beetroot in [50], and the results demonstrated that the evacuated tube with heat pipe-based solar dryer has the potential to shorten the drying time and guarantee improved quality characteristics of dried beetroot slices. The average betalain content, phenolic content and antioxidant capacity of ETSD dried beetroot slices were higher than those of sun drying.

Any single drying method has its advantages and disadvantages, hence hybrid techniques made up of complimentary drying methods that each contribute their own advantages of the highest interest. The osmoticaly pretreated beetroots in sugar-salt mixed solution were further dehydrated using convective tray drier (55, 65 and 75 °C) up to a moisture content of 40 to 60% db) followed by microwave drying (540, 810 and 1080 W) to a moisture content of 6% to overcome the slow removal of moisture content in the end [51]. The results proved that beetroots dried at high air temperature followed by high microwave power showed high water activity, high total soluble solids and improved hardness as compared to fresh beetroot. In the study [34], beetroot cubes were produced using a combination of convective pre-drying (CPD) and vacuum-microwave finish drying (VMFD) at 240, 360, or 480 W, and convective drying in hot air at 60 °C. Compared to the convective approach, VMFD dramatically decreased drying shrinkage and the overall drying time. VMFD significantly shorted the total drying time and reduced drying shrinkage in comparison with convective method. The quality of beetroot cubes dried by CPD-VMFD can be enhanced by boosting microwave output and shortening drying time of CPD. Four hybrid drying methods, consisting in ohmic heating (17.5 V/cm) or microwave pretreatment (525 or 420 W) followed by forced convection at 100 °C by microwave were applied to obtain high quality beetroot powder [52].

The drying technique used may have a variety of effects on the color, shape, structure, nutritional and nutraceutical components. As a consequence, it is crucial to choose the best drying technique. The optimization of the drying procedure is a critical step toward obtaining dehydrated beetroot with the lowest nutrient loss and maximum potential activities.

1.3 Application of pretreatments in beetroot processing

In order to strengthen the drying process and improve the product quality, many different pretreatments have been proposed. The application of pretreatments can not only reduce drying time, boost drying rate, improve moisture distribution, and minimize energy consumption, but they can also improve the functional and nutritional quality features of dried products over untreated samples [53].

Freezing pretreatment has been used in fruits and vegetables to accelarate the drying process, and maintain the product's quality. Large ice crystals form during freezing, resulting in a breakdown of the cellular structure and the formation of the porous structure [54], which could facilitate water migration and enhance mass transfer. As a result, freezing pretreatment has been used in fruits and vegetables to improve drying rate, reduce drying time and energy consumption, and maintain product quality [55]. Freezing pretreatment might damage the tissue structure, leading to the physicochemical changes of raw materials. At the same time, shortening the drying time could reduce the thermal exposure of raw materials, to better preserve the nutritional value [30]. Nevertheless, freeze-thaw pretreatment has an additional thawing process compared to freezing pretreatment, which is an efficient option to improve the drying rate by changing the permeability of cell membrane and destroying the structure of cell wall [56]. Due to ice-crystal formation and cell structure damage caused by freeze-thaw pretreatment [57], it is usually used in food industry. Freeze-thaw often occur in the circulation of meat products, so there has been many researches on Freeze-thaw pretreatment of meat products, such as Pacific white shrimp [58], tilapia fillets [59], and instant sea cucumber [60]. Freeze-thaw as a pretreatment method has also been applied in the different dried fruits and vegetables such as garlic slices [61], cape gooseberry [62], and quince fruit [63].

Ultrasound is the frequency of a sound wave (more than 20 kHz) that induces cavitation in liquids, resulting in high pressure and temperature. Strong shear, cavitation, and turbulence effects cause changes in food matrix subjected to ultrasound [64]. It has been reported that ultrasonic can be used to dry beetroots. The use of ultrasound in a drying process can overcome the drawbacks of traditional drying technologies by increasing the drying rate. The use of ultrasound for drying beetroots has been reported. Application of ultrasound in a drying process can overcome these shortcomings of drying methods by improving the drying rate. The mechanical energy provided by ultrasound can cause periodic compression and expansion, which is the same as that when continuously pressed and relaxed in a sponge, known as the “sponge effect” [65].

This mechanism may have stronger forces than surface tension, which binds water molecules within fluid capillaries, producing minuscule channels and allowing matter to move [6]. The use of ultrasound considerably damaged the beetroot microstructure, shortened drying time, and increased the external mass transfer coefficients (28-49%) and effective diffusion coefficient (60-73%) [30]. In the study [66], ultrasound-assisted beetroot drying decreased the drying time by approximately 55%, reduced in energy consumption, and about three times increase in drying rate was observed in comparison with HAD. Meanwhile, ultrasound-assisted drying retained the original color of the sample, attractive appearance, and betanin retention was approximately 15% higher than hot air drying. Ultrasound bath (indirect) and ultrasound probe (direct) used as pretreatments in the production of oven-dried beet snacks decreased the total drying time up to 24% and 26%, respectively [67]. Therefore, ultrasound is an effective pretreatment when combined with other drying methods to dry beetroots, which significantly enhances the drying time and quality of beetroot. The effect of ultrasound and freezing pre-treatment on the drying curves, microstructure, and bioactive compounds of beetroots was investigated in [30]. Results displayed that the application of freezing pretreatment and ultrasound caused significantly destroyed the microstructure of beetroots, reduced the drying time, and enhanced the mass transfer. Besides, freezing caused significant increases in betalain and total polyphenol contents and antioxidant activity in comparison with those of the raw sample.

Osmotic dehydration (OD) is most widely practiced pretreatments prior to drying to reduce energy consumption and improve food quality, which involves the immersion of material in hypertonic solution (mainly sucrose or sodium chloride solution) for several hours [68]. During osmotic pretreatment, plant cellular structure acts as a semi-permeable membrane, undergoes countercurrent mass transfer: the solute flows into the product, while moisture is transferred from the inside to the hypertonic solution, which can dislodge 10%–70% of water from fruits and vegetables at ambient temperature without causing phase changes, which provides an alternative way to reduce drying time, and slows down the thermal effect of drying respect to the degradation of bioactive compounds [69]. In a study in which beets were pretreated by osmosis in a sugar-salt solution, the beets were first dried using a convective tray dryer combined with microwave drying at different air temperatures and microwave powers [51]. The results displayed that osmotic dehydration was an effective pretreatment prior to combine drying, which reduced the final drying time and improved the quality of dried beetroots. Meanwhile, microwave inassociation with hot air drying of osmotically pretreated beetroot slices exhibited better rehydration properties, lesser color degradation, stiff texture and higher total soluble solid. In the study [70], beetroots were pretreated by osmotic dehydration (OD) and ultrasound (US). The results demonstrated that US resulted in a higher drying rate and lower lipid, ash and energy values, while OD promoted higher ash and sodium values. It was revealed that the US was more efficient pretreatment for producing beetroot chips, because it significantly redued the drying time and made the sensory preference reach to an intermediate level.

Conventional hot water blanching is the most popular and commercially adopted method, because of its simple equipment and convenient operation. It has been widely used in the pretreatment of agricultural products to improve the drying speed and enhance the product quality, but hot water blanching can generate a large quantity of waste water and increase the pollutant emissions [55]. It has been reported that blanching with conventional methods such as hot-water immersion will lead to the loss of water soluble vitamins, minerals, and compounds [71]. Therefore, for the food industry, the use of blanching as an alternative method is very attractive. In order to minimize nutrients especially water-soluble nutrients and solids dissolved in hot water and reduce wastewater, steam blanching has been developed to replace hot water blanching [55]. Steam blanching can significantly improve the retention of ascorbic acid [72], significantly inactivate the biological enzyme [73], enhance extraction of phytochemicals in blueberries [74]. For the purpose of obtaining beetroot powder, beetroots were blanched using various methods, including hot water blanching with cold water immersion, steam blanching with cold water immersion, and steam blanching with refrigeration. The research revealed that beetroot powder prepared by blanching with refrigeration was the best [75]. To assess the efficiency of various blanching techniques, including vacuum-steam pulsed blanching (VSPB), steam blanching (SB), and hot water blanching (HWB) were used to pretreat beetroots. The results indicated that VSPB took less time to completely inactive peroxidase and polyphenol oxidase enzymes, retained more betalains and total phenolics in red beetroots, and mitigated cell damages compared to HWB and SB. The study demonstrated that VSPB is a potential blanching technology for beetroot [76]. The influence of blanching, ultrasound and freezing conditions on physical properties of freeze-dried red beet was investigated in [77]. The results showed that ultrasound reduced the water activity, while water blanching in reduced shrinkage and improved porosity of samples. In addition to the pretreatment, the sample's quality was impacted by the freezing conditions before drying. Slowly frozen samples had the best porosity, while combined freezing caused the greatest shrinkage, lowest porosity, and lowest water activity [77]. The influence of pretreatment methods (thermal or nonthermal) on the properties of powders obtained from beet juice and pomace after the freeze-drying process were investigated. The results showed that steam and ultrasound led to a significant reduction in parameter *b* in the dried pomace. After pretreatment with ultrasound and steam for 15 min, a substantial rise in betanin was seen in lyophilizates [78]. Instant controlled pressure drop (DIC) was applied as a blanching pre-treatment before drying, the resulted showed the combination of DIC blanching pre-treatment with swell drying treatment maintained the preservation of the betanin concentration, total phenolic, total flavonoids and antioxidant capacity dried beetroots [79].

Ohmic heating is an electron heating method based on the passage of electrical current through the food product having electrical resistance [80], and electric energy is converted into heat, and the heat generated through food is directly related to voltage gradient and conductivity [81]. Pretreatment with different powers (420 W or 525 W for 3 min) of microwave and ohmic heating (OH) at 17.5 V/cm (2 min) in the study [52], it was found that the OH reduced the rehydration time and had the lowest rehydration capacity, whereas the microwave had the slowest rehydration time and the largest rehydration capacity. Meanwhile, the microstructure of the samples revealed that the moderate hybrid heating treatment was OH pretreatment combined with microwave-convection drying.

Because of its ability to produce non-thermal permeability of cell membranes, pulsed electric field (PEF) has grown in popularity. According to reports, the PEF pretreatment enhanced moisture diffusivity, lowering drying temperatures by 20-25 °C due to tissue damage caused by electroporation. However, more tissue structure disintegration has been noted in the PEF pre-treated samples, and rehydration after drying does not allow the texture to recover to its original pre-drying state [82].

It has been proved that the use of pretreatments ahead of drying is beneficial for improving the drying process efficiency and enhancing the quality of fruits and vegetables. However, there have been few reports on the connections between pretreatment microstructure alterations and the evolution of physicochemical attributes (texture, color, and rehydration ratio) of foods. As a result, more investigation is required to investigate the links between pretreatments, microstructure, and physicochemical aspects of products in order to improve structure formation and change functional qualities of food by selecting appropriate pretreatment methods.

1.4 Application and development prospect of beetroots in food industry

In addition to prolonging the shelf life, value addition and processing increase market opportunities and economic value of the product. Beetroot offers a lot of processing and value-adding potential. Dried beetroots can be consumed as chips as an alternative for traditional fatty acid-rich snacks, or as a component of quick meal (instant food) following simple or easy preparations [83–84]. Due to its health benefits, beetroot should be eaten on a daily basis in one form or more. As a result, appropriate processing and preservation techniques are required to get most advantages from beetroot. The beetroots can be utilized in salads and soups, baked as a whole, boiled in stews, roasted into tarts, pickled, and processed into jam, powder, wine, dehydrated slices, and juice [42, 85–88].

Natural colorants are considered as safe substances for consumption and are more likely than synthetic colorants to be used commercially as food additives [5]. Beetroot powder can be applied as natural colorant for foods, an ingredient in beverages for athletes [47] and in meat products [89]. Beetroot powder or extracted pigments are used industrially for improving the color of tomato pastes, sauces, soups, desserts, jams, jellies, ice creams, sweets, and breakfast cereals [90]. Because of its numerous health-promoting properties, beetroot has significant promise as functional food ingredients used in the food and medical industries. In the study [91], beetroot powders were used as a potential substitute of nitrite for fermented dry sausages, and the results displayed that the addition of beetroot powders decreased moisture content and a_w, and increased weight loss of sausages. Furthermore, beetroot powders affected the colour, pigments and lactic acid bacteria counts of sausages. In another study, beetroot powder was used to replace nitrite in Turkish fermented sausage [89]. The use of beetroot powder increased *a* value of samples and protected the desired red color during storage. The suggested storage period of reformulated Turkish fermented sausage using beetroot powder instead of nitrite was 56 days at 4 °C in vacuum bags.

The applicability of beetroot powder as a potential source of dietary fibre for baked rolls was investigated in [92]. It was found that the increase of beetroot powder in dough improved water absorption, delayed the development time of dough, and prolonged the stability of dough, but the mixed tolerance index decreased. With the increase of beetroot powder, the volume, specific volume and the lightness of baking rolls reduced significantly, while the redness of products increased. Cake supplemented by beetroot powder was developed in [93], four samples were prepared to contain different proportions of beetroot powder (5, 10, 15, and 20% *w/w*) in combination with wheat flour, and the results indicated that the cake formulated by 15% (*w/w*) beetroot powder was comparatively more acceptable than other formulations (0, 5, 10 and 20% *w/w*) with better color, taste, flavor and texture. In the study [94], beetroot powder was added in wheat flour to make nutritionally fortified Chinese steamed bread. Beetroot powder addition greatly decreased the specific volume and staling rate, while increasing hardness and chewiness of Chinese steamed bread. Moreover, with the increase of beetroot powder incorporation, the antioxidant potential of Chinese steamed bread in vitro increased and the digestibility of starch in vitro decreased. Beetroot puree was added to jackfruit seed crackers to increase the appearance and nutritional content [95]. In the study [96], the effect of lyophilized beetroot water extract added to cemen paste on the Turkish pastirma quality was investigated. The results revealed that the addition of lyophilized beetroot water extract (1.0% or 1.2%) to cemen paste effectively improved the color stability, lipid oxidation, microbial and sensory quality of pastırma during storage. The application of beetroot extract in cooked meat revealed that beetroot extract decreased the number of *L. monocytogenes* cells, pH values, and lipid oxidation in cooked pork. Meanwhile, cooked pork become darker and redder compared to the control samples. So it was suggested that beetroot extract could be used as a natural preservative in cooked meat production to inhibit the growth of *L. monocytogenes* [26]. Research has shown that beetroot pulp (0-40%), as a component in noodle production, may improve nutritional status, thereby increasing nutritional value, bioactive compounds, and color intensity [97]. The results showed that he betalain content, total phenol content and antioxidant activity of formulated noodles increased with an increase in level of beetroot incorporated. It proved that noodles with 30% beetroot were the best in nutritional, phytochemical, cooking and sensory quality attributes.

In recent years, there has been an increasing interest in the biological activity of beetroot and its potential use as a functional food for health promotion and disease prevention. Beetroot seems to be a powerful dietary source of health-promoting agents with the potential to treat a variety of pathological conditions, and beetroot supplementation holds promise as an economic, practical and importantly natural dietary intervention in clinical settings. Due to the high biological activity of beetroot, there are still several unexplored areas in which supplementation might confer health benefits, including pain reduction, cognitive function, vascular function and insulin resistance, especially in older and diseased populations [98]. The oxidative and physical stability of the reformulated mayonnaise with processed beetroot was studied in [99]. Results demonstrated that the oxidative stability of mayonnaise at the end of a storage period of 4 weeks (4 °C) was significantly improved by microwaved beetroot addition, and the antioxidant capacity of microwaved beetroot was equivalent to that of synthetic antioxidants used in commercial products. Betalains and betalain-rich diets are non-toxic, and may prove to be a promising alternative to supplement therapies for oxidative stress-, inflammation-, and dyslipidaemia-related diseases [100]. The use of betalains in food and associated industries may help allay worries about the potential health dangers of artificial colorants because of their toxicological safety, low cost, availability, biodegradability, and potential health effects [101].

Further research is required to explore and make use of pigments, dietary fiber and antioxidants in beetroot. Beetroot contains a huge number of bioactive compounds that can be used as a functional food source to treat a variety of diseases [5]. Beetroot should be considered as a healthy food used by consumers as well as innovative functionalized food products in food industry.

SECTION 2
OBJECTS, MATERIALS AND METHODS OF RESEARCH

This section introduces the experimental protocol in the study, defines the research topic and materials, describes the determination methods of indicators, and processes the analysis methods for experimental data. The research was conducted at School of Food and Bioengineering, Hezhou University in China.

2.1 Objects and plan of theoretical and experimental research

Objective of the study: The first main objective of this study was to evaluate the influence of different drying methods (sun drying, hot air drying, heat pump drying, microwave drying, vacuum drying, freeze drying and vacuum microwave drying) on the the changes of physical properties, bioactive compounds and antioxidant activity in beetroots. The second main objective of this study was to investigate the different freeze-thaw pretreatments on the physical properties, bioactive compounds and antioxidant activity of dried beetroots. The third main objective of this study was to research on the application of dried beetroot, pretreated by freeze-thaw method in the food industry (meat products and biscuits). The scheme of theoretical and experimental research are presented in Fig. 2.1.

2.2 Materials and equipment of this research

2.2.1 Raw material, chemicals and solvents

Fresh beetroots (*Beta vulgaris* L.) were procured from a local market (Xuzhou, China) and stored at 4 °C before use.

Ascorbic acid assay kit was obtained from Nanjing Jiancheng Institute of Bioengineering (Nanjing, China). 2,2-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS, purity ≥ 98%), 1,1-diphenyl-2-picrylhydrazyl (DPPH, purity ≥ 98%), gallic acid (purity ≥ 98%), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox, purity ≥ 98.0%), 2,4,6-tripyridinyl-1,3,5-triazine

(TPTZ, purity ≥ 98.0%), Folin-Phenol reagent (1.0 mol/L), catechin, and rutin (purity ≥ 98%) were supplied by Shanghai Yuanye Bio-Technology Co., Ltd (Shanghai, China). All other reagents used in this experiment were of analytical grade.

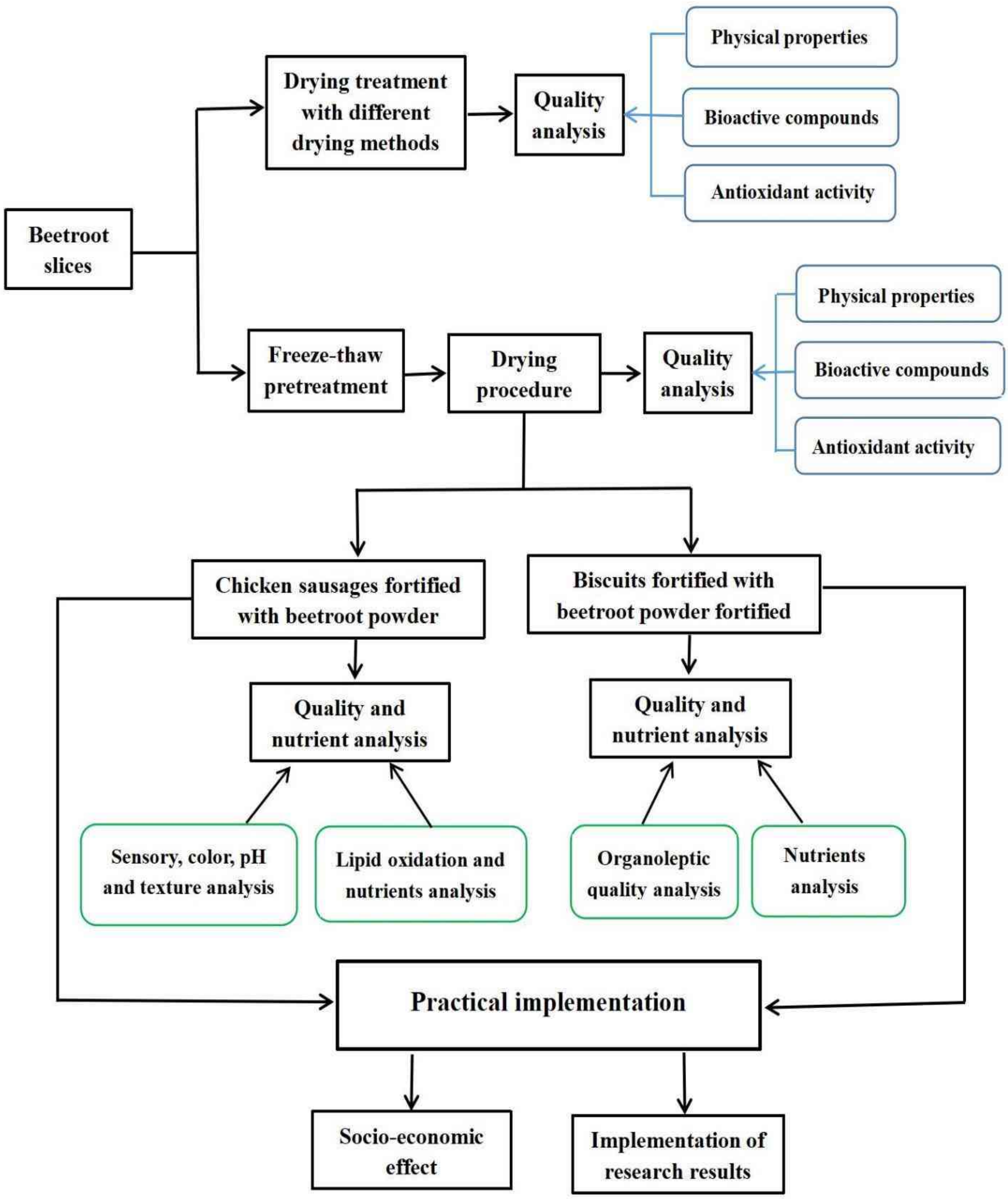


Fig. 2.1 Scheme of theoretical and experimental research

2.2.2 Equipment used in this research

Microwave drying system (SAM-255, CEM Corporation, USA). Microwave vacuum dryer (WBZ-10, Guiyang Xinqi Microwave Industry Co., Ltd, China). Freeze dryer (FDU-2110, Tokyo Rikakikai Co., Ltd, Japan). Vacuum drying oven (BPZ-6033B, Shanghai Yiheng Scientific Instrument Co., Ltd, China). Hot air dryer (DHG-9245A, Shanghai Yiheng Scientific Instrument Co., Ltd, China). Heat pump dryer (L3.5AB, Guangdong IKE Industrial Co., Ltd, China). Texture analyzer (TA.XT PLUS, Stable Micro Systems Ltd, UK). Colorimeter (CR-400, Konica Minolta Sensing, Inc., Japan). Scanning electron microscope (Quanta 450 FEG, FEI Nano Ports, USA). Thermal emission scanning electron microscope (Gemini 300, Carl Zeiss AG, Germany). Vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, China). Centrifuge (H1850, Xiangyi Centrifuge Co., Ltd, China). pH meter (PHS-3C, Shanghai Yidian Scientific Instruments Co., Ltd, China). Visible spectrophotometer (722N, Shanghai Youke Instrument Co., Ltd, China). Moisture analyzer (HX204, Mettler Toledo Co., Ltd, Switzerland). Refrigerator (BCD-225SLDA, Qingdao Haier Biotechnology Co., Ltd, China). Ultra-low temperature freezer (DW-FL450A1, Zhongke Meiling Low Temperature Technology Co., Ltd, China). Muffle furnace (KSL-1200X, Hefei Kejing Material Technology Co., Ltd, China). Kjeldahl nitrogen analyzer (ATN-300, Shanghai Hongji Instrument Equipment Co., Ltd, China). Fat analyzer (SZF-06, Shanghai Xinjia Electronics Co., Ltd, China). Baking oven (MG38CB-AA, Guangdong Midea Kitchen Appliance Manufacturing Co., Ltd, China). Meat grinder (ZY-001, Langfang Jiapei Electrical Appliances Co., Ltd, China). Thermostat water bath (HH-S2, Jiangsu Jinyi Instrument Technology Co., Ltd, China)

2.3 Research Methods

Research methods include a complex of traditional and modern methods of sensory assessment, physics, chemistry, microbiology, experimental planning, and experimental data processing.

2.3.1 Moisture content determination

A moisture analyzer was used to measure the sample's moisture content (wet basis) at 105 °C until it attained a consistent weight.

2.3.2 Determination of rehydration ratio

Rehydration ratio was determined according to the method given by Bozkir and Ergün [102]. Dried beetroot samples (2.0 ± 0.1 g) were immersed in a beaker with 200 mL of distilled water and the beaker was placed in the thermostat water bath at 80 °C for 15 min. Rehydrated beetroots were taken out, absorbed the superficial water with absorbent paper, and then weighed. Rehydration ratio was calculated according to Equation (1).

$$RR = \frac{W_2}{W_1} \tag{1}$$

Where, RR is rehydration ratio, W_1 is the mass of dried beetroot samples, g, W_2 is the mass of beetroots after rehydration, g.

2.3.3 Determination of shrinkage rate

The shrinkage rate was determined by the solid displacement method using superfine quartz sand. Based on the volume change of the sample, shrinkage rate was calculated according to Equation (2) [103].

$$SR = \frac{V_0 - V_1}{V_0} \times 100 \tag{2}$$

Where SR is shrinkage rate, %, V_0 is the volume of fresh beetroots, mL, V_1 is the volume of dried beetroots, mL.

2.3.4 Color measurement

Fresh beetroots were crushed into a pulp and then tested to guarantee color uniformity. Dried beetroot samples were ground into powder to determine the color.

Color parameters were measured using a colorimeter equipped with D65 illuminant system and 8 mm measuring area in the CIELAB system. Color parameters were expressed as L, a, and b. L indicates lightness read from 0 (completely black) to 100 (completely white), $+a$ value represents redness and $-a$ is greenness, and $+b$ value shows yellowness ($-b$ is blueness) on the hue-circle

[104]. Total color change (ΔE) represents the magnitude of color change of sample after drying. Chroma (C) is the quantitative attribute of colorfulness, which denotes the saturation of the color. Hue angle ($H°$) indicates the color nuance and defines as follows: 0 (red–purple), 90 (yellow), 180 (bluish-green), 270 (blue) [9]. The ΔE, C and $H°$ were calculated according to Equation (3), Equation (4) and Equation (5), respectively.

$$\Delta E = \sqrt{(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2} \tag{3}$$

$$C = \sqrt{a^2 + b^2} \tag{4}$$

$$H° = \tan^{-1}\left(\frac{b}{a}\right) \tag{5}$$

Where, L, a, b are the values of dried samples, L_0, a_0, b_0 are the values of fresh samples.

2.3.5 Texture analysis

Determination of hardness for dried beetroots: The textural profile of dried beetroot was analyzed using the texture analyzer equipped with a cylindrical probe (P/2). The following test specifications were used: Test force in compression mode; pre-speed and test speed of 2 mm/s; 10 mm/s post-speed and 10 mm test distance; and trigger force of 5.0 g. Ten measurements were taken for each sample, and the average was calculated.

According to the twice compression method, texture profile analysis (TPA) of meat products was determined using the texture analyzer equipped with a cylindrical probe (P50). The sample was compressed twice, with a 5-s delay between the descents, pre-speed of 5 mm/s; test-speed and post-speed of 1 mm/s; compression ratio of 50%; trigger force of 5.0 g [105]. The following texture profile parameters were quantified: hardness, springiness, cohesiveness, gumminess, chewiness, and resilience. The result was the average of at least eight measurements per batch.

Determination of texture profile analysis (TPA) of sausage products. Sample was cut into 40x20 mm (heightxdiameter) cylinders to determine the texture. The experiment uses the TPA puncture method to measure sausage products. The probe model is P/5. Set the measured parameters, 5 mm/s before the test rate, 1 mm/s test rate, 1 mm/s after the test rate, 50 % compression ratio, 5 g trigger force. The measurement indicators include hardness, elasticity, cohesiveness, chewiness, adhesiveness and recovery.

Determination of texture profile analysis (TPA) of biscuits. Texture analyzer fitted with a cylindrical probe (P2) was used to determine the hardness, fracturability, springiness, cohesiveness, gumminess and chewiness of biscuits. Biscuits were measured after cooling for 24 h. The testing parameters were as follows: Test force using puncture mode, pre-speed and test speed of 1 mm/s, post-speed of 5 mm/s and test distance of 10 mm, and trigger force of 5.0 g. Performed eight measurements on each group of samples and calculated the average value.

2.3.6 Microstructure analysis

The microrphology of dried beetroot was observed using a scanning electron microscope (Quanta 450 FEG). Dried beetroots were chopped into thin slices, placed to a copper tube with the cross section facing up, and then covered in gold using an ion sputtering device. An accelerating voltage of 20.0 kV was used for the scanning.

The microrphology of dried beetroot, pretreated by freeze-thaw method was observed using a thermal emission scanning electron microscope (Gemini 300). Dried beetroots were sliced into thin slices and placed on a copper tube with the cross-section facing up, and then gold was plated using an ion sputtering device. The scanning was done with a 5.0 kV accelerating voltage.

2.3.7 Preparation of beetroot extracts

Dried beetroots obtained from three repetitions were mixed and then ground into powder (passed through a 60-mesh sieve). Two grams of beetroot powder were placed in a 50 mL centrifuge tube and extracted with a vortex mixer for 2 minutes at room temperature with a 50% (v/v) ethanol solution (20 mL). After centrifugation at 5000 rpm for 10 min. The sediments were further extracted twice with 20 mL of 50% ethanol solution (v/v). Three extraction supernatants were poured into a 100-mL volumetric flask and the volume was made up to 100 mL with 50% (v/v) ethanol solution. The extracts were stored in reagent bottles at 4 °C for further analysis.

2.3.8 Determination of betalains content

The betalains content was determined using the colorimetric method described in [106] with appropriate modifications. The extract was diluted with 0.05 M phosphate buffer solution (pH 6.5) to obtain absorption value between 0.8 and 1.0 at 538 nm, and then the absorbance of diluted extract was measured at 480, 538, and 600 nm, respectively. The betalains content was calculated according to Equation (6).

$$BC(mg/g) = \frac{(A_{538}/A_{480} - A_{600}) \times DF \times MW \times 100 \times V}{\varepsilon \times l \times m} \quad (6)$$

Where, BC is betalains content, mg/g; A_{538}, A_{480}, and A_{600} are the absorbance of diluted extract at 480, 538, and 600 nm, respectively, DF is the dilution factor, and l is the path length (1 cm) of the cuvette; V is the volume of beetroot extract, L; m is the mass of beetroot powder, g. The molecular weights (MW) and molar extinction coefficients (ε) of betanin (MW = 550 g/mol; ε = 60000 L/(mol cm) in H_2O; λ = 538 nm) and indicaxanthin (MW = 308 g/mol; ε = 48000 L/(mol cm) in H_2O; λ = 480 nm) were used to quantify betacyanins content and betaxanthins content, respectively.

2.3.9 Measurement of ascorbic acid content

The ascorbic acid content was evaluated by a colorimetric technique using the ascorbic acid determination kit. Results were expressed as mg/100g.

2.3.10 Determination of total phenolic content (TPC)

Total phenolic content was determined by Folin-Ciocalteu method [107] with little modifications. 0.5 mL diluted extract was combined with 2.5 mL of 10% (v/v) Folin-Ciocalteu's reagent, followed by 2 mL of 7.5% (w/v) sodium carbonate solution. The mixture was incubated for 15 min at 50 °C before being cooled to room temperature, and the absorbance at 760 nm was measured against a blank. With varied gallic acid concentrations (0–0.1 mg/mL), a standard curve was produced. The total phenolic content was expressed as milligrams of gallic acid equivalents (GAE) per gram.

2.3.11 Measurement of total flavonoids content (TFC)

Total flavonoids content was determined using a modified aluminum chloride colorimetric method [108]. 30 μL of 5% $NaNO_2$ solution (w/v) was combined with 0.5 mL of diluted sample extract before standing for 5 min. Then 30μL of 10% $AlCl_3$ solution (w/v) was added and stirred for 6 min. 40 μL of distilled water and 0.4 mL of 1.0 M NaOH solution were added last. The mixture was given 15 min to stand at room temperature. The mixture's absorbance was measured at 510 nm. A calibration curve was obtained using different concentrations (0–1.0 mg/mL) of rutin/catechin. Results were expressed as milligrams rutin/catechin equivalents (RE/CE) per gram.

2.3.12 Determination of DPPH radical scavenging ability

The DPPH assay was conducted according to the method reported in [109]. The reaction took place in the dark at room temperature for 30 minutes after the diluted sample extract (2 mL) was combined with 4 mL of 0.2 mM DPPH solution for 30 s. The absorbance of the mixture at 517 nm was measured. A calibration curve with Trolox at concentrations of 0–80 μmol/L was established. Results were showed as milligrams of Trolox equivalents (TE) per gram.

2.3.13 Ferric reducing antioxidant power (FRAP) assay

Ferric reducing antioxidant power (FRAP) was determined according to Benzie et al [110]. FRAP reagent was prepared by mixing 20 mM $FeCl_3$ solution, 0.3 M acetate buffer (pH 3.6) and 10 mM Tri-2-pyridyl-s-triazine (TPTZ) solution in 40 mM HCl solution with the ratio of 1:10:1 (v/v/v). Before use, the FRAP reagent was incubated at 37 °C. FRAP reagent (6.0 mL) was fully reacted with 0.2 mL of diluted sample extract. The absorbance at 593 nm was measured after a 10-minute incubation at 37 °C. A calibration curve was obtained using different concentrations (0–600 μmol/L) of Trolox. All solutions got ready the day of analysis. The results were expressed as mg TE/g.

2.3.14 Determination of ABTS radical scavenging ability

The 2,2′-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) assay was conducted by the colorimetric method reported in 111] with small modifications. To make the $ABTS^{+}\cdot$ solution, 7 mM ABTS and 2.45 mM $K_2S_2O_8$ solution were mixed in equal quantities. The $ABTS^{+}\cdot$ solution was left to stand for 16 h in the dark at room temperature. Before the measurement, the $ABTS^{+}\cdot$ solution was diluted with 80% (v/v) ethanol to provide an absorbance of 0.70 ± 0.02 at 734 nm. Diluted extract (0.4 mL) was reacted with 3.6 mL diluted $ABTS^{+}\cdot$ solution for 6 min at room temperature. Absorbance was read at 734 nm. Trolox with different concentrations (0–150 μmol/L) was used as a calibration curve. Results were expressed as milligrams Trolox equivalents (TE) per gram (mg TE/g).

2.3.15 Sensory evaluation of meat products

Group of 20-trained specialists from the School of Food and Bioengineering, Hezhou University, China, conducted a sensory evaluation. Before participating in the sensory evaluation, the specialists were trained on the sensory descriptors of the different sausages. A ten-point hedonic scale was used to test the color, odor, flavor, texture and overall acceptability of sausage samples. The hedonic scale consisted of ten points: 1 – terrible; 2 – don't like it very much; 3 – dislike moderately; 4 – don't like it a bit; 5 – neither likes nor dislikes; 6 – like it slightly; 7 – moderately liked; 8 – really like it; 9 – like it very much; 10 – excellent.

2.3.16 Sensory evaluation of sausage products

Invite 10 food majors with sensory evaluation experience to form an evaluation team. Cut off both ends of the heated sausage, cut the middle part into a 1 cm-long cylinder, and distribute sausage products of different experimental groups to the group members for evaluation. Mainly evaluate the color, hardness, flavor, viscosity and overall acceptability of sausage products. The scoring table is shown in Table 2.1.

Table 2.1

Sensory evaluation standard of sausage products

Evaluation index	**Evaluation score**		
	1~3 Score	**4~6 Score**	**7~9 Score**
Color	Average appetite, normal	No appetite, poor color	Appetite, attractive color
Texture	The taste is rough and hard	The taste is slightly rough and hard	The taste is fine and elastic
Flavor	No sausage taste	Average sausage taste	Suitable sausage taste
Viscosity	Sticky teeth	Slightly sticky teeth	Non-sticky teeth
Overall acceptability	Not accept	Accept	Like

2.3.17 Sensory evaluation of biscuits

According to the GB/T 20980-2021 General quality of biscuits [112], 10 experienced sensory evaluators without special hobbies were selected to conduct sensory evaluation of biscuits. Biscuits were placed in a white porcelain plate under natural light. Criteria for sensory evaluation of biscuits is shown in Table 2.2.

Table 2.2

Criteria for sensory evaluation of biscuits

Index	Evaluation criterion	Score/ point
Color	Uniform color, purple red, no white powder and no burning. Color is uniform, with a small amount of over burnt and over white. Uneven color, poor luster, and a lot of over burnt and over white.	21～30 16～20 1～15
Appearance	Complete appearance, no cracks, even thickness, few concave bottoms. The appearance is basically complete, with a few cracks, basically uniform thickness, and few concave bottoms. Incomplete appearance, uneven thickness, many cracks and concave bottoms.	11～15 7～10 1～6

continuation of Table 2.2

Organization structure	Fine tissue, the fault is uniform, uniform and fine small pores inside. Rough tissue, basically uniform small pores, and different size of cavities. Poor organization, uneven small holes, and obvious difference in hole size.	11～15 7～10 1～6
Taste	The taste is crisp, pure, and not sticky. The taste is crisp, sweet or light, slightly sticky. The taste is soft, not brittle, rough, too sweet or too light, sticky.	16～20 13～15 1～12
Odor and flavor	Rich fragrance, unique beetroot flavor, harmonious smell, and no peculiar smell. Relatively strong flavor, low beetroot flavor, harmonious smell, and no peculiar smell. Fragrance is not obvious, without beetroot flavor, with peculiar smell.	16～20 8～15 1～7

The panelists were asked to evaluate the biscuits for different sensory attributes, namely color (30 points), taste (20 points), organization structure (15 points), appearance (15 points), odor and flavor (20 points), and the overall acceptability was 100 points.

2.3.18 Determination of pH value in meat products

The pH values of the samples were determined using a pH meter. Taking 10 g of meat products emulsion, added 100 mL of distilled water, well-mixed, and then stand for 10 min. At last, took the supernatant and measured the pH value for three times [113].

2.3.19 Determination of TBARS and peroxide value in meat products

The thiobarbituric acid reactive substances (TBARS) value was determined using the method described in [114]. Peroxide value was measured according to the method in [115].

2.3.20 Determination of ash, fat and protein content in meat products and biscuits

Ash contents of samples were determined according to AOAC (2000) [116]. Fat content was measured using the Soxhlet extraction method in accordance with

AOAC (2006) [117]. Protein content was analyzed was determined by the automatic Kjeldahl nitrogen analyzer.

2.3.21 Microbiological analyses of meat products

25 g of meat products sample was homogenized with 225 mL of 0.1% peptone water, and serially diluted to a decimal scale. Lactic acid bacteria were quantified using agar (30 °C/72 h) under anaerobic conditions, aerobic mesophilic bacteria on a standard agar medium (35 °C/48 h), and total coliforms on brilliant green bile broth (35 °C/24 h). For mould-yeast count, potato dextrose agar (pH: 3.5) was used (aerobically incubation for 5 days at 25 °C).

2.3.22 Cooking loss in sausage products

Weigh 35 g of minced meat into a 50 ml centrifuge tube and centrifuge (3000 rpm, 5 min) to remove air bubbles in the tube. Then, heat it in a water bath (75 °C, 30 min), cool the heated sample at room temperature for 1 hour, weigh it after cooling, and record its mass. The calculation of cooking loss is shown in formula 7.

$$Cooki\ ng\ Loss = \frac{w_0 - w_1}{w_0} \times 100\% \tag{7}$$

Where w_0-weight of raw meat batters, g; w_1-weight of cooked meat batters, g.

2.3.23 Emulsion stability of sausage products

Pour the liquid lost during cooking (centrifuge tube upside down for 40 minutes) into a glass dish. Moisture loss is the weight of the liquid lost by cooking and drying after heating at 105 °C for 16 hours, while fat loss is the mass of the sample remaining after the drying of the liquid lost by cooking. The calculation of water loss and fat loss is shown in formulas 8 and 9.

$$Moi\ sture\ Loss = \frac{w_2 - w_3}{w_0} \times 100\% \tag{8}$$

$$Fatt\ \ Loss = \frac{w_3}{w_0} \times 100\% \tag{9}$$

Where w_0-weight of raw meat batters, g; w_2-weight of cooking liquid, g; w_3-remaining weight after heating, g.

2.3.24 Moisture distribution of sausage products

In this experiment, low- field nuclear magnetic resonance (LF-NMR) technology was used to determine the dynamic distribution of internal water content of chicken intestines and raw meat paste in different experimental groups. Wrap the raw meat mince with plastic wrap into spherical samples with a diameter of about 1cm, cut the chicken intestines into 1cm×1cm×4cm, and wrap the sample with plastic wrap into cylindrical samples and place them in a nuclear magnetic test tube (test tube diameter is 1.8 cm, height 18 cm), use the analysis application software to determine the sample relaxation time. Inversely perform the lateral relaxation (T2) through the CONTIN software, and display the corresponding relaxation time (T2B, T21 and T22) and amplitude (A2B, A21 and A22). Use the imaging software that comes with the system to scan the sample into an MRI picture, and use the pseudo- color IPT.2014 software to make the MRI picture pseudo-color processing.

2.4 Laboratory research protocols

The research was carried out at Hezhou University in China, Sumy National Agricultural University in Ukraine, the results of experiments are confirmed by relevant research protocols. Research protocols are given in the Addition A. "Protocols of experimental data".

2.5 Statistical analysis

All experiments were performed in at least triplicate, and all values are expressed as mean ± standard deviation (SD). Figures were drawn using Origin 2017 (Origin Lab, MA, USA). One way analysis of variance (ANOVA) and the Tukey’s multiple range test / Ducan’s multiple range test were computed with the SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA) at a statistical significance level of 95% confidence level ($p<0.05$). By default, if the samples are listed in order in the column, values with different letters in the same column indicate a significant difference ($p<0.05$). If samples are indicated in turn in a row, values with different letters in the same row indicate a signifcant difference ($p<0.05$).

SECTION 3
TECHNOLOGY FOR OBTAINING DRIED BEETROOT AND IMPROVING THE FUNCTIONAL AND TECHNOLOGICAL PROPERTIES BY FREEZE-THAW PRETREATMENT

3.1 Technology for obtaining dried beetroots

Fresh beetroots contain amounts of moisture and can not be stored for a long time. Additionally, it is expensive to transport fresh beetroots and simple to damage mechanical components. Therefore, transporting fresh beetroot over great distances is not recommended. As a result, processing beetroots is required to cut shipping costs and increase storage time. Drying is a well-known process for maintaining the quality of vegetables and fruits, and it works by using heat to remove moisture [118], which plays a critical role in extending the shelf life of fresh perishable foods, lowering packing costs, and reducing transportation weight [119]. Drying fresh beetroots can reduce moisture content and water activity, which in turn reduces microbial development, chemical reactions, and enzymatic activity, as well as storage and transportation expenses [120].

It is well known that the drying process causes nutritional losses and changes the chemical and physical properties of raw materials. Therefore, it is critical to select appropriate drying method/conditions in order to achieve high-quality dehydrated beetroots.

3.1.1 Effects of drying conditions on quality attributes of beetroots

3.1.1.1 Effects of heat pump drying conditions on quality characteristics of beetroots

Based on the inverse Carnot cycle theory, heat pump drying (HPD) can adjust the drying temperature and air humidity separately, recover energy from exhaust, and increase energy efficiency [36], which is particularly suitable for the heat-sensitive vegetables and fruits as drying can occur at low temperatures.

Studies have shown that agricultural items dried using HPD have better color and flavor qualities than those dried using the traditional hot air dryer. The bioactive components and antioxidant power of beetroot may be lost during the heat pump drying process. Consequently, the objective of this study was to investigate the influence of various heat pump drying conditions on the quality attributes of beetroots.

Experiment design. The one-factor-at-a-time method was applied in this study to design experiments repeated three times. Investigated factors include slice thickness, drying temperature, and loading density. The levels of loading density were 1.5, 2.0, 2.5, and 3.0 kg/m^2, respectively, those of drying temperatures were 45, 50, 55, 60, and 65 °C, correspondingly, and slice thicknesses were 2, 5, and 8 mm, individually. The beetroot samples were put single layer on a rectangular polyethylene tray (50 × 74 cm), which was put into a heat pump dryer.

Results of physicochemical properties and antioxidant activity in beetroots. The effect of loading density on the heat pump drying of beetroots was carried at drying temperature of 65 °C and slice thickness of 5 mm. The color changes of beetroots affected by different loading densities are presented in Table 3.1.

Table 3.1

Effect of different loading densities on color parameters of beetroots

Loading density, kg/m^2	L	a	b	ΔE
1.5	38.56 ± 1.17^{a}	21.62 ± 0.71^{d}	0.82 ± 0.20^{e}	7.40 ± 0.11^{a}
2.0	37.44 ± 0.60^{ab}	23.11 ± 0.24^{c}	1.47 ± 0.09^{c}	5.95 ± 0.32^{b}
2.5	37.75 ± 0.86^{ab}	24.77 ± 0.31^{b}	2.37 ± 0.30^{b}	4.10 ± 0.12^{c}
3.0	38.95 ± 1.01^{a}	25.28 ± 0.44^{b}	1.23 ± 0.05^{d}	3.82 ± 0.09^{d}
FD beetroots	38.71 ± 0.90^{a}	28.73 ± 0.16^{a}	2.86 ± 0.07^{a}	-

The L values of beetroots dried at different loading densities were not significantly different compared to freeze dried (FD) beetroots. The a values of beetroots significantly increased with the increase of loading density, and were significant lower than that of freeze dried (FD) beetroots ($p < 0.05$). Different loading densities had significant effects on the *b* values of beetroots, and the *b* values of beetroots dried at different loading densities significantly lower than that of FD beetroots ($p < 0.05$). In terms of ΔE, decreased with the increase of loading density, and the beetroots dried at loading density of 3.0 kg/m^2 showed the lowest ΔE (3.82 ± 0.09), indicating that the color of beetroots dried at loading density of 3.0 kg/m^2 was close to that of FD beetroots.

As seen in Fig. 3.1, the rehydration ratio of dried beetroots increased with increasing loading density, and no significant difference was observed in rehydration ratio between beetroots dried at loading density of 2.5 kg/m^2 and 3.0 kg/m^2. The beetroots dried at loading density of 1.5 kg/m^2 displayed the lowest rehydration ratio of 4.68 ± 0.05.

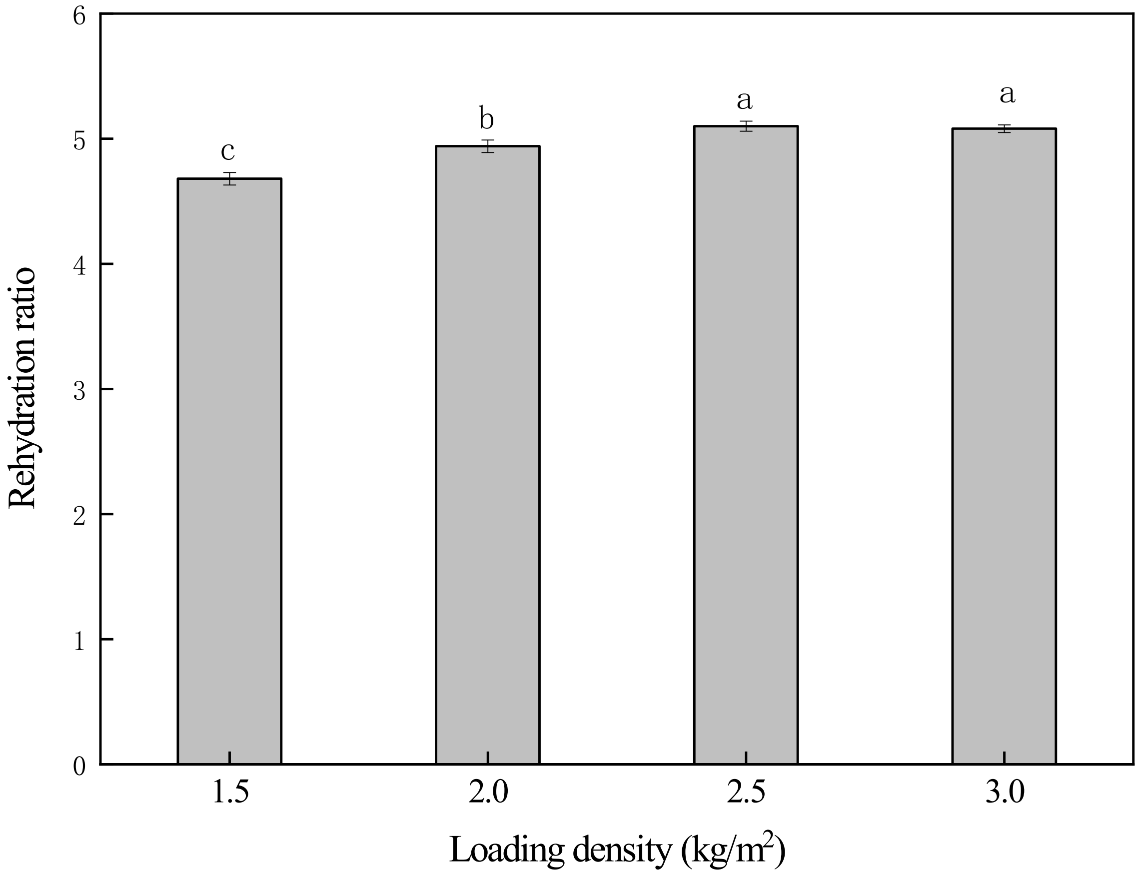


Fig. 3.1 The effect of loading density on rehydration ratio of dried beetroots

Contents of betalains and ascorbic acid presented in Table 3.2 indicate the influence of loading density. Contents of betacyanins and betaxanthins were showed the same tendency, and increased with the increase of loading density from 2.0 to 3.0 kg/m^2. Betacyanins content was the highest (2.81 ± 0.03 mg/g) for dehydrated beetroots at loading density of 2.0 kg/m^2, and the lowest (2.50 ± 0.06 mg/g) for dehydrated beetroots dried at loading density of 3.0 kg/m^2, while betaxanthins content reached to the highest (1.67 ± 0.02 mg/g) at loading density of 2.0 kg/m^2, and to the lowest (1.41 ± 0.01 mg/g) at loading density of 3.0 kg/m^2.

Table 3.2

Effect of different loading densities on betalains content and ascorbic acid content of dried beetroots

Loading density, kg/m^2	Betacyanins, mg/g	Betaxanthins, mg/g	Ascorbic acid, mg/100g
1.5	2.69 ± 0.02^b	1.56 ± 0.05^b	309.93 ± 5.21^a
2.0	2.81 ± 0.03^a	1.67 ± 0.02^a	302.16 ± 3.14^{ab}
2.5	2.67 ± 0.02^b	1.59 ± 0.01^b	296.55 ± 1.95^{bc}
3.0	2.50 ± 0.06^c	1.41 ± 0.01^c	290.29 ± 5.97^c

It can be seen from Table 3.2 that the ascorbic acid content decreased with the increase of loading density. It is not surprising that the larger loading density was, the longer the drying time was, and the more serious destruction of ascorbic acid was. Because the ascorbic acid is a heat-sensitive substance, which will be destroyed after long-time drying. The beetroots dried at 1.5 kg/m^2 showed the highest ascorbic acid of 309.93 ± 5.21 mg/100g.

Contents of total phenolic and total flavonoids in dehydrated beetroots affected by loading density were determined and are demonstrated in Fig. 3.2. Actually, there were no significant differences in total phenolic ($p > 0.05$) among dehydrated beetroots obtained at different loading densities, indicating that the loading density has little effect on the total phenolic content of dehydrated beetroots. The total phenolic content of dehydrated beetroots ranged from 9.36 ±

0.20 to 9.83 ± 0.17 mg GAE/g. The content of total flavonoids increased with the increase of the loading density, but the increase was not significant ($p > 0.05$) when the loading densities were 2.0, 2.5, and 3.0 kg/m^2. The dehydrated beetroots dried at loading density 1.5 kg/m^2 showed the lowest total flavonoids content of 7.57 ± 0.16 mg CE/g.

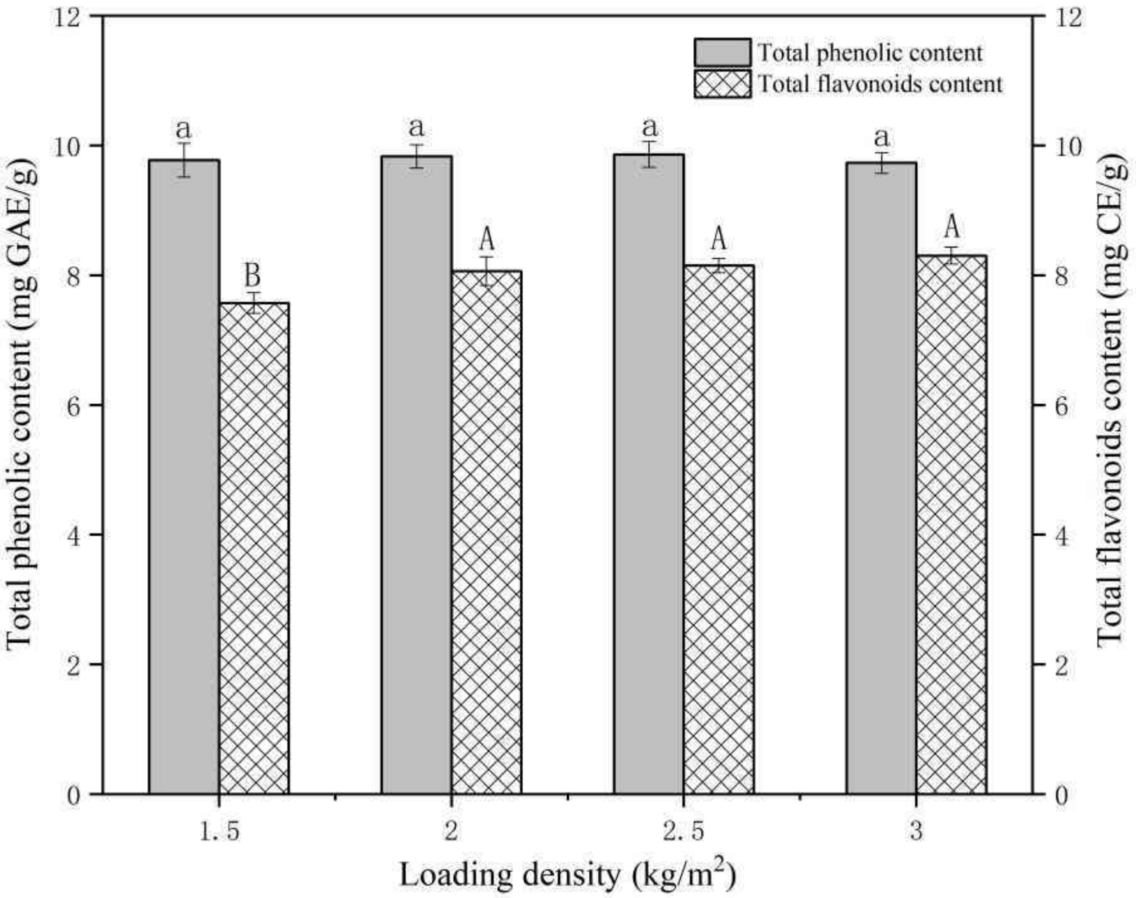


Fig. 3.2 Contents of total phenolic and total flavonoids of dehydrated beetroots as affected by different loading densities

In order to achieve a more complete view, three methods (ABTS, DPPH and FRAP assays) were used to evaluate the antioxidant activities of dehydrated beetroots. Each method is based on a different chemical system and/or reaction, choosing multiple methods can be expected to obtain different antioxidant activity results, allowing researchers to better understand the great variety and range of action of antioxidant compounds found in beetroots [30]. Table 3.3 shows the antioxidant activities of dehydrated beetroots under difference loading densities.

The scavenging ability of DPPH radicals decreased with the increase of the loading density. ABTS radical scavenging ability decreased first and then increased with the increase of loading density. It was obvious that FRAP value decreased with the increase of loading density, but there was no difference in FRAP values among the loading densities of 2.0, 2.5 and 3.0 kg/m^2. The highest DPPH radical scavenging activity, FRAP value and ascorbic acid content were found in the dried beetroots obtained at loading density of 1.5 kg/m^2, indicating that DPPH radical scavenging and FRAP values were direct correlations to ascorbic acid content. Correlations between ascorbic acid content and FRAP value were also reported in other studies [121].

Table 3.3

Antioxidant activities of dehydrated beetroot samples at different loading densities

Loading density, kg/m^2	DPPH, mg TE/g	ABTS, mg TE/g	FRAP, mg TE/g
1.5	1.28 ± 0.04^a	22.75 ± 0.42^a	15.98 ± 0.13^a
2.0	1.11 ± 0.01^b	20.89 ± 0.68^b	15.33 ± 0.36^b
2.5	1.08 ± 0.02^b	21.82 ± 0.46^{ab}	15.06 ± 0.08^b
3.0	1.02 ± 0.02^c	22.48 ± 0.52^b	14.81 ± 0.23^b

To explore the influence of drying temperature on the bioactive compounds and antioxidant activities of dehydrated beetroots. The beetroot samples were dried at loading density of 2.0 kg/m^2 and slice thickness of 5 mm, and the temperature of drying ranged 45, 50, 55, 60, and 65 °C.

The color parameters of dried beetroots affected by different drying temperatures are displayed in Table 3.4. The highest *L* value of beetroot was dried at 50 °C, indicating the brightest character. The lowest *L* value was found in the dried beetroot produced using the lowest temperature of 45 °C, a similar conclusion has been reported in [122]. Compared to FD beetroots, the effect of drying temperature on *L* value was not significant. FD beetroots had the highest *a* value, indicating the most redness. The value of *a* was discovered to decrease during the drying temperature range from 45 to 60 °C, and subsequently to increase at 65 °C. There was an decrease in yellowness (*b*) with an increase in drying temperature. The color variations of samples after drying at various temperatures cannot be fully explained by the individual analyses of the *L*, *a*, and *b* parameters. The Maillard reaction takes place during drying, creating dark pigments that alter the sample's color. The drying temperature has an impact on this process, with higher temperatures generating more dark pigments [122]. However, the drying time that the sample is subjected to this condition is also an important factor, on the other hand, drying time is a key aspect since the shorter the exposure time, the lower the formation of dark pigments, with a compensatory effect [123]. The ΔE values of beetroots dried at 45, 50, and 65 °C were significantly lower than those of beetroots dried at 55 °C and 60 °C, and there was no significant difference in ΔE values among the beetroots dried at 45, 50, and 65 °C ($p > 0.05$). As a result, dried beetroots submitted to 45 °C displayed a larger tendency towards redness, yellowness, in comparison with those of dried beetroots subjected to other drying temperatures.

Table 3.4

Effect of different drying temperatures on color parameters of beetroots

Drying temperature, °C	*L*	*a*	*b*	ΔE
45	36.27 ± 0.27^{c}	25.43 ± 0.22^{b}	1.91 ± 0.14^{b}	4.22 ± 0.30^{c}
50	39.20 ± 0.95^{a}	25.04 ± 1.18^{bc}	1.55 ± 0.23^{bc}	4.05 ± 0.34^{c}
55	37.44 ± 0.60^{abc}	23.11 ± 0.24^{c}	1.47 ± 0.09^{bc}	5.95 ± 0.32^{ab}
60	36.39 ± 1.56^{bc}	23.03 ± 0.34^{c}	1.44 ± 0.13^{bc}	6.47 ± 0.19^{a}
65	39.10 ± 0.62^{ab}	24.99 ± 1.29^{bc}	1.22 ± 0.23^{c}	4.17 ± 0.27^{c}
FD beetroots	38.71 ± 0.90^{abc}	28.73 ± 0.16^{a}	2.86 ± 0.07^{a}	-

Rehydration capability, a key quality indicator for dried products, measures how well the material maintains its original shape following drying and the degree to which the cellular structure has been harmed. It relies on the properties of the materials, the conditions of drying and rehydration, the degree of cellular material damage during drying, and the kind of pretreatment used. Typically, the drying process alters the material's structure permanently and prevents it from returning to its original shape. The rehydration ratio of dried beetroots prepared at different drying temperatures are illustrated in Fig 3.3. It can be seen that rehydration ratio of dried beetroots decreased significantly ($p < 0.05$) with the increase of drying temperature. Similar trend has been reported in [124]. Rehydration ratios at drying temperatures of 45 to 65 °C varied from 5.17 ± 0.09 to 4.50 ± 0.19, respectively. This could be because as the drying temperature rises throughout the drying process, the moisture on the sample's surface evaporates quickly, leaving a hard layer, and the high temperature disrupts the structure of the tissue, resulting in a drop in rehydration ratio [125]. As we know, the lower the rehydration ratio, the more severe the damage to the sample's cell structure.

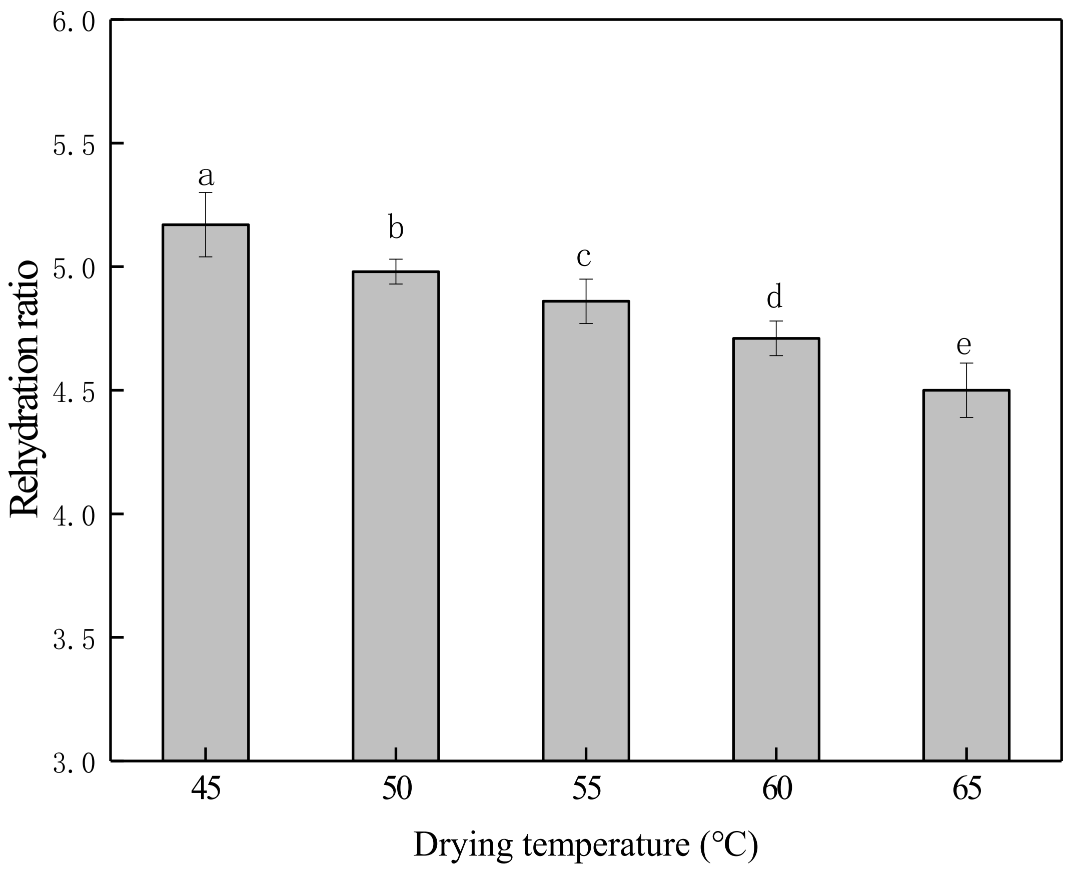


Fig 3.3 Influence of drying temperature on the rehydration ratio of dried beetroots

Betalains are naturally occurring water-soluble, nitrogen-containing pigments that can be separated into red-violet betacyanins and yellow-orange betaxanthins [126]. Table 3.5 displays the betalains content of dried beetroots as determined by the amounts of betacyanins (known as betanin) and betaxanthins (known as indicaxanthin). The betalains content of beetroots dried at various temperatures showed significant variances ($p < 0.05$). With an increase in drying temperature, dried beetroot had a significantly higher betacyanins content, ranging from 1.96 ± 0.02 to 3.59 ± 0.09 mg/g. Betacyanins content was the highest (3.59 ± 0.09 mg/g) for beetroot dried at 65 °C, and the lowest (1.96 ± 0.02 mg/g) for beetroot dried at 45 °C. With a rise in drying temperature, both betaxanthins and betacyanins content exhibited the same trend. The betaxanthins content of dried beetroot ranged from 1.17 ± 0.01 to 2.09 ± 0.05 mg/g. The betaxanthins content was also the highest (2.09 ± 0.05 mg/g) for beetroot dried at 65 °C. According to reports, betalains in beetroots can degrade in a variety of ways during thermal processing, including decarboxylation, isomerization, and cleavage by acids and heat [127]. It was reported that betalains content and antioxidant activity of beetroot powder depended on drying temperature, and betacyanins decreased whereas betaxanthins increased with the increase of drying temperature from 50 to 120 °C [128]. In this study, the amount of betacyanins and betaxanthins varied significantly among the beetroots dried at various temperatures and increased with higher drying temperatures, indicating that the dehydration process's maximum drying temperature was insufficient to degrade the pigment. On the contrary, higher drying temperatures led to higher pigment concentrations.

Table 3.5

Effect of different drying temperatures on betalains content and ascorbic acid content of dried beetroots

Drying temperature, °C	Betacyanins, mg/g	Betaxanthins, mg/g	Ascorbic acid, mg/100g
45	1.96 ± 0.02^{e}	1.17 ± 0.01^{e}	230.61 ± 2.57^{e}

continuation of Table 3.5

50	2.44 ± 0.02^{d}	1.57 ± 0.02^{d}	272.48 ± 1.53^{d}
55	2.81 ± 0.03^{c}	1.67 ± 0.02^{c}	302.16 ± 3.41^{c}
60	3.17 ± 0.03^{b}	1.93 ± 0.02^{b}	313.17 ± 6.82^{b}
65	3.59 ± 0.09^{a}	2.09 ± 0.05^{a}	365.83 ± 1.78^{a}

As an essential antioxidant, ascorbic acid plays an numerous role in human diet. It is generally known that ascorbic acid is highly vulnerable to oxidation in certain situations, such as heat, the presence of heavy metal ions and oxygen, and alkaline pH [129]. As shown in Table 3.5, the ascorbic acid content of dried beetroots were found in a range from 230.61 ± 2.57 to 365.83 ± 1.78 mg/100g that a significant ($p < 0.05$) increase with increasing drying temperature, being the highest value (365.83 ± 1.78 mg/100g) at 65 °C.

Figure 3.4 depicts how the total phenolic content and total flavonoid content of dried beetroot are affected by the drying temperature. As observed in Fig 3.4, the total phenolic content of dried beetroots at different drying temperatures increased from 8.39 ± 0.06 to 11.07 ± 0.60 mg GAE/g. The total phenolic content in dried beetroots was positively related to the heat pump drying temperatures. The beetroot sample dried at 65 °C exhibited the highest total phenolic content of 11.07 ± 0.60 mg GAE/g. Thermal treatment is well acknowledged to be the most important factor that might influence the amount of phenolic chemicals. The total phenolic data obtained in this study suggested that raising the drying temperature greatly enhanced the total phenolic content in beetroot, which is consistent with Gokhale and Lele [124], who reported that total phenolic content of beetroots increased with the increase of drying temperatures (50–120 °C). It has been reported by Kubra and Rao [130] that heat energy may cause the breakdown of the cellular constituents leading to a higher release of polyphenols from the matrices, which may be the reason for the high content of total phenolic obtained at 65 °C in the current study.

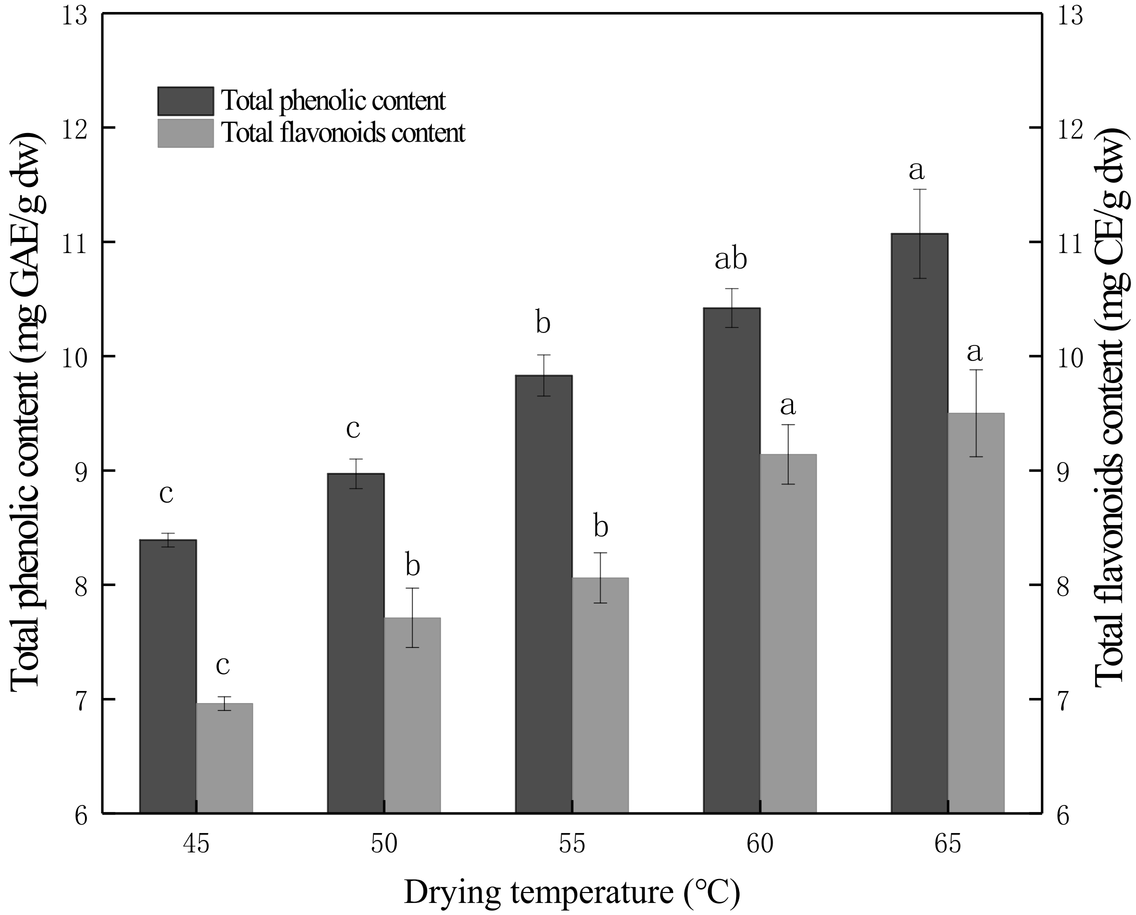


Fig 3.4 Effect of different drying temperatures on total phenolic content and total flavonoids content of dried beetroots

As seen from Fig 3.4 that increase in drying temperature led to an increase in total flavonoids content. The total flavonoids content exhibited the similar trend as total phenolic content. The highest content (9.50 ± 0.38 mg CE/g) of total flavonoids in dried beetroot was obtained at 65 °C. This total flavonoids content decreased to 9.14 ± 0.34 mg CE/g for the beetroot dried at 60 °C, and the total flavonoids loss was further obtained by decreasing the drying temperature, so the total flavonoids content was reached 6.96 ± 0.14 mg CE/g at 45 °C. The breakdown of cellular components caused by high drying temperatures releases the flavonoids and makes them available for extraction. However, a little exposure period during the drying process is good for the retention of flavonoids [131]. It has been shown that the presence of betalains and polyphenols influences antioxidant capacity, which increases after thermal treatment [126].

The influence of different drying temperatures on the antioxidant activities of dehydrated beetroots is presented in Table 3.6.

Table 3.6

Antioxidant activities of dehydrated beetroots at different drying temperatures

Drying temperature, °C	DPPH, mg TE/g	ABTS, mg TE/g	FRAP, mg TE/g
45	1.56 ± 0.03^{a}	20.49 ± 0.16^{b}	12.74 ± 0.45^{d}
50	1.25 ± 0.01^{b}	20.74 ± 0.13^{b}	14.21 ± 0.35^{c}
55	1.11 ± 0.01^{c}	20.89 ± 0.56^{b}	15.62 ± 0.66^{b}
60	0.84 ± 0.01^{d}	23.17 ± 0.45^{a}	16.46 ± 0.08^{b}
65	0.40 ± 0.02^{e}	24.10 ± 0.16^{a}	17.81 ± 0.04^{a}

As observed in Table 3.6, a significant ($p < 0.05$) decrease of DPPH radical scavenging ability in dried beetroots by increasing the drying temperatures, where the lowest DPPH radical scavenging ability in dried beetroot was 0.40 ± 0.02 mg TE/g at 65 °C.

With an increase in drying temperature, it was evident that ABTS radical scavenging ability increased. The ABTS radical scavenging ability was the lowest (20.49 ± 0.16 mg TE/g) at 45 °C and the highest (24.10 ± 0.16 mg TE/g) at 65 °C. Similar trend has been reported in [124].

As seen in Table 3.6, the dried beetroots showed the lowest (12.74 ± 0.45 mg TE/g) FRAP value at 45 °C, while the highest (17.81 ± 0.04 mg TE/g) FRAP value at 65 °C. The ABTS radical scavenging ability and FRAP values of beetroots followed similar trends with drying temperatures, peaking at 65 °C. Additionally, raising the drying temperature may result in a higher rise in the FRAP value and ABTS radical scavenging ability.

The effect of slice thickness on the heat pump drying of beetroots was investigated at the loading density of 2.0 kg/m^2 and drying temperature of 65 °C. Color parameters of beetroots affected by slice thicknesses are shown in Table

3.7. Compared to FD beetroots, the *L* values of beetroots with different slice thicknesses were not significant difference. The beetroots with different slice thicknesses showed significantly lower *a* values in comparison with that of FD beetroots. Meanwhile, the *b* values of beetroots with different slice thicknesses significantly lower than that of FD beetroots. The Δ*E* values of beetroots with different slice thicknesses were significant differences, and the beetroots with slice thickness of 2 mm showed the lowest Δ*E* value (2.44 ± 0.12).

Table 3.7

Effect of different slice thicknesses on color parameters of beetroots

Slice thickness, mm	*L*	*a*	*b*	Δ*E*
2	38.24 ± 1.14^{a}	26.63 ± 0.76^{b}	1.70 ± 0.10^{b}	2.44 ± 0.12^{c}
5	37.44 ± 0.60^{ab}	23.11 ± 0.24^{d}	1.47 ± 0.09^{c}	5.95 ± 0.32^{a}
8	39.92 ± 1.12^{a}	24.68 ± 0.72^{c}	1.40 ± 0.07^{c}	4.48 ± 0.20^{b}
FD beetroots	38.71 ± 0.90^{a}	28.73 ± 0.16^{a}	2.86 ± 0.07^{a}	-

Fig 3.5 shows the rehydration ratio of dried beetroots affected by different slice thicknesses. Significant differences were observed in the rehydration ratio of beetroots with different slice thicknesses ($p < 0.05$). The rehydration ratio significantly decreased with the increase of slice thickness, and the beetroots with 2 mm illustrated the highest rehydration ratio. Meanwhile, the lowest rehydration ratio of beetroots with slice thickness of 8 mm was 4.15 ± 0.03.

Table 3.8 shows the betalains content and ascorbic acid content in dehydrated beetroots at different slice thicknesses. The results revealed that the slice thickness significantly ($p < 0.05$) affected betacyanins content, which reached to the highest (2.81 ± 0.03 mg/g) at 5 mm and the lowest (2.01 ± 0.03 mg/g) at 8 mm. It was obvious that betaxanthins content of dehydrated beetroots significantly ($p < 0.05$) decreased with the increase of slice thickness. When the thickness of dehydrated beetroots was 8 mm, the betaxanthins content reached to the lowest (1.12 ± 0.01 mg/g).

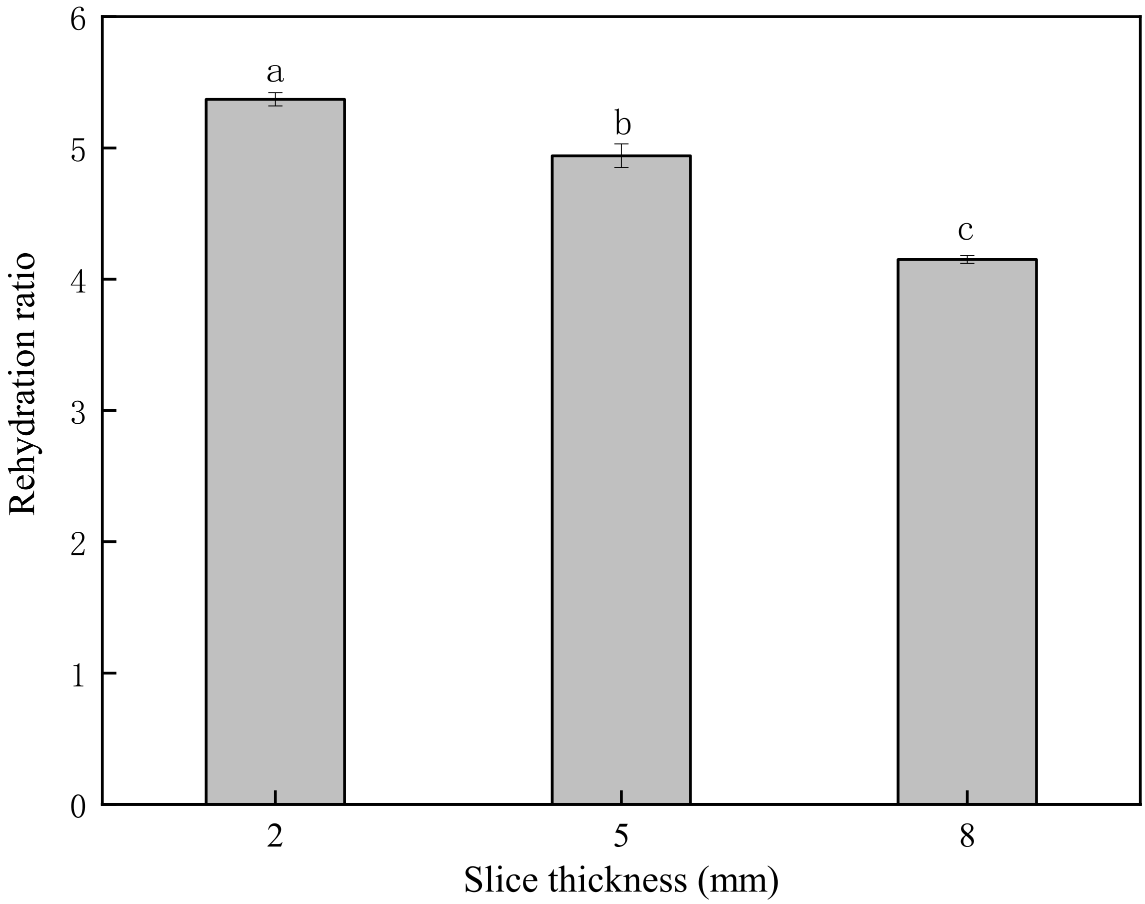


Fig 3.5 Rehydration ratio of dried beetroots with different slice thicknesses

As shown in Table 3.8, slice thickness was significantly ($p < 0.05$) affected ascorbic acid content of dehydrated beetroots. The highest ascorbic acid content (302.16 ± 3.41 mg/100g) of dehydrated beetroots was obtained at the slice thickness of 5 mm.

Table 3.8

Effect of different slice thicknesses on antioxidant capacity of beetroots

Slice thickness, mm	Betacyanins, mg/g	Betaxanthins, mg/g	Ascorbic acid, mg/100g
2	2.35 ± 0.02^{b}	2.00 ± 0.02^{a}	287.27 ± 2.77^{b}
5	2.81 ± 0.03^{a}	1.67 ± 0.02^{b}	302.16 ± 3.41^{a}
8	2.01 ± 0.03^{c}	1.12 ± 0.01^{c}	229.96 ± 3.61^{c}

The effect of slice thickness on the contents of total phenolic and total flavonoids are illustrated in Fig 3.6. No significant difference ($p > 0.05$) was noticed in total phenolic content of dehydrated beetroots with slice thickness of 2 mm and 5 mm. The total phenolic content of dehydrated beetroots was significantly ($p < 0.05$) reduced at slice thickness of 8 mm, in comparison with other slice thicknesses. The change trend of total flavonoids content with slice thickness was consistent with total phenolic content. The lowest total flavonoids content of dehydrated beetroots was 6.24 ± 0.31 mg CE/g at slice thickness of 8 mm.

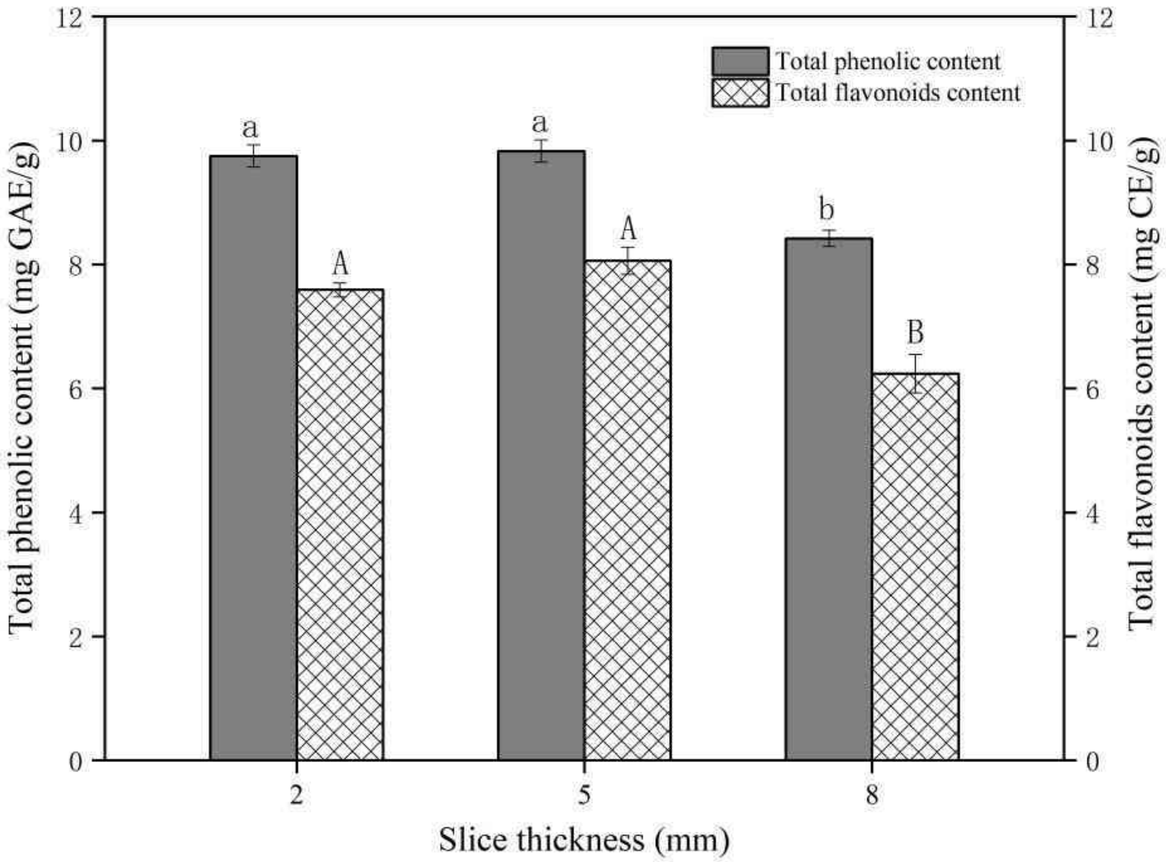


Fig 3.6 Contents of total phenolic and total flavonoids of dehydrated beetroots as affected by slice thickness

Table 3.9 shows the changes of antioxidant activities at different slice thicknesses. DPPH radical scavenging ability increased significantly ($p < 0.05$) with the increase of slice thickness. The free radical scavenging ability of DPPH was found to be the highest (1.75 ± 0.00 mg TE/g) in the dehydrated beetroots with slice thickness of 8 mm. As observed from Table 3.9, no significant difference ($p > 0.05$) was observed in ABTS radical scavenging ability of beetroots at different slice thicknesses. It was found that the maximum FRAP value in dehydrated beetroots was obtained at slice thickness of 5 mm, which was highly correlated with ascorbic acid content and betacyanins content in dehydrated beetroots.

Table 3.9

Antioxidant activities of dehydrated beetroots at different slice thicknesses

Slice thickness, mm	DPPH, mg TE/g	ABTS, mg TE/g	FRAP, mg TE/g
2	0.98 ± 0.02^{c}	20.96 ± 0.26^{a}	14.29 ± 0.24^{b}
5	1.11 ± 0.01^{b}	20.89 ± 0.68^{a}	15.62 ± 0.66^{a}
8	1.75 ± 0.00^{a}	20.00 ± 0.31^{a}	12.29 ± 0.22^{c}

Heat pump drying is an energy efficient technique, which can be used to dehydrate products with heat-sensitive compounds. The effect of heat pump drying conditions, including loading density, drying temperature, and slice thickness on the physical properties, bioactive compounds of dehydrated beetroots as well as its antioxidant activities were investigated. Higher loading density prolonged drying time, causing more loss in ascorbic acid and DPPH radical scavenging ability. With increase in loading density from 2.0 to 3.0 kg/m^2, there was no significant difference in total phenolic content and total flavonoids content of dehydrated beetroots. However, contents of betacyanins and betaxanthins in dehydrated beetroots decreased significantly with the increase of loading density from 2.0 to 3.0 kg/m^2. Drying temperature and slice thickness demonstrated significant impacts on the bioactive compounds and antioxidant activities of dehydrated beetroots. Contents of betalains, total phenolic, total flavonoids, and ascorbic acid of dehydrated beetroots increased significantly with increasing drying temperature. The FRAP value of dehydrated beetroots increased significantly with the increase of drying temperature, while the DPPH radical scavenging ability decreased with increasing drying temperature. Contents of ascorbic acid and betacyanins reached to the highest value in the dehydrated beetroots with 5 mm. The DPPH radical scavenging ability of dehydrated beetroots increased with increasing of slice thickness. Changes in FRAP values were found to be correlated with changes in content of ascorbic acid and betacyanins.

Overall, the optimal heat pump drying conditions were loading density of 2.0 kg/m^2, drying temperature of 65 °C, and slice thickness of 5 mm.

3.1.1.2 Effects of microwave vacuum drying conditions on quality of beetroots

Microwave vacuum drying (MVD) or vacuum microwave drying (VMD) is one of novel technologies, and a gentle and effective drying technique. The microwave's intense heating and the vacuum's low boiling point cause the material to be dried at a comparatively low temperature in a short period of time, helping to maintain a high level of healthy nutrition and sensory quality [132]. Although MVD has been studied in food applications, no studies have been found in the literature on the effects of drying conditions on the physicochemical attributes and antioxidant activity of beetroots. Therefore, this study was to investigate the effect of microwave vacuum drying conditions, including sample thickness, microwave power, and vacuum degree, on the physicochemical properties and antioxidant activity of beetroots.

Experiment design. Fresh beetroots were washed, peeled, and then cut into slices (diameter = 60 mm). The one-factor-at-a-time method was applied in this study to design experiments. Fresh beetroot slices (800.0 g) were put on the tray (610 × 430 × 50 mm) of a vacuum microwave dryer for continuous dehydration at different microwave power (500, 1000, and 1500 W), vacuum degree (–50, –70, and –90 kPa), and sample thickness (2, 4, and 6 mm). The drying process stopped as the final moisture content of beetroots lower than 7.0%.

Experimental results and discussions. Fresh beetroots were dried at sample thickness of 2 mm, vacuum degree of –80 kPa, and microwave power levels of 500, 1000, and 1500 W to ascertain the impact of microwave power on the physicochemical parameters of beetroots. It can be seen from Fig. 3.7 that with an increase in microwave power, the drying time dramatically decreased, varied from 34.0 ± 1.0 to 87.3 ± 1.5 min. The drying time decreased by 43.0% when microwave power increased double (from 500 to 1000 W), and when the microwave power was increased to 1500 W, the drying time was only 38.9% of that of the microwave power of 500 W.

The sample's cell structure will be damaged during the drying process. The rehydration ratio decreased in direct proportion to the degree of cell structural damage. Rehydration ratio was seen to decrease as microwave power rose from 500 to 1500 W. The microwave power of 1500 W caused the most cell structural damage, as evidenced by the fact that this power level resulted in the lowest rehydration ratio.

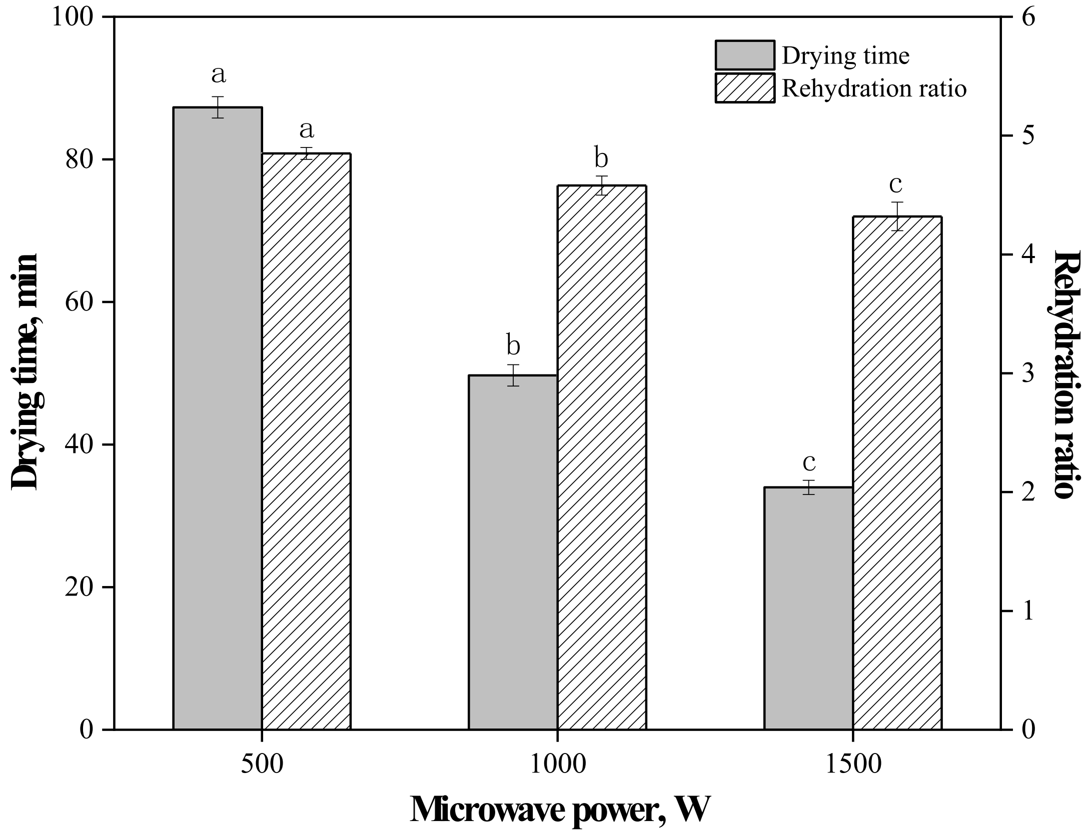


Fig. 3.7 Drying time and rehydration ratio at different microwave powers

The L_0, a_0, and b_0 of fresh beetroots were 37.52 ± 1.03, 28.47 ± 0.74, and 6.02 ± 0.22, respectively. As displayed in Table 3.10, *L* values of dried beetroots were found to be higher than fresh beetroots, indicating that the color of beetroots became brighter after drying. Similar results were also found for obtaining beetroot powder [47, 52]. The beetroots dried at microwave power of 1000 W showed the highest *L* value of 43.44 ± 0.56, showing a lighter color than those of other microwave powers. No significant difference was observed in *L* values at microwave power of 500 W and 1500 W ($p > 0.05$). The *a* values of dried beetroots prepared at different microwave powers ranged from 22.92 ± 0.42 to 23.81 ± 0.55, and were lower than that of fresh beetroots. Compared with other microwave powers, *a* value of beetroots obtained at 1000 W was larger, representing a greater redness. The lowest *b* value (2.83 ± 0.08) was obtained from the beetroots dried at microwave power of 500 W, which was significantly different from other microwave powers. The chroma (*C*) value is a good indicator of the color, distinguishing vivid and dull color [133]. The lower *C* value of dried beetroots at 500 W indicated lower saturation and a duller appearance compared with those of dried beetroots obtained at other microwave powers. *H*° value of dried beetroots illustrated a slight decrease as the microwave power increased. The *H*° value of beetroots dried at 1500 W was the lowest (6.52 ± 0.29), indicating that the beetroots were much more red. At different microwave powers, the total color difference (ΔE) were between 6.46 ± 0.42 and 7.95 ± 0.33 compared to the fresh beetroots. It was reported that the ΔE parameters of microwave vacuum dried red beetroot samples were between 5.06 and 13.39 in [46]. The beetroots carried to 1500 W showed the lowest ΔE value, while the beetroots subjected to 1000 W showed the highest ΔE value of 7.95 ± 0.33.

Parameters *L*, *a*, *C*, and ΔE were similarly influenced by microwave power, presenting the highest values in the dried beetroots carried to 1000 W. Beetroots dried at 1500 W displayed the most ideal color, with the lowest ΔE and *H*° values.

Table 3.10

Color changes of dried beetroots as affected by microwave powers

Color parameter	Microwave power, W		
	500	1000	1500
L	40.92 ± 1.22^{b}	43.44 ± 0.56^{a}	40.58 ± 0.66^{b}
a	22.92 ± 0.42^{b}	23.81 ± 0.55^{a}	23.36 ± 0.54^{ab}
b	2.83 ± 0.08^{b}	3.51 ± 0.20^{a}	3.56 ± 0.22^{a}
C	23.09 ± 0.41^{b}	24.07 ± 0.56^{a}	23.63 ± 0.56^{ab}
H°	8.08 ± 0.29^{a}	6.74 ± 0.30^{b}	6.52 ± 0.29^{b}
Δ*E*	7.35 ± 0.37^{a}	7.95 ± 0.33^{a}	6.46 ± 0.42^{b}

Contents of betalains, ascorbic acid, total phenolic and total flavonoids in beetroots affected by different microwave powers are exhibited in Table 3.11. Betacyanins content decreased significantly with the increase of microwave power ($p < 0.05$). The highest content of betacyanins (4.65 ± 0.03 mg/g) was obtained from beetroots dried at 500 W.

Dried beetroots obtained at 500 W showed the highest betaxanthins content (3.34 ± 0.06 mg/g) in comparison with other microwave powers. It can be explained that polar bonds in molecules with multiple polar bonds, such as betalains, ascorbic acid, and flavonoid compounds, can become weaker under the influence of microwave energy radiation. Those bonds can vibrate dramatically under microwave irradiation, causing the bond rupture to induce chemical reactions [134].

There was no significant difference in betaxanthins content, ascorbic acid content and total flavonoids content of beetroots carried to 1000 W and 1500 W ($p > 0.05$). The highest ascorbic acid content (939.1 ± 3.3 mg/100g) was noted in dried beetroots obtained at 500 W.

Table 3.11

Impact of microwave power on the contents of bioactive compounds in dried beetroots

Bioactive compounds	Microwave power, W		
	500	1000	1500
Betacyanins, mg/g	4.65 ± 0.03^a	4.29 ± 0.07^b	4.02 ± 0.04^c
Betaxanthins, mg/g	3.34 ± 0.06^a	2.85 ± 0.04^b	2.82 ± 0.01^b
Ascorbic acid, mg/100g	939.1 ± 3.3^a	794.4 ± 11.7^b	789.5 ± 5.6^b
Total phenolic, mg GAE/g	11.26 ± 0.18^a	8.19 ± 0.08^b	11.37 ± 0.08^a
Total flavonoids, mg RE/g	28.34 ± 0.44^a	25.92 ± 0.49^b	26.04 ± 0.49^b

As seen in Table 3.11, the total phenolic content of dried beetroots ranged from 8.19 ± 0.08 to 11.37 ± 0.08 mg GAE/g, and the beetroots dried at 1000 W exhibited the lowest total phenolic content, which significantly lower than those of beetroots dried at 500 W and 1500 W ($p < 0.05$).

The dried beetroots' maximum total flavonoids content (28.34 ± 0.44 mg RE/g) was detected at microwave power of 500 W. The content of total flavonoids decreased as microwave power increased. Cranberries dried in a microwave vacuum with a similar outcome have been reported in [135]. As a result, the beetroots dried at microwave power of 500 W demonstrated higher contents of betalains, ascorbic acid, total phenolic, and total flavonoids compared to other microwave powers.

Effects of microwave power on the FRAP values of dried beetroots are shown in Fig. 3.8. As presented in Fig. 3.8, ferric reducing ability power (FRAP) value of dried beetroots decreased significantly with the increase of microwave power ($p < 0.05$). It was clearly shown that dried beetroots obtained at microwave power of 500 W, revealed the highest FRAP value of 14.70 ± 0.17 mg TE/g.

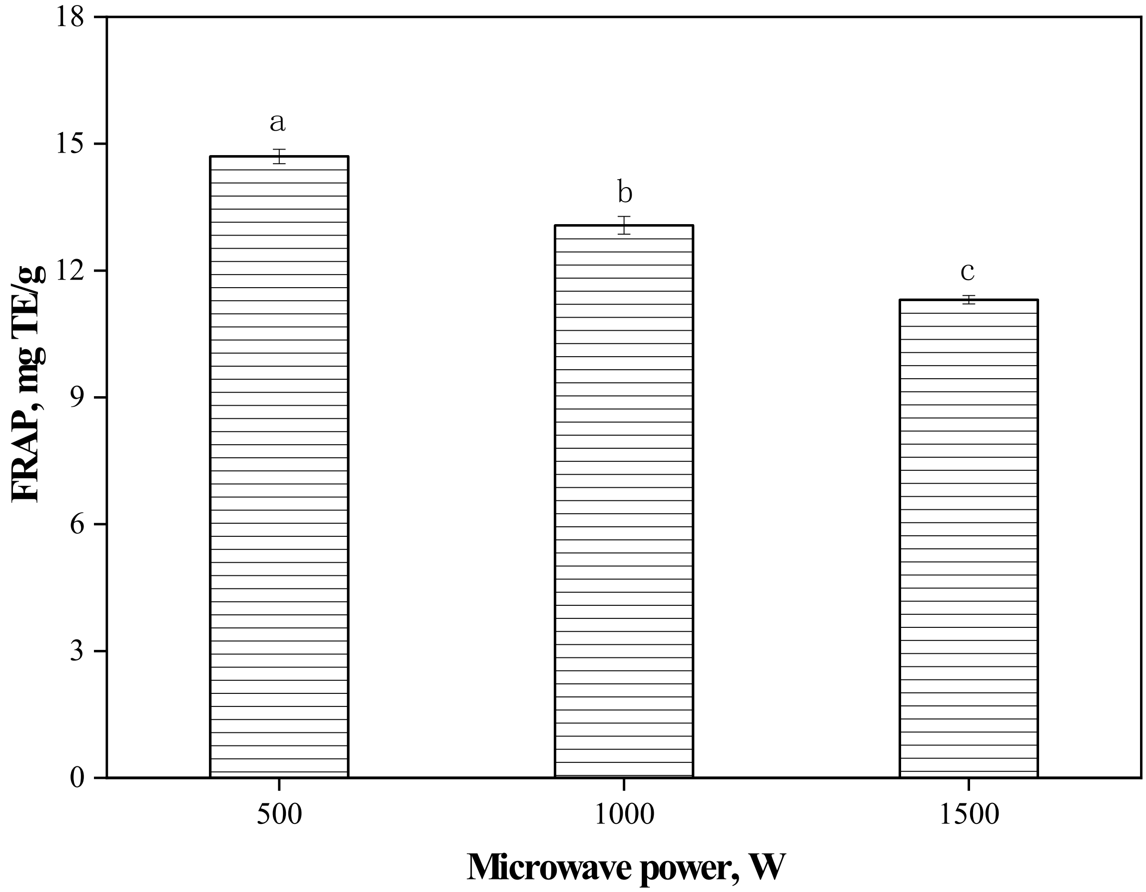


Fig. 3.8 Effects of microwave power on the FRAP values of dried beetroots

The highest FRAP value, as well as contents of betalains, ascorbic acid and total flavonoids were found in the beetroots subjected to 500 W, indicating that FRAP value was direct correlation to contents of betalains, ascorbic acid and total flavonoids. These results are in agreement with the result in [126], it was discovered that the presence of betalains, which may have risen during the treatments, as well as other polyphenols affects the increase in antioxidant activities of samples. Similar correlations were also reported in other studies about drying bitter melon [121], cranberries [135], and red pepper [136].

The studies were conducted at microwave power of 1500 W and slice thickness of 2 mm to examine the impact of vacuum degree on the physicochemical characteristics and antioxidant activity of beetroots. Investigations were conducted at three vacuum degree levels: –50, –70, and –90 kPa. Effect of vacuum degree on the drying time and rehydration ratio of beetroots are illustrated in Fig. 3.9.

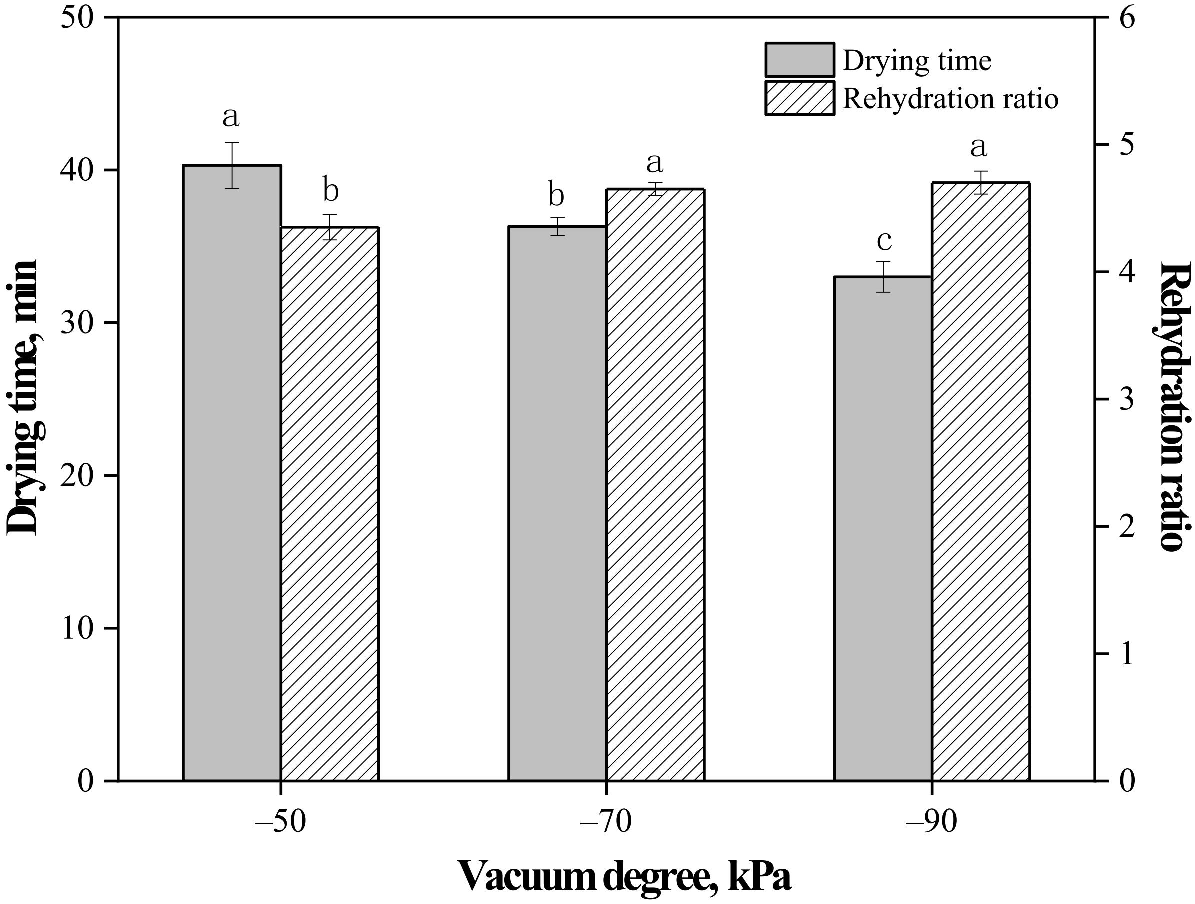


Fig. 3.9 Drying time and rehydration ratio at different vacuum degrees

The drying time of beetroots decreased progressively with rising vacuum degree. It took only 33.0 ± 1.0 min to dry fresh beetroots at vacuum degree of –90 kPa, reduced by 18.1% and 9.1% compared to the drying time at –70 kPa (36.3 ± 0.6 min) and –50 kPa (40.3 ± 1.5 min). As observed in Fig. 3.8, the rehydration ratio of dried beetroots gradually increased as vacuum degree increased. The rehydration ratio varied from 4.35 ± 0.10 to 4.60 ± 0.12 as the vacuum degree increased from –50 to –90 kPa. This could be because as the vacuum degree rises, less damage is done to the tissue's structure, leading to an increase in rehydration ratio.

The physical reflection of some chemical changes in processed foods, as well as quality losses, are both determined by color characteristics [136]. Table

3.12 shows the color parameters of dried beetroots affected by different vacuum degrees. Values *L*, *a,* and *b* in dried beetroots were found to be higher than those of fresh beetroots. Dried beetroots had the maximum *L* value (41.17 ± 0.90) at vacuum degree of –50 kPa and the lowest value (38.62 ± 1.02) at vacuum degree of –70 kPa. It was discovered that the value of *a* increased as the vacuum degree increased. The highest *a* value was found in beetroots dried at –90 kPa. The *b* values of beetroots dried at various vacuum degrees showed significant differences, and increased with the increase of vacuum degree ($p < 0.05$).

It was also observed that increasing vacuum degree significantly increased *C* value of dried beetroots ($p < 0.05$). The highest *C* value (24.28 ± 0.35) of beetroots was appeared at –90 kPa. As seen in Table 3.12, values of *H*° and Δ*E* displayed the same trends, both decreased significantly with the increase of vacuum degree ($p < 0.05$). The *H*° values of dried beetroots ranged from 6.39 ± 0.18 to 8.49 ± 0.34, indicating that all dried beetroots exhibited in purple-red range. The beetroots dried at –90 kPa indicated the lowest *H*° value of 6.39 ± 0.18, indicating a more redness hue. The lowest Δ*E* value of beetroots dried at –90 kPa, while the highest value (7.61 ± 0.37) was obtained at –50 kPa,

Table 3.12

Color characteristics of dried beetroots as affected by vacuum degree

Color parameter	Vacuum degree, kPa		
	–50	–70	–90
L	41.17 ± 0.90^{a}	38.62 ± 1.02^{b}	40.46 ± 1.09^{a}
a	22.73 ± 0.45^{b}	23.25 ± 0.63^{b}	23.99 ± 0.35^{a}
b	2.67 ± 0.13^{c}	3.00 ± 0.06^{b}	3.73 ± 0.11^{a}
C	22.89 ± 0.45^{b}	23.44 ± 0.63^{b}	24.28 ± 0.35^{a}
H°	8.49 ± 0.34^{a}	7.71 ± 0.27^{b}	6.39 ± 0.18^{c}
Δ*E*	7.61 ± 0.37^{a}	6.20 ± 0.33^{b}	5.90 ± 0.27^{c}

In comparison with those beetroots dried at other vacuum degrees, the beetroots dried at vacuum degree of –90 kPa displayed a larger tendency toward red and yellow, more color saturation, a more red hue, and a smaller overall color difference.

The results to the influence of different vacuum degrees on the bioactive compounds are given in Table 3.13. As far as we known, vacuum treatment can remove the available oxygen or at low oxygen levels reduce pigment degradation better than under air atmosphere [46]. It was observed that betacyanins content and betaxanthins content considerably increased as the vacuum degree increased ($p < 0.05$). The explanation is that betalains are sensitive to high temperature and long-term processing. Therefore, the beetroots dried at vacuum degree of –90 kPa had the largest contents of betaxanthins (2.91 ± 0.01 mg/g) and betacyanins (4.09 ± 0.03 mg/g)

Due to its poor heat-treatment stability, ascorbic acid is a crucial indicator of the quality of food. It has been reported that the drying process can lead to significant loss of ascorbic acid content [137]. The ascorbic acid content of dried beetroots was clearly affected by vacuum degrees ($p < 0.05$). The ascorbic acid content of dried beetroots increased with a rise in vacuum degree from –50 to –90 kPa.

Table 3.13

Impact of vacuum degree on the contents of bioactive compounds in dried beetroots

Bioactive compounds	Vacuum degree, kPa		
	–50	–70	–90
Betacyanins, mg/g	3.38 ± 0.02^{c}	3.65 ± 0.02^{b}	4.09 ± 0.03^{a}
Betaxanthins, mg/g	2.57 ± 0.01^{c}	2.79 ± 0.01^{b}	2.91 ± 0.01^{a}
Ascorbic acid, mg/100g	730.2 ± 1.9^{c}	835.4 ± 9.4^{b}	870.2 ± 12.3^{a}
Total phenolic, mg GAE/g	12.47 ± 0.09^{a}	9.56 ± 0.11^{b}	9.64 ± 0.06^{b}
Total flavonoids, mg RE/g	25.49 ± 0.57^{a}	22.37 ± 0.56^{b}	20.09 ± 0.56^{c}

The highest total phenolic content was occurred in the beetroots dried at –50 kPa. It can be explained that the degradation of betacyanins may lead to the production of other phenolic compounds [10]. The degradation of phenolics in beetroots dried at –70 kPa and –90 kPa was higher than that of beetroots dried at –50 kPa. There was no significant difference in total phenolic content between beetroots dried at –70 kPa and –90 kPa ($p > 0.05$).

A clear dependency between vacuum degree and total flavonoids loss was observed in beetroots, subjected to vacuum microwave drying. With an increase in vacuum degree from –50 to –90 kPa, there was a significant decrease in total flavonoids content ($p < 0.05$), which can be explained that the degradation of betcyanins and betaxanthins lead to other flavonoid compounds.

The beetroots prepared at –90 kPa showed the lowest total flavonoids content of 20.09 ± 0.56 mg RE/g. Thus, it was found that the dried beetroots subjected to –90 kPa displayed higher betalains content and ascorbic acid content, and lower total phenolic and total flavonoids content in comparison with those dried beetroots subjected to other vacuum degrees.

Effects of vacuum degree on the FRAP values of dried beetroots are shown in Fig. 3.10. It can be seen from Fig. 3.10 that FRAP decreased slightly with the increase of vacuum degree. The lowest FRAP value of beetroots was observed at –90 kPa, which was only 10.23 ± 0.15 mg RE/g.

To explore the influence of sample thickness on the physicochemical properties and antioxidant activity of beetroots, the experiments were conducted at microwave power of 1500 W and vacuum degree of 2 mm. Three different levels of slice thickness, namely 2, 4, and 6 mm were investigated.

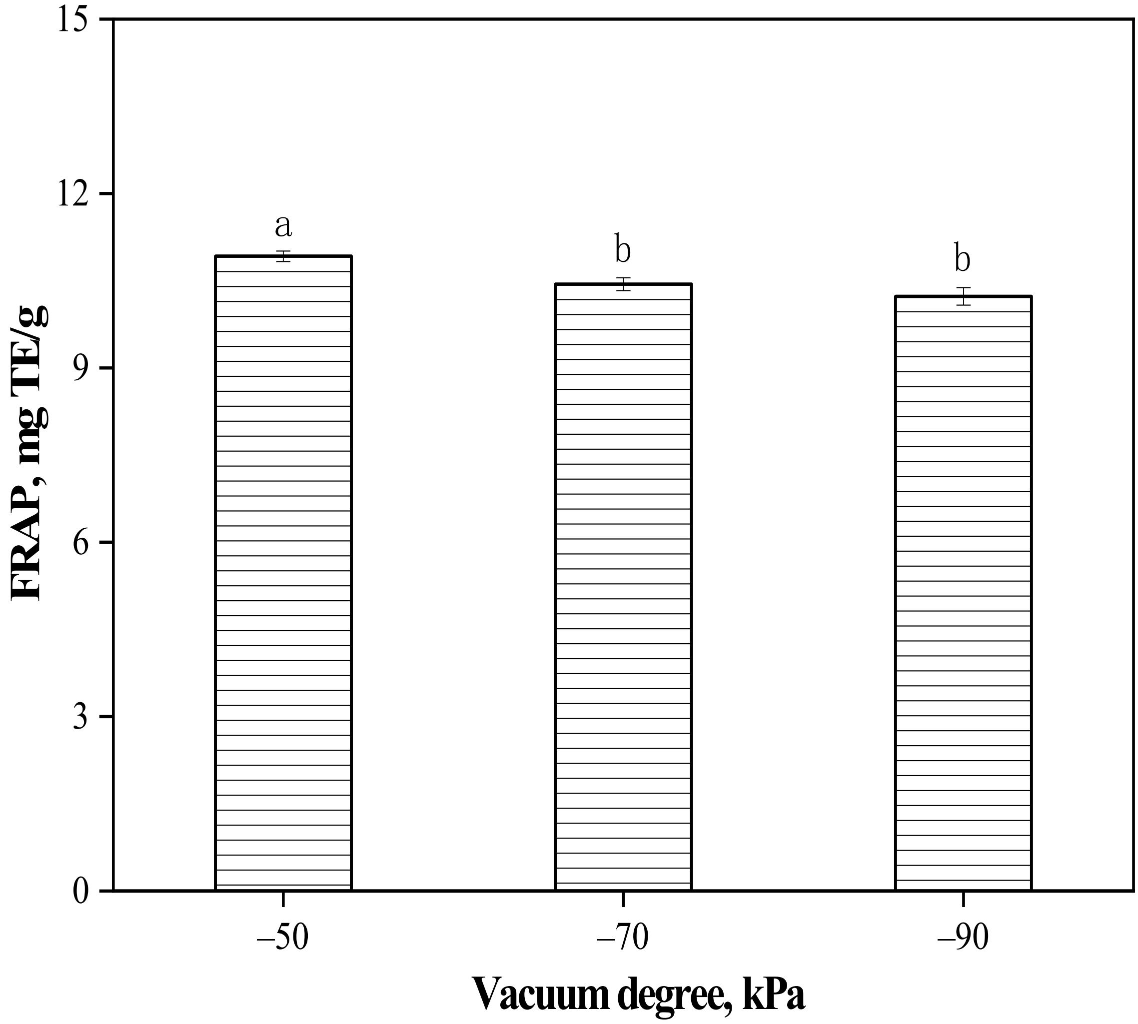


Fig. 3.10 Effects of vacuum degree on the FRAP values of dried beetroots

The drying time and rehydration ratio of beetroots affected by sample thickness is presented in Fig. 3.11. With increasing sample thickness of beetroots, the drying time of beetroots rose. When the sample thickness increases, the distance of internal moisture migration to the surface increases, and the drying time increases accordingly.

When beetroot samples were 2 mm, the drying time was 34.0 ± 1.0 min, which was only 50.5% as long as beetroot samples were 6 mm. In other words, the drying time increased by 97.9% as the sample thickness of beetroots increased from 2 to 6 mm. It can be seen from Fig. 3.11 that rehydration ratio of dried beetroots significantly decreased with the increase of sample thickness ($p < 0.05$).

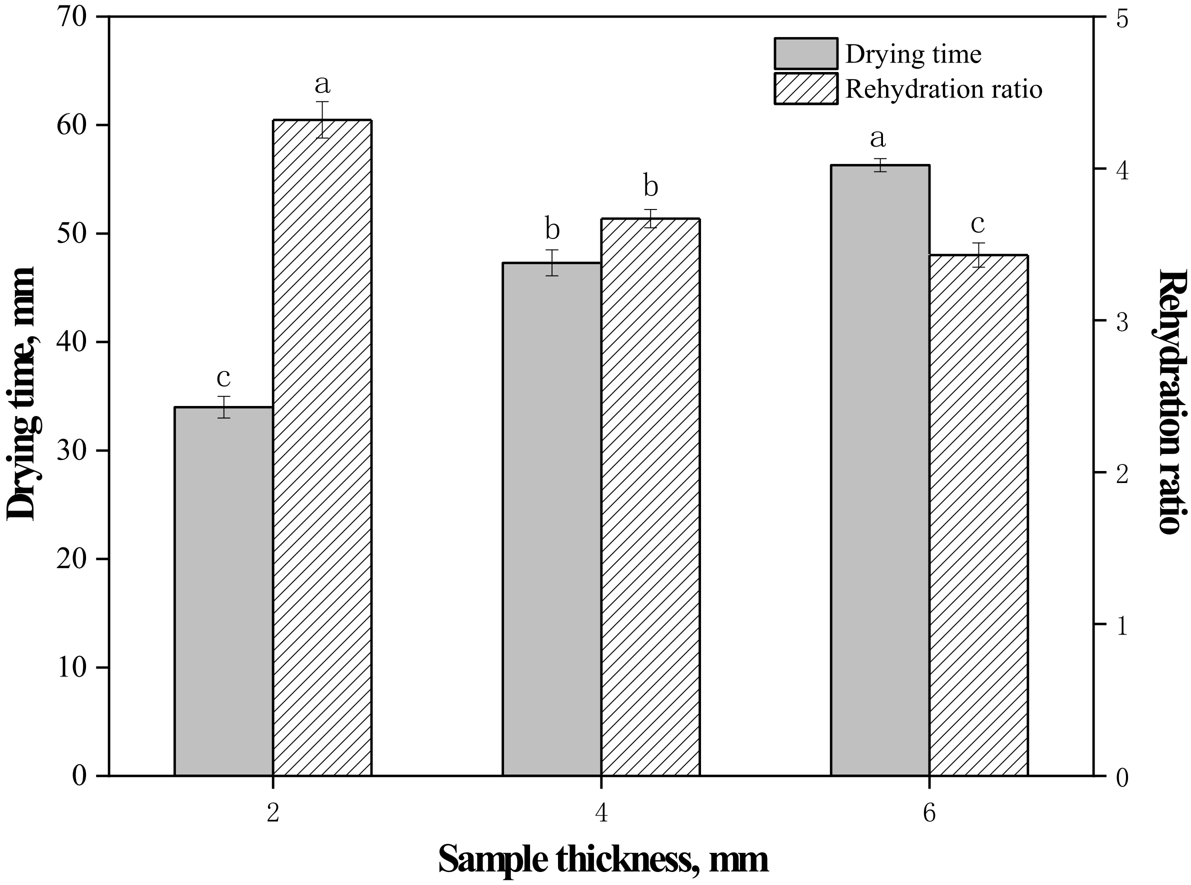


Fig. 3.11 Drying time and rehydration ratio at different sample thicknesses

The beetroots with sample thickness of 2 mm had the highest rehydration ratio (4.32 ± 0.12), while the beetroots with sample thickness of 8 mm showed the lowest rehydration ratio (Fig. 3.11). This might be related to the drying time, and as the sample thickness increased, the drying time was prolonged, and the structural damage to the sample was more serious, so the rehydration ratio of dried beetroots significantly reduced ($p < 0.05$).

The color characteristics of dried beetroots affected by sample thickness are illustrated in Table 3.14. The *L* values of beetroots with different thicknesses after drying were higher than that of fresh beetroots, and there was no significant difference in *L* values of dried beetroots with thickness of 4 mm and 6 mm. Compared with fresh beetroots, the vacuum microwave dried beetroots showed lower *a* values. The dried beetroots with thickness of 2 mm showed the highest *a* value of 23.36 ± 0.54, while the dried beetroots with thickness of 4 mm had the lowest *a* value. The changes of *b* values were similar to that of *a* values. The highest *b* value (3.56 ± 0.22) was appeared in dried beetroots with thickness of 2 mm.

Table 3.14

Color changes of dried beetroots as affected by sample thickness

Color parameter	Sample thickness, mm		
	2	4	6
L	40.58 ± 0.66^{b}	42.73 ± 0.53^{a}	42.15 ± 0.67^{a}
a	23.36 ± 0.54^{ab}	21.05 ± 0.21^{c}	21.97 ± 0.26^{b}
b	3.56 ± 0.22^{a}	2.48 ± 0.12^{b}	2.67 ± 0.10^{b}
C	23.63 ± 0.56^{ab}	21.19 ± 0.20^{c}	22.13 ± 0.26^{b}
H°	6.52 ± 0.29^{b}	8.47 ± 0.43^{a}	8.21 ± 0.25^{a}
ΔE	6.46 ± 0.42^{c}	9.74 ± 0.37^{a}	8.67 ± 0.49^{b}

The lower *C* value was found in dried beetroots with thickness of 4 mm, demonstrating that a lower saturation and a duller appearance compared to those of dried beetroots with other thicknesses. *H*° values of dried beetroots showed a slight increase as the sample thickness increased. The *H*° value of beetroots with thickness of 2 mm was the lowest of 6.52 ± 0.29, indicating that the beetroots became much more red. The beetroots with thickness of 4 mm displayed the highest ΔE, while the beetroots with thickness of 2 mm showed the lowest ΔE of 6.46 ± 0.42, which was much more close to the color of fresh beetroots. It has been reported that the main causes of material discoloration during the drying process were the Maillard and enzymatic reactions [137]. Enzymatic reactions and the Maillard reaction can be considerably reduced during the vacuum microwave drying process, giving the sample attractive color characteristics.

The effect of sample thickness on the content of bioactive compounds in dried beetroots is shown in Table 3.15. There was no significant difference in contents of betacyanins and betaxanthins in the beetroots with thickness of 2 mm and 6 mm ($p > 0.05$). The beetroots with thickness of 4 mm showed the lowest contents of betacyanins (3.44 ± 0.02 mg/g) and betaxanthins (2.52 ± 0.01 mg/g). As can be seen, sample thickness had a significant effect on ascorbic acid content of dried beetroots ($p < 0.05$). The lowest ascorbic acid content (676.8 ± 7.3 mg/100g) was observed in beetroots with thickness of 4 mm. No significant difference was found in total phenolic content of beetroots with thickness of 4 mm and 6 mm ($p > 0.05$). The beetroots with thickness of 2 mm illustrated the highest total phenolic content, which was 11.26 ± 0.18 mg GAE/g. The total flavonoids content of dried beetroots significantly decreased with the increase of sample thickness ($p < 0.05$). The highest total flavonoids content of dried beetroots with thickness of 2 mm was 26.04 ± 0.49 mg RE/g. To sum up, the optimal sample thickness of beetroots was 2 mm, resulting in higher content of bioactive compounds in dried beetroots.

Table 3.15

Impact of sample thickness on the content of bioactive compounds in dried beetroots

Bioactive compounds	Sample thickness, mm		
	2	4	6
Betacyanins, mg/g	4.02 ± 0.04^{a}	3.44 ± 0.02^{b}	3.97 ± 0.00^{a}
Betaxanthins, mg/g	2.82 ± 0.01^{a}	2.52 ± 0.01^{b}	2.83 ± 0.00^{a}
Ascorbic acid, mg/100g	789.5 ± 5.6^{b}	676.8 ± 7.3^{c}	869.4 ± 3.8^{a}
Total phenolic, mg GAE/g	11.26 ± 0.18^{a}	8.40 ± 0.10^{b}	8.64 ± 0.10^{b}
Total flavonoids, mg RE/g	26.04 ± 0.49^{a}	22.81 ± 0.98^{b}	21.53 ± 0.24^{c}

As shown in Fig. 3.12, no significant difference in FRAP values was observed between dried beetroots with thickness of 2 mm and 6 mm ($p > 0.05$). It was clearly shown that the dried beetroots obtained at thickness of 4 mm revealed the lowest FRAP value of 10.62 ± 0.08 mg TE/g.

In this study, FRAP assay was used to evaluate the antioxidant activity of dried beetroots. More methods should be employed to evaluate the total antioxidant capacity of beetroots due to the different mechanisms of antioxidants. Moreover, it is critical to avoid high temperature and long time treatment in the processing of beetroots.

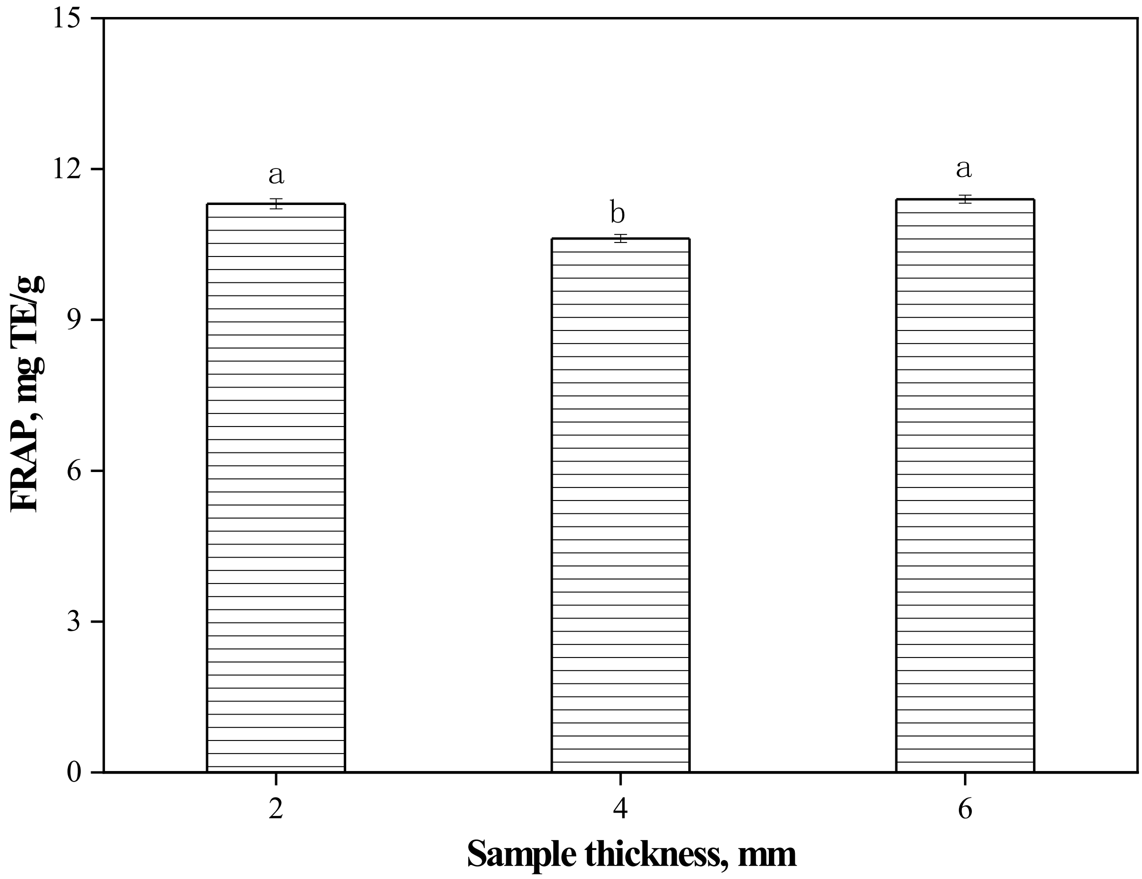


Fig. 3.12 Effects of sample thickness on the FRAP values of dried beetroots

The results of this study revealed that microwave power, vacuum degree, and sample thickness had significant effects on physicochemical properties and antioxidant activity of beetroots. The drying time, rehydration ratio, betacyanins content and betaxanthins content of beetroots decreased with the increase of microwave power, while the rehydration ratio, values of *a*, *b* and *C*, betacyanins content, and betaxanthins content of beetroots increased with the increase of vacuum degree. In other words, low vacuum degree prolonged drying time, resulting in lower rehydration ratio, more yellowish hue, larger total color change, and more loss in betacyanins and betaxanthins. The beetroots dried at 500 W displayed longer drying time, higher rehydration ratio, more yellowish hue, higher contents of betacyanins and betaxanthins compared with other microwave powers. Meanwhile, the dried beetroots obtained at –90 kPa presented the shortest drying time, the best color appearance, the highest rehydration ratio, betacyanins and betaxanthins contents. The beetroots with thickness of 2 mm presented the highest rehydration ratio, betalains content, total phenolic content and total flavonoids content, and the lowest ΔE.

The best physicochemical attributes and antioxidant activity of dried beetroots were maintained by using appropriate microwave power, vacuum degree, and sample thickness. The most suitable conditions for drying beetroots with a vacuum microwave were microwave power of 500 W, vacuum degree of –90 kPa, and sample thickness of 2 mm, which led to better physicochemical properties as well as antioxidant activity of dried beetroots. Microwave vacuum dried beetroots, which contain a high concentration of bioactive components and have a high antioxidant activity, can be used as functional foods and value-added foods.

3.1.2 Influence of microwave-assisted drying methods on quality attributes of dried beetroots

It is vital to take into account combined drying methods because every drying technique has advantages and disadvantages. Combining two or more drying techniques to create a hybrid drying technology that is suitable for the properties of the dried material [138]. A large number of researches on the combined drying of fruits and vegetables have been carried out.

Previous researches have indicated that the combination of microwave and hot air drying is better suitable for agricultural product processing [139–140]. However, the right combination of conventional drying techniques might produce surprising results. There are few studies in the literature on the impact of various microwave-assisted drying methods, particularly combinations of microwave drying and vacuum drying, and combinations of microwave drying and hot air drying, on the quality attributes of beetroots. Therefore, different hybrid microwave-assisted drying methods were conducted to dry beetroots, exploring the effect of different combinations of microwave-assisted drying methods on the quality characteristics of beetroots, and looking forward to obtaining high-quality dried beetroots in this study.

3.1.2.1 Experimental conditions for different microwave-assisted drying methods

Before drying, fresh beetroots were stored at 4 °C. To remove impurities, the beetroots were washed under running water. The washed beetroots were peeled and cut with a stainless steel slicer, chopped into slices with 2 mm in thickness and 80 mm in diameter.

Three drying devices, namely a microwave drying system, a hot air drying oven, and a vacuum drying oven, were used in this study. Fresh beetroot slices were subjected to different microwave-assisted drying methods as below:

High-power microwave drying followed by low-power microwave drying (HMD+LMD): Fresh beetroot slices were firstly dried at 650 W, and then dried at 325 W in microwave drying system; the transition point of moisture content was 28.0 %.

High-power microwave drying (HMD): Fresh beetroot slices were dried at 650 W in the microwave drying system.

Low-power microwave drying (LMD): Fresh beetroot slices were dried at 325 W in the microwave drying system.

High-power microwave drying followed by hot air drying (HMD+HAD): Fresh beetroot slices were dried at 650 W, and then dried under 60 °C in the hot air drying oven; the transition point of moisture content was 28.0 %.

Hot air drying followed by low-power microwave drying (HAD+LMD): Fresh beetroot slices were dried at 60 °C in the above hot air drying oven, and then dried at 325 W; the transition point of moisture content was 28.0 %.

High-power microwave drying followed by vacuum drying (HMD+VD): Fresh beetroot slices were dried at 650 W in the microwave drying system, and then dried at 60 °C in the vacuum drying oven; the transition point of moisture content was 28.0 %.

Vacuum drying followed by low-power microwave drying (VD+LMD): Fresh beetroot slices were dried at 60 °C in the vacuum drying oven, and then dried at 325 W in the microwave drying system; the transition point of moisture content was 28.0 %.

Moisture content transition point of beetroots was determined according to the results of the pre-experiment. The drying process was stopped as the moisture content of beetroots below 7.0 %.

3.1.2.2 Results and discussions on the influence of microwave-assisted drying methods on quality attributes of beetroots

The drying time, moisture content, rehydration ratio and hardness of beetroots carried to different microwave-assisted drying methods are showed in Table 3.16. The drying time refers to the time it takes to dry fresh beetroots to the final moisture content (less than 7.0%). As shown in Table 3.16, there were significant differences in drying time among different microwave-assisted drying methods ($p < 0.05$), ranged from 67.0 ± 3.5 to 308.0 ± 6.2 min. It required 67.0 ± 3.5 min for HMD, reduced by 24.7% and 47.2% in comparison with the drying time for HMD+LMD (89.0 ± 3.5 min) and LMD (127.0 ± 3.5 min). The drying time for HAD+LMD was lower than that of HMD+HAD. Meanwhile, the drying time for HMD+VD was higher than that of HMD+HAD, but lower than that of VD+LMD. Furthermore, the drying times for HMD+LMD, HMD, and LMD were less than the drying times for combined drying methods (HMD+HAD, HAD+LMD, HMD+VD, and VD+LMD). VD+LMD required the longest drying time of 308.0 ± 6.2 min. As we all know, short drying time can greatly reduce production costs and improve production efficiency.

The moisture content of dried product plays a critical role in maintaining product quality. The moisture content of dried beetroots prepared by different microwave-assisted drying methods ranged from 6.17 ± 0.74 to 6.48 ± 0.40%. There was no significant difference in the moisture content of beetroots subjected to different microwave-assisted drying methods ($p > 0.05$).

Rehydration capacity is common used as a quality indicator for dehydrated products that can indicate the cellular degree and structural disruption caused by drying process [141]. The beetroots dried by HMD absorbed a higher quantity of water than those of beetroots dried by other microwave-assisted drying methods. The beetroots dried by HMD displayed the highest rehydration ratio and followed by those prepared by HAD+LMD, HMD+HAD, HMD+LMD, LMD, HMD+VD, and VD+LMD, while the beetroots subjected to VD+LMD illustrated the lowest rehydration ratio of 3.55 ± 0.22.

Table 3.16

The drying time, moisture content, rehydration ratio and hardness of beetroots affected by different microwave-assisted drying methods

Drying methods	Drying time, min	Moisture content,%	Rehydration ratio	Hardness, g
HMD+LMD	89.0 ± 3.5^{f}	6.23 ± 0.63^{a}	3.90 ± 0.13^{abc}	868.4 ± 105.2^{b}
HMD	67.0 ± 3.5^{g}	6.17 ± 0.74^{a}	4.22 ± 0.17^{a}	803.9 ± 103.2^{b}
LMD	127.0 ± 3.5^{e}	6.19 ± 0.59^{a}	3.88 ± 0.22^{abc}	840.0 ± 105.9^{b}
HMD+HAD	230.0 ± 8.7^{c}	6.20 ± 0.75^{a}	3.95 ± 0.11^{ab}	1332.0 ± 109.2^{a}
HAD+LMD	185.0 ± 6.2^{d}	6.29 ± 0.76^{a}	4.15 ± 0.05^{ab}	932.6 ± 118.2^{b}
HMD+VD	265.0 ± 10.0^{b}	6.40 ± 0.27^{a}	3.81 ± 0.08^{bc}	1237.7 ± 81.2^{a}
VD+LMD	308.0 ± 6.2^{a}	6.48 ± 0.40^{a}	3.55 ± 0.14^{c}	910.9 ± 100.2^{b}

Texture is a vital quality attribute that affects food acceptance and was evaluated through hardness. As seen in Table 3.16, the hardness of dried beetroots ranged from 803.9 ± 103.2 to 1332.0 ± 109.2 g. Beetroots carried to HMD+HAD showed the maximum hardness value of 1332.0 ± 109.2 g, whereas beetroots prepared by HMD demonstrated the lowest hardness value, indicating that the texture of HMD beetroots was soft. There was no significant difference in the hardness of beetroots prepared by HMD+LMD, HMD, LMD, HAD+LMD, and VD+LMD ($p > 0.05$). The hardness of the beetroots prepared by HMD+HAD and

HMD+VD needed higher levels, indicating hot air drying and vacuum drying process changed the texture profiles of the HMD beetroots ($p < 0.05$). The results revealed that the hardness of beetroots obtained by HMD+HAD and HMD+VD was significantly higher than those of beetroots subjected to HMD, LMD, HMD+LMD, HAD+LMD, and VD+LMD.

Color parameters of food are important attributes that determine the physical reflection of quality loss and certain chemical changes during processing [136]. The color of beetroots is important, especially due to the presence of betalains in beetroots, which is highly valued [142]. Color parameters of beetroots before and after drying are provided in Table 3.17. *L* value presents the brightness of beetroots, and varied from 36.83 ± 0.94 to 43.55 ± 0.75. Fresh beetroots illustrated the lowest *L* value, while beetroots subjected to HMD+LMD displayed the highest *L* value of 43.55 ± 0.75. HMD led to lower *L* value of beetroots than other microwave-assisted drying methods. The color of beetroots became significantly brighter after drying ($p < 0.05$).

Table 3.17

Color changes of beetroots prepared by different microwave-assisted drying methods

Drying methods	L	a	b	ΔE
HMD+LMD	43.55 ± 0.75^{a}	22.79 ± 0.35^{bcd}	3.82 ± 0.15^{b}	9.36 ± 0.67^{ab}
HMD	40.84 ± 1.02^{b}	22.20 ± 0.19^{cd}	3.47 ± 0.13^{b}	8.26 ± 0.60^{c}
LMD	42.05 ± 1.02^{ab}	21.76 ± 0.67^{d}	3.54 ± 0.29^{b}	9.22 ± 1.01^{ab}
HMD+HAD	42.78 ± 1.08^{ab}	21.48 ± 0.47^{d}	2.09 ± 0.25^{c}	10.36 ± 0.87^{a}
HAD+LMD	42.12 ± 1.26^{ab}	23.37 ± 0.85^{bc}	3.55 ± 0.40^{b}	8.08 ± 1.50^{c}
HMD+VD	41.19 ± 0.55^{b}	21.86 ± 0.91^{d}	2.20 ± 0.25^{c}	9.18 ± 0.91^{ab}
VD+LMD	41.87 ± 1.05^{ab}	23.80 ± 0.77^{b}	3.19 ± 0.31^{b}	7.77 ± 1.25^{c}
Fresh beetroots	36.83 ± 0.94^{c}	28.78 ± 0.79^{a}	6.34 ± 0.54^{a}	-

Meanwhile, the dried beetroots showed significantly lower *a* and *b* values than those of fresh beetroots ($p < 0.05$). The decreases in *a* and *b* values were due to the degradation of pigments, such as betacyanins and betaxanthins. Values of *a* in beetroots ranged from 21.48 ± 0.47 to 23.80 ± 0.77. Compared to other microwave-assisted drying methods, VD+LMD resulted in a larger *a* value, was closed to the value of fresh beetroots. The *b* values of dried beetroots ranged from 2.09 ± 0.25 to 3.82 ± 0.15. Beetroots carried to HMD+LMD exhibited a higher *b* value, which was close to that of fresh beetroots. Beetroots prepared by HMD+HAD and HMD+VD, showed lower *b* values than those of beetroots carried to other microwave-assisted drying methods. Beetroots carried to HMD+HAD showed the lowest *a* and *b* values.

Beetroots subjected to VD+LMD exhibited the lowest ΔE value, while beetroots prepared by HMD+HAD showed the highest ΔE value of 10.36 ± 0.87. Moreover, beetroots subjected to VD+LMD displayed the most desirable color with the lowest ΔE. In addition, the color of beetroots prepared by HMD+HAD was the worst, indicating that the different combinations of hot air drying and microwave drying had great impacts on the color of final products.

In order to comprehensively study the effects of different microwave assisted drying methods on the microstructure of dried beetroots, the microstructure was determined using scanning electron microscope (SEM). The results are illustrated in Fig. 3.13.

Different microwave-assisted drying methods had a great impact on the internal structure of dried beetroots. As shown in Fig. 3.13, beetroots dried by HMD+LMD, HMD and LMD had porous structures, which can be explained by the fact that during the microwave drying process, a large amount of microwave energy was absorbed by beetroots, which generated an internal pressure, and the water quickly evaporated to cause microscopic holes [143]. However, beetroots dried by HMD+HAD and HAD+LMD demonstrated denser structures and collapse of the cell wall structure, indicating certain damage to the cell structure of beetroots. Beetroots obtained using HMD+VD and VD+LMD were found to have thin porous walls and a few large microscopic holes, resulting in negative effects on the texture of products.

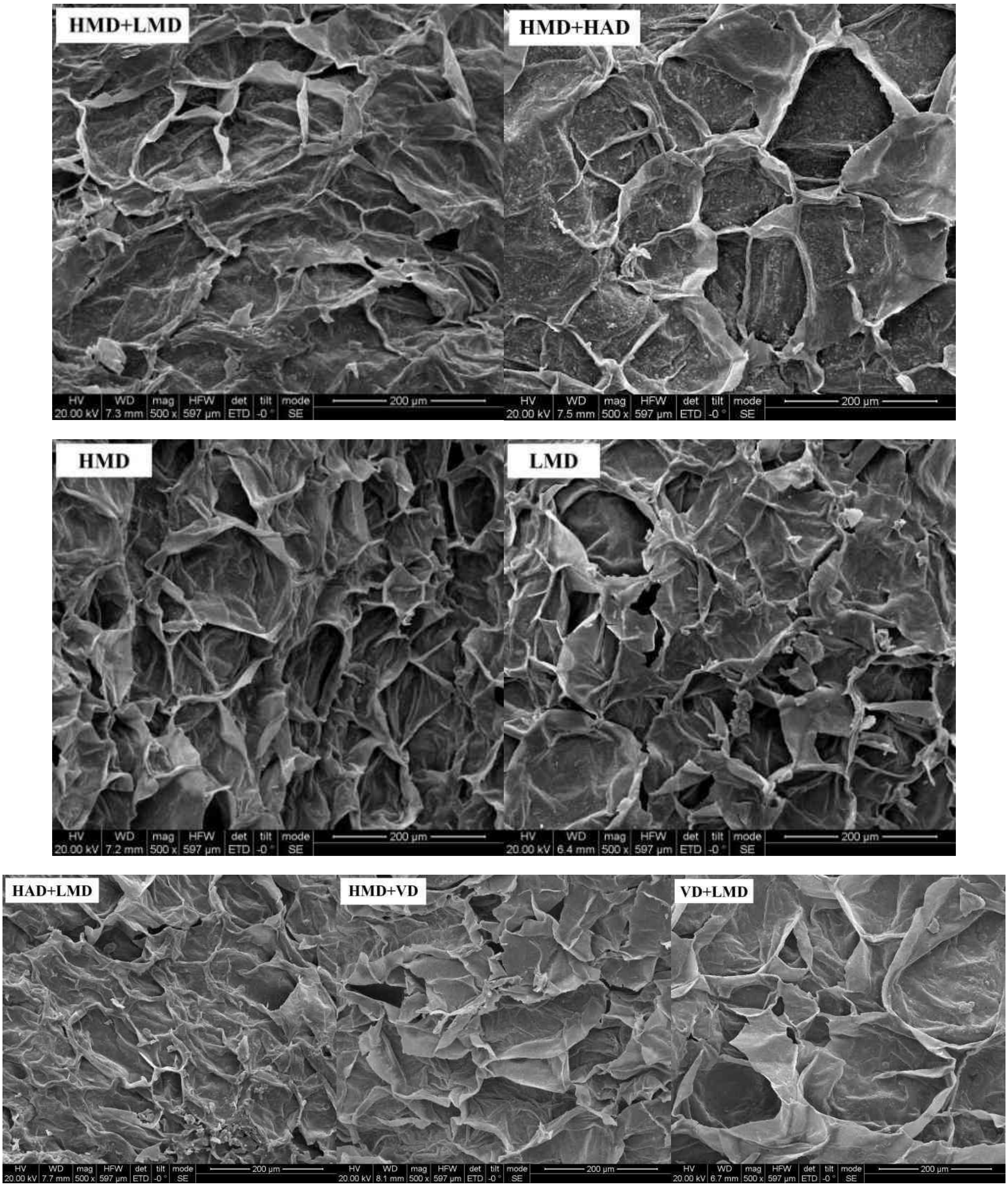


Fig. 3.13 SEM micrographs (500 × magnification) of dried beetroots dried using different microwave-assisted drying methods

Contents of betalains, ascorbic acid and total flavonoids of dried beetroots presented in Table 3.18 are proposed. Beetroot contains a large amount of betalains that can be applied as food colorant or food additive [126]. Betalains are water-soluble pigments including betacyanins and betaxanthins. The results showed that betacyanins content of beetroots prepared by VD+LMD was the highest of 4.09 ± 0.05 mg/g, while the minimum betacyanins content of 2.81 ± 0.05 mg/g was observed in beetroots obtained using LMD. The content of betaxanthins ranged from 2.43 ± 0.04 to 3.45 ± 0.04 mg/g. The betaxanthins content of beetroots obtained by VD+LMD was significantly higher than those of beetroots subjected to other microwave-assisted drying methods ($p < 0.05$). The lowest betaxanthins content of beetroots was 2.43 ± 0.04 mg/g, which was carried to LMD.

As displayed in Table 3.18, the beetroots prepared by HMD showed the highest ascorbic acid content of 272.3 ± 4.4 mg/100g, closed following by those of VD+LMD and HMD+LMD. The beetroots carried to HMD+VD displayed the lowest ascorbic acid content of 222.1 ± 1.9 mg/100g. Compared to HMD+LMD and LMD, HMD led to the highest ascorbic acid content of beetroots, demonstrating that ascorbic acid contents increased with the increase of microwave powers. A similar discovery was reported in [144]. Ascorbic acid is well recognized to be highly vulnerable to oxidation under specific circumstances, such as heat, heavy metal ions, alkaline pH, and the presence of oxygen [129]. The result showed that HMD, HMD+LMD and VD+LMD illustrated higher retention of ascorbic acid, which may be due to the shorter drying time of beetroots and keep away from oxygen at the first stage, thereby reducing the loss of ascorbic acid.

Flavonoids are a kind of bioactive compounds with numerous health benefits in beetroots. Different microwave-assisted drying methods had significant effects on total flavonoids content ($p < 0.05$). It can be seen from Table 3.18 that the total flavonoids content of dried beetroots varied from 12.76 ± 0.08 to 16.74 ± 0.26 mg RE/g. Beetroots obtained using LMD, HMD+HAD, and HMD+VD exhibited lower total flavonoids content. Meanwhile, the beetroots prepared by VD+LMD showed the largest total flavonoids content of 16.74 ± 0.26 mg RE/g. Beetroots prepared by VD+LMD and HAD+LMD showed relatively high total flavonoids content, which can be explained that the thermal treatment of beetroots accelerated the release of bound flavonoids due to the breakdown of cellular components, and the inactivation of endogenous oxidative enzymes enhanced the total flavonoids concentration in beetroots [75].

Table 3.18

Contents of betalains, ascorbic acid and total flavonoids of dehydrated beetroots prepared by different microwave-assisted drying methods

Drying methods	Betacyanins, mg/g	Betaxanthins, mg/g	Ascorbic acid, mg/100g	Total flavonoids, mg RE/g
HMD+LMD	3.08 ± 0.05^{d}	2.73 ± 0.04^{bc}	262.1 ± 1.0^{ab}	14.94 ± 0.39^{b}
HMD	3.18 ± 0.06^{d}	2.74 ± 0.05^{b}	272.3 ± 4.4^{a}	13.91 ± 0.31^{c}
LMD	2.81 ± 0.05^{e}	2.43 ± 0.04^{d}	239.3 ± 3.8^{d}	12.86 ± 0.21^{d}
HMD+HAD	3.52 ± 0.09^{c}	2.51 ± 0.07^{d}	254.6 ± 2.0^{bc}	12.91 ± 0.18^{d}
HAD+LMD	2.97 ± 0.03^{de}	2.56 ± 0.02^{cd}	253.5 ± 4.4^{c}	15.64 ± 0.09^{b}
HMD+VD	3.78 ± 0.09^{b}	2.81 ± 0.08^{b}	222.1 ± 1.9^{e}	12.76 ± 0.08^{d}
VD+LMD	4.09 ± 0.05^{a}	3.45 ± 0.04^{a}	265.4 ± 4.6^{ab}	16.74 ± 0.26^{a}

Beetroots are high in phytochemicals that have antioxidant properties. There are several methods to evaluate antioxidant capacity. Different mechanisms of antioxidants, such as reducing capacity, decomposition of peroxides, free radical scavenging, and binding of transition-metal ion catalysts [145–146]. Using multiple methods can be expected to obtain different antioxidant activity results, allowing us to better understand the great variety and range of action of antioxidant components found in beetroots [30]. In present study, FRAP value and ABTS radical scavenging activity were used to evaluate the antioxidant activity of dried beetroots.

Fig. 3.14 presents the FRAP values of dried beetroots affected by different microwave-assisted drying methods. The FRAP value in beetroots subjected to VD+LMD was the highest of 14.95 ± 0.18 mg TE/g, followed by those of HMD and HMD+LMD, which were significantly higher than those of beetroots prepared by other microwave-assisted drying methods ($p < 0.05$). HMD+VD led to the lowest FRAP value of 11.60 ± 0.06 mg TE/g. FRAP values of beetroots carried to HMD and LMD were significantly different, but no significant difference was seen in FRAP between LMD and HMD+HAD ($p > 0.05$). There were significant differences ($p < 0.05$) in the FRAP values of beetroots prepared by different combinations of HMD+HAD, HAD+LMD, HMD+VD, and VD+LMD.

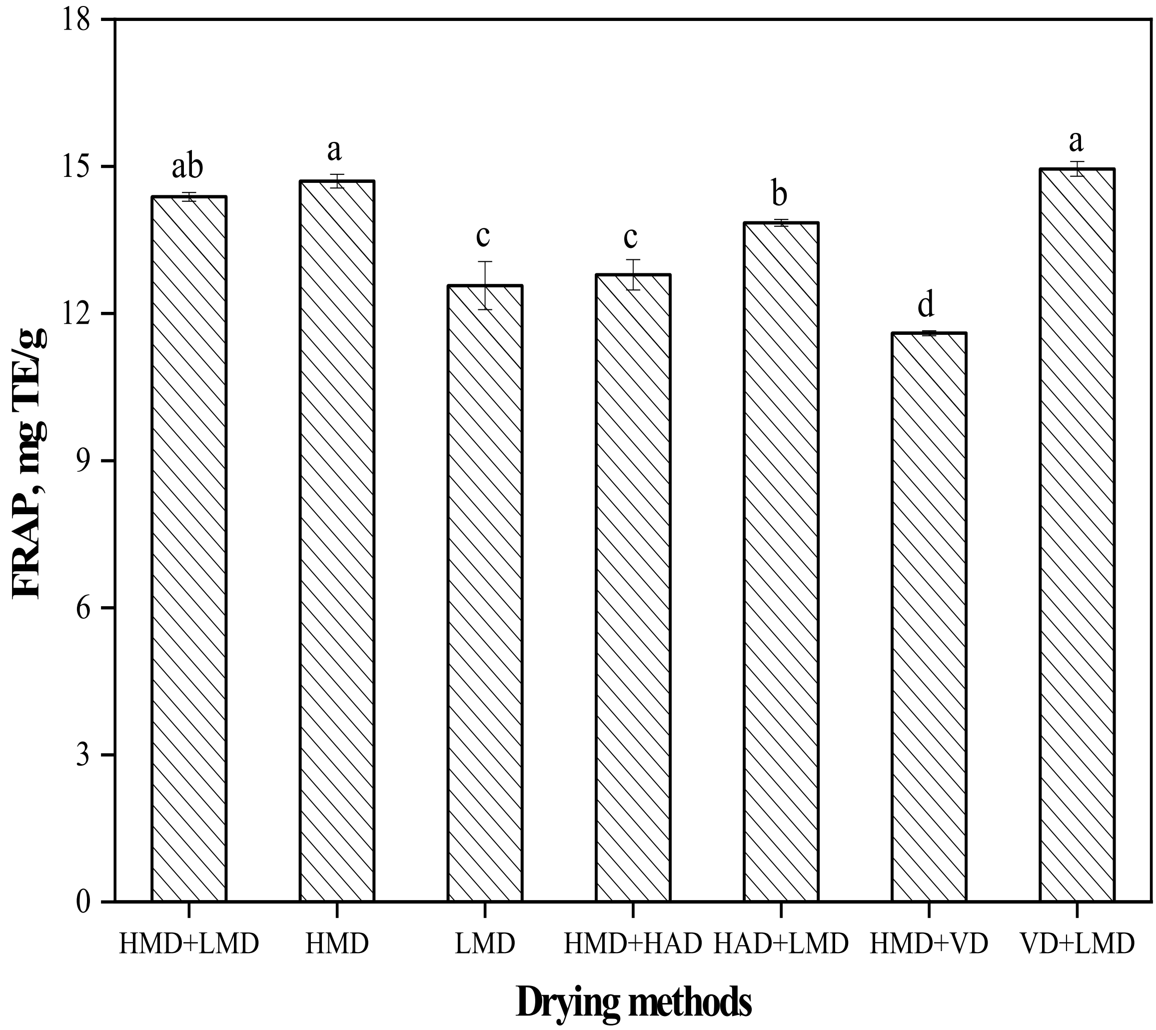


Fig. 3.14 Effect of different microwave-assisted drying methods on FRAP values of beetroots.

Results of different microwave-assisted drying methods on the ABTS radical scavenging activity of beetroots are provided in Fig.3.15.

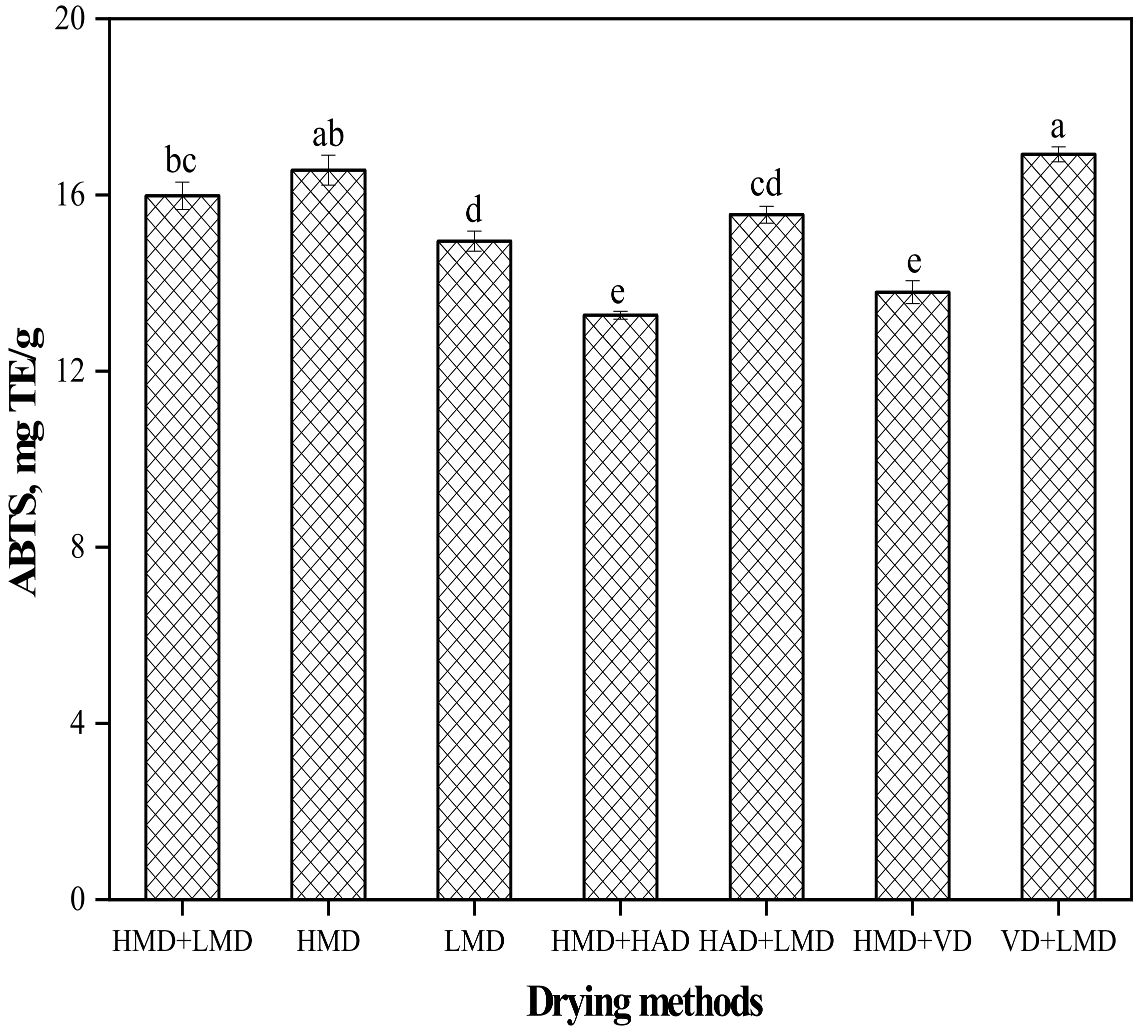


Fig.3.15 Effect of different microwave-assisted drying methods on ABTS radical scavenging activity of beetroots.

Beetroots obtained using VD+LMD showed the highest ABTS radical scavenging activity equivalent to 16.92 ± 0.21 mg TE/g, whereas the lowest ABTS radical scavenging activity value corresponding to 13.27 ± 0.12 mg TE/g was obtained using HMD+HAD. As shown in Fig. 3.15, HMD+VD and HMD+HAD showed no significant effect on the ABTS radical scavenging activity of beetroots, and ABTS radical scavenging activities significantly lower than those of other microwave-assisted drying methods ($p < 0.05$). As a result of this, VD+LMD and HMD could well maintain ABTS radical scavenging activity of beetroots.

In this research, FRAP assay and ABTS assay were carried out to evaluate antioxidant activity of beetroots. Results were presented in Fig. 3.14 and Fig. 3.15. Beetroots carried to VD+LMD exhibited the highest FRAP value and ABTS radical scavenging activity. This meant that VD+LMD resulted in the highest antioxidant activity of dried beetroots, which could be attributed to the existence of bioactive components in beetroots such as total flavonoids, ascorbic acid, and other non-nutrient phytochemicals. Only two techniques were utilized in this investigation to evaluate the antioxidant capacity of beetroots. Future analysis can utilize more comprehensive evaluation techniques.

In terms of physical properties, VD+LMD led to the longest drying time. No significant difference in the moisture content among the dried beetroots using different microwave-assisted drying methods ($p > 0.05$). The hardness of dried beetroots obtained by HMD+HAD and HMD+VD were significantly higher than those of other microwave-assisted drying methods ($p < 0.05$). Beetroots dried by VD+LMD showed a desirable color with the lowest ΔE. Dried beetroots prepared by HMD+LMD, HMD and LMD showed porous structures. However, beetroots carried to HMD+HAD and HAD+LMD exhibitd a few denser structures and collapse of the cell wall structure.

Different microwave-assisted drying methods can significantly affect the bioactive compounds of beetroots. Beetroots subjected to VD+LMD showed the highest contents of betacyanins, betaxanthins, and total flavonoids. Moreover, beetroots obtained using LMD displayed the lowest betacyanins content and betaxanthins content. In addition, HMD led to the highest ascorbic acid content of 272.3 ± 4.4 mg/100g.

For antioxidant activity results, beetroots prepared by VD+LMD revealed the largest FRAP value and ABTS radical scavenging activity. In other words, VD+LMD led to higher antioxidant activity of beetroots compared to other microwave-assisted drying methods. The dehydrated beetroots obtained using VD+LMD displayed powerful antioxidant capacity, which can be used as an antioxidant in the food industry.

3.1.3 Influence of drying methods on the quality characteristics of dried beetroots

A variety of drying technologies, including hot air drying, vacuum drying, microwave drying, microwave vacuum drying, and freeze drying, have been used to produce dried vegetables. Drying method causes nutritional losses and affects the chemical and physical properties of the source material during the drying process. Thus, selecting the best drying technique is primarily determined by the final product's quality [147]. Dried beetroot powder and dehydrated beetroot slices are available in the market. The drying processing has a significant impact on the quality of the material. Product quality, drying time, and energy efficiency are all important considerations when selecting a drying method. The drying method has a considerable impact on the finished product's bioactive components and antioxidant activity. As a result, it is critical to select an appropriate drying method in order to achieve high-quality dried items.

There is little research in the literature on the influence of different drying techniques on the quality features of dried beetroots. Therefore, the purpose of the research was to investigate the influence of different drying methods, including freeze drying, heat pump drying, microwave drying, vacuum drying, and microwave vacuum drying, on the quality characteristics of dried beetroots.

3.1.3.1 Experimental conditions for different drying methods

Fresh beetroots were washed, peeled, and cut into slices with 75 mm in diameter and 4 mm in thickness. The beetroot slices (300.0 ± 3.0 g) were carried to five different ways, respectively. The detailed drying conditions are as follows:

Freeze drying (FD): Fresh beetroots slices were frozen at –20 °C for 12 h and then placed on the cavity in the freeze dryer at 4 Pa. The condenser temperature was set at –80 °C.

Heat pump drying (HPD): Fresh beetroots slices were spread on a polyethylene tray of heat pump dryer. The temperature of heat pump drying was 65 °C.

Vacuum drying (VD): Fresh beetroots slices were put on a tray of vacuum drying oven. The vacuum drying conducted at vacuum degree of 0.095 MPa and temperature of 60 °C.

Microwave drying (MD): Fresh beetroots slices were spread on a circular fiberglass tray of microwave drying system. The microwave power was 390 W.

Microwave vacuum drying (MVD): Fresh beetroots slices were placed uniformly on a tray of microwave vacuum dryer. Drying was carried out under constant vacuum of 0.09 MPa and microwave power of 1000 W.

All of the drying experiments were carried out three times.

3.1.3.2 Results and discussions on the influence of drying methods on the quality of beetroots

Results of drying time and final moisture content of beetroots obtained by different drying methods are presented in Table 3.19. The drying time required by FD was the longest of 29.67 ± 0.58 h. MD and MVD were much faster drying methods than FD, VD, and FD. Significant differences ($p < 0.05$) in drying time were noted among different drying methods, except MVD and MD. It required the shortest drying time (0.77 ± 0.03 h) for MD to reach the final moisture content, while the drying time for MVD was 1.09 ± 0.01 h and was very close to MD. This indicated that the drying time was significantly reduced as microwave was used. The drying time of MD was reduced by 97.40% compared to FD, which was only 9.83% that of VD and 11.27% that of HPD. The drying time required for MVD was about 3.67% of FD time, and reduced up to 84.04% and 86.08% in comparison with HPD and VD, respectively.

Table 3.19

Drying time and final moisture content of beetroots obtained by different drying methods

Drying method	Drying time, h	Final moisture content, %
FD	29.67 ± 0.58^a	4.31 ± 0.61^a
HPD	6.83 ± 0.31^c	4.64 ± 0.78^a

continuation of Table 3.19

VD	7.83 ± 0.29^{b}	4.41 ± 0.81^{a}
MD	0.77 ± 0.03^{d}	4.82 ± 0.60^{a}
MVD	0.56 ± 0.01^{d}	5.44 ± 0.68^{a}

It is well known that the moisture content of dried product is critical for quality control and stability. Table 3.19 shows the final moisture content of dried beetroots. According to the results, the final moisture content ranged from 4.31 ± 0.61 to 5.44 ± 0.68%.

Dried beetroots prepared by VD and FD displayed a slightly lower final moisture content comparing to those of MD, HPD, and MVD. There were no significant difference ($p > 0.05$) in the final moisture content among all beetroots dried using different methods.

Drying process usually leads to irreversible structural changes and restricts the material from restoring its original shape. The effect of different drying methods on the rehydration ratio of dried beetroots is presented in Fig. 3.16. It was observed that rehydration ratio of dried beetroots ranged from 3.26 ± 0.07 to 4.77 ± 0.11 for different drying methods.

The difference was not statistically significant ($p > 0.05$) between the rehydration ratio of the beetroots dried by FD and HPD. As shown in Fig. 3.16, the MVD beetroots had significantly higher ($p < 0.05$) rehydration ratio than that of beetroots prepared by other drying methods.

Meanwhile, the lowest rehydration ratio (3.26 ± 0.07) was noticed in the beetroots obtained using MD, indicating the most severe damage to the cell structure of the beetroots.

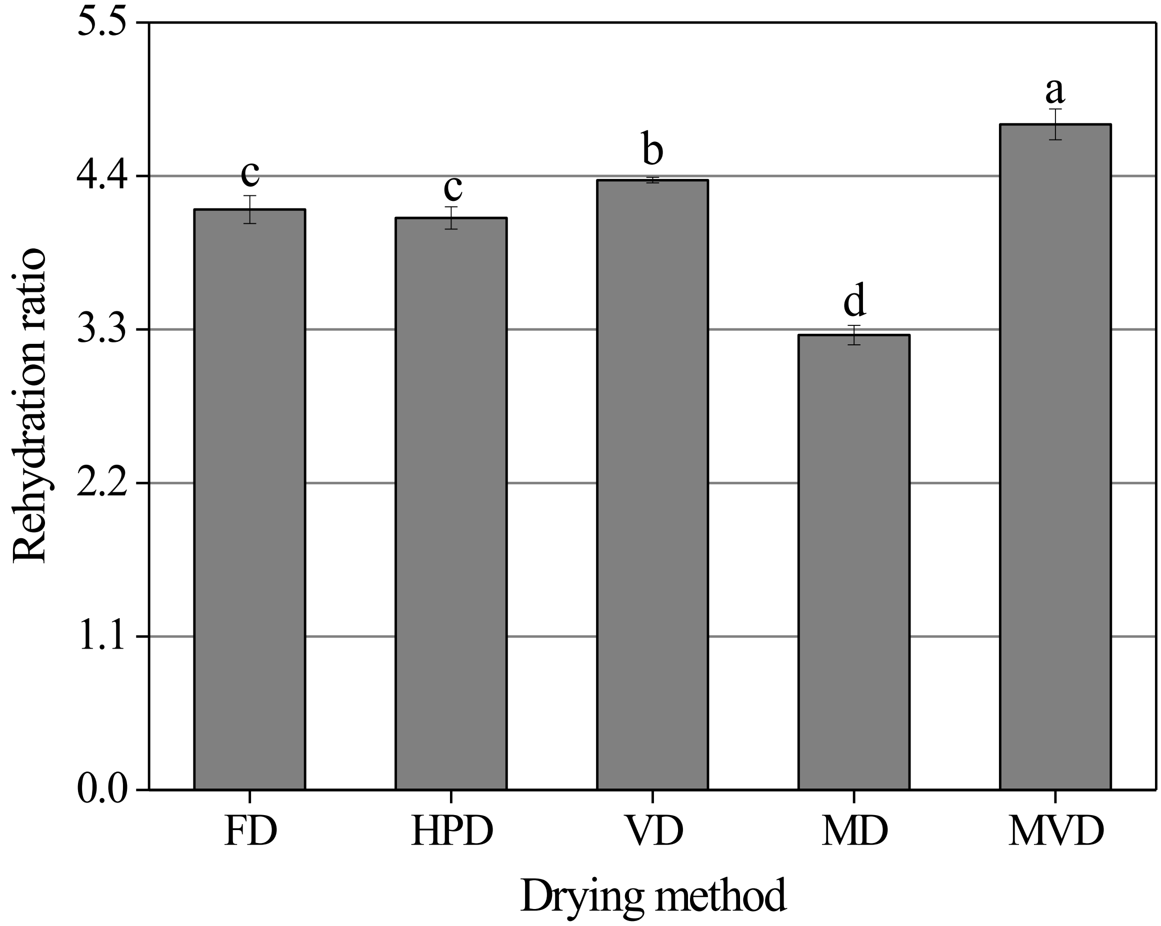


Fig. 3.16 Rehydration ratio of dried beetroots affected by different drying methods

The color values of dried food had great impacts on the quality and acceptability of products by consumers [67]. Color parameters of beetroots affected by drying methods are presented in Table 3.20.

Table 3.20

Color parameters of beetroots prepared by different drying methods

Drying method	*L*	*a*	*b*	*C*	*H*°	Δ*E*
Fresh beetroot	37.54±0.69^{d}	28.62±0.61^{a}	6.09±0.20^{a}	29.27±0.63^{a}	4.63±0.11^{e}	-
FD	43.52±0.62^{a}	27.76±0.68^{b}	4.02±0.16^{b}	28.05±0.66^{b}	6.88±0.39^{d}	6.43±0.53^{c}
HPD	39.65±0.53^{c}	21.92±0.69^{d}	1.07±0.08^{f}	21.94±0.69^{d}	20.60±0.98^{a}	8.65±0.68^{a}
VD	41.00±0.60^{b}	25.46±0.45^{c}	1.95±0.11^{e}	25.53±0.46^{c}	13.07±0.61^{b}	6.28±0.46^{c}

continuation of Table 3.20

MD	41.82±0.91[b]	21.94±0.44[d]	3.49±0.24[c]	22.22±0.43[d]	6.26±0.43[d]	8.38±0.66[a]
MVD	40.97±0.99[b]	22.79±0.33[d]	2.93±0.13[d]	22.98±0.33[d]	7.75±0.69[c]	7.50±0.69[b]

As exhibited in Table 3.20, *L* values of dried beetroots ranged from 39.65 ± 0.53 to 43.52 ± 0.62, and the lowest value was in beetroots dried by HPD and the highest value using FD. There were no significant differences in *L* values among the beetroots prepared by VD, MD, and MVD ($p > 0.05$). Obviously, it can be seen that the *L* values of dried beetroots were significantly higher than that of fresh beetroots, demonstrating beetroots turned brighter after drying process.

The *a*, *b* and *C* values of beetroots after drying were decreased significantly ($p < 0.05$) in comparison with those of fresh beetroots. The decrease of *a* and *b* values might be due to the degradation of pigments. The *a* values of dried beetroots prepared by different drying methods ranged from 21.92 ± 0.69 to 27.76 ± 0.68, and the beetroots obtained using FD showed the highest *a* value. It was noted that *b* values of beetroots subjected to different drying methods varied significantly ($p < 0.05$). The highest *b* value (6.68 ± 0.35) was obtained from beetroots carried to FD, while the lowest *b* value of beetroots was obtained using HPD. *C* values of dried beetroots varied from 21.94 ± 0.69 to 28.05 ± 0.66. The beetroots prepared by HPD displayed the lowest *C* value of 21.94 ± 0.69, indicating the smallest saturation and the dullest appearance, while the beetroots prepared by FD showed the highest *C* value among all the dried beetroots. *C* values of beetroots decreased after drying, resulting in a lower saturation and a duller appearance.

Compared with fresh beetroots, *H*° values of beetroots were significantly increased ($p < 0.05$) after different drying processing. The *H*° with values from 6.26 ± 0.43 to 20.60 ± 0.98, was in the red range to yellow-red for dried beetroots obtained by different drying methods. The beetroots prepared by HPD showed the highest *H*° value of 20.60 ± 0.98, indicting the heat pump drying caused a great degree shift to more yellow-red colors. In terms of ΔE, the beetroots dried by FD and VD had no significant difference and showed lower values than those of beetroots prepared by MVD, MD, and HPD. The Δ*E* values of beetroots subjected to different drying methods ranged from 6.28 ± 0.46 to 8.65 ± 0.68. The beetroots dried by HPD showed the biggest Δ*E* of 8.65±0.68, indicating that HPD resulted greater changes in color of dried beetroots than other drying methods.

As a result, dried beetroots prepared by FD showed the most ideal color with the highest values of *L*, *a*, *b* and *C*, and relatively lower *H*° and Δ*E* in comparison with the beetroots carried to other drying methods.

In order to comprehensively study the effect of different drying methods on the microscopic attributes of beetroots, the microstructures of dried beetroots prepared by different drying methods were analyzed by scanning electron microscope (SEM). The results were displayed in Fig. 3.17.

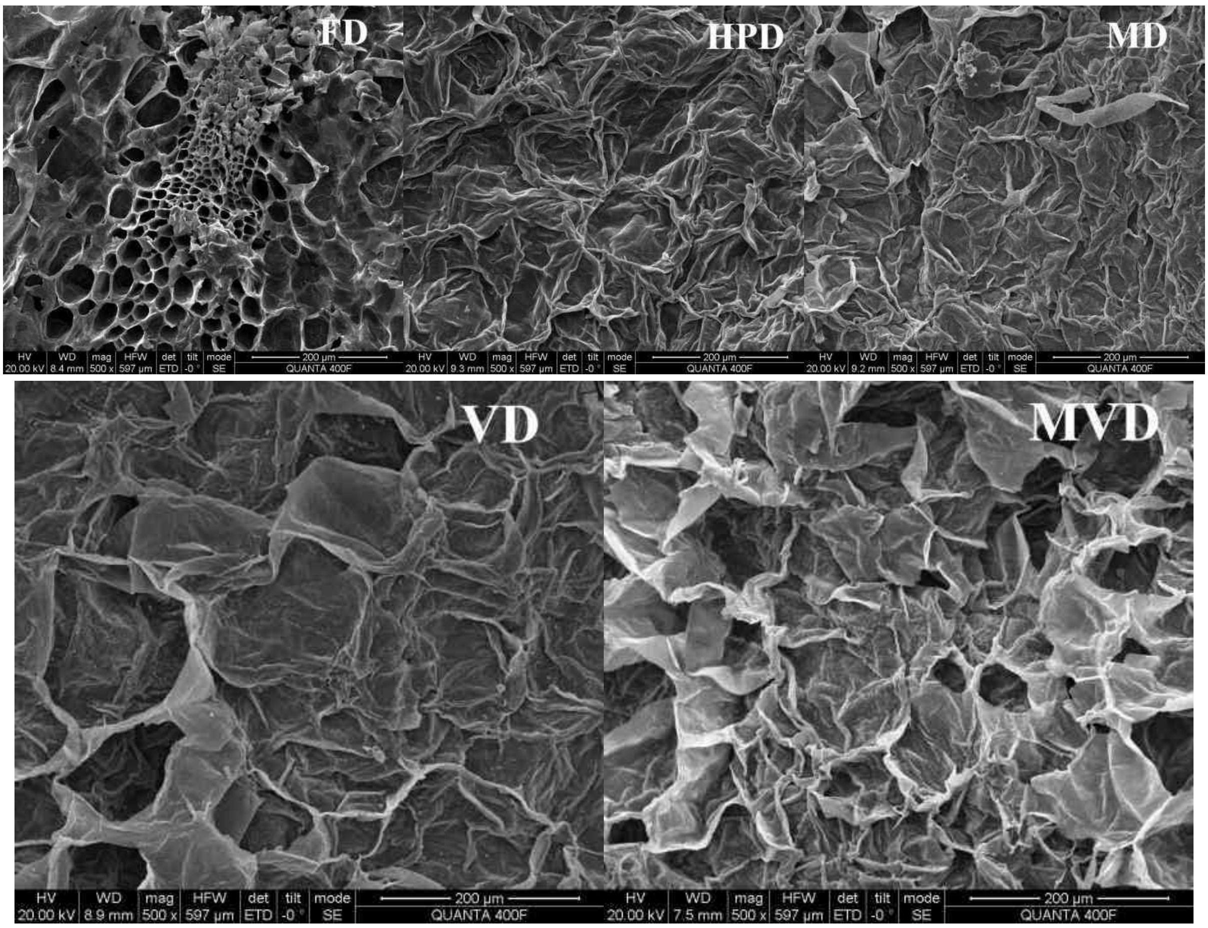


Fig. 3.17 Microstructures (500 × magnification) of dried beetroots prepared by different drying methods

The beetroots dried by FD displayed porous structures with thin pore wall, indicating that FD played an active role in maintaining porous cellular structures of beetroot tissue. It has been reported that the porous microstructure of the FD sample was formed by ice sublimation in the vacuum environment without cell shrinkage and external force collapse [148].

Compared with FD beetroots, thicker pore walls and denser structures were observed in the beetroots prepared by HPD, which was due to the shrinkage and collapse of cells during water evaporation.

During the process of MD and MVD, rapid moisture evaporation caused the microscopic holes, so similar to FD beetroots, the beetroots dried by MVD and MD also had porous structures. The VD beetroots were found with thin porous walls and a few large microscopic holes, resulting in negative effects on the product's texture.

Beetroot contains high amounts of betalains that can be used as food colorants and food additives [126]. Drying processing will consequently change betalains content and the color of the products. The influence of different drying methods on betalains content of dried beetroots is presented in Fig. 3.18.

As shown in Fig. 3.18, different drying methods significantly affected the betacyanin content of dried beetroots ($p < 0.05$). The betacyanin content of dried beetroots obtained using different drying methods varied from 2.98 ± 0.02 to 5.48 ± 0.03 mg/g. Meanwhile, the betaxanthin content ranged from 2.40 ± 0.02 to 3.57 ± 0.20 mg/g in the dried beetroots carried to different drying methods.

The contents of betacyanin (2.98 ± 0.02–5.48 ± 0.03 mg/g) and betaxanthin (2.40 ± 0.02–3.57 ± 0.20 mg/g) of dried beetroots obtained using different drying were higher than the range propsed in [87] for seven beetroots varieties: 2.3 ± 0.2–3.9 ± 0.5 mg/g for betacyanin content, and 1.5 ± 0.2–2.4 ± 0.3 mg/g for betaxanthin content.

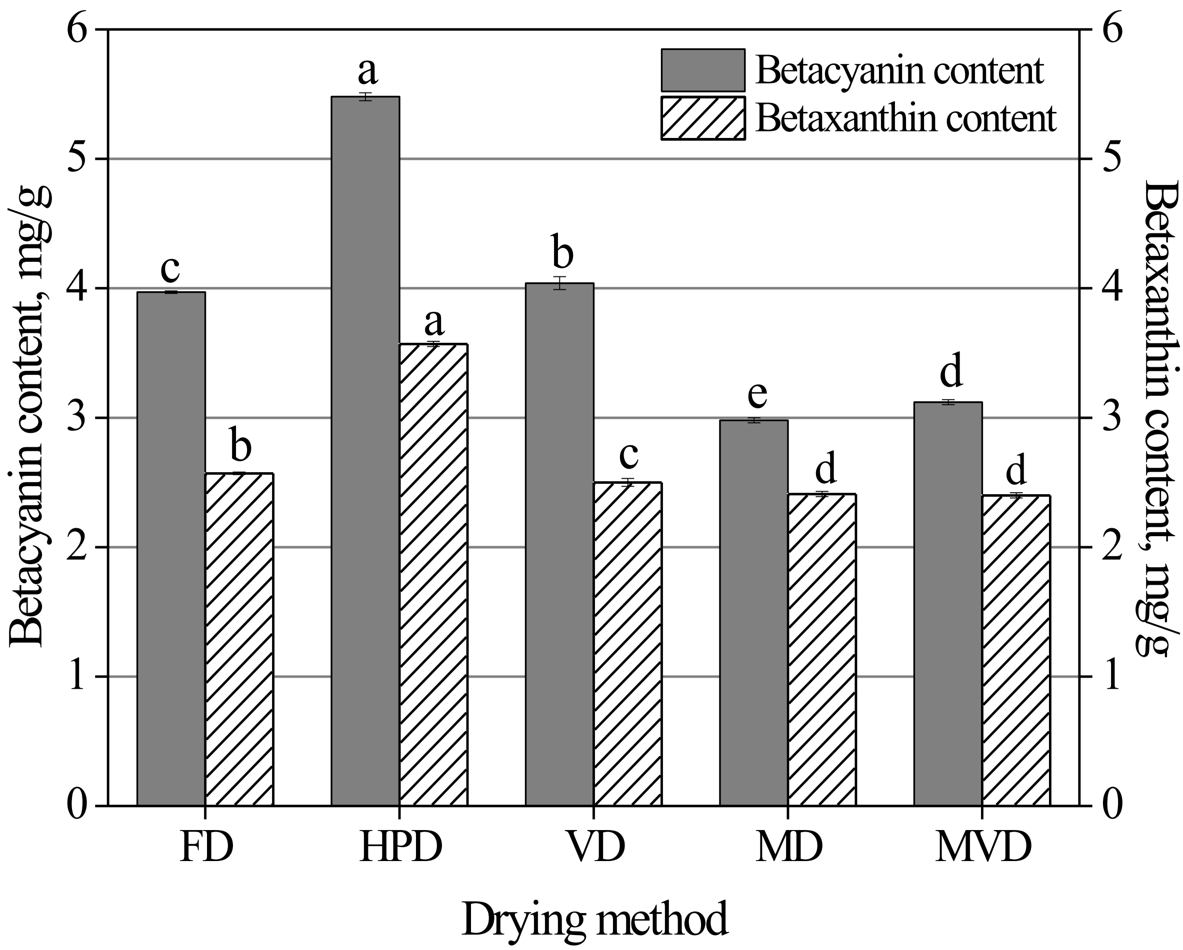


Fig. 3.18 Betalains content of dried beetroots prepared by different drying methods

Beetroots prepared by HPD illustrated the greatest betacyanin content of 5.48 ± 0.03 mg/g and the highest betaxanthin content of 3.57 ± 0.20 mg/g, demonstrating that HPD played a remarkable role for the betalains preservation during drying (Fig. 3.18). The lowest betaxanthin content of dried beetroots was observed in MVD, and no significant difference was observed in betacyanin content between MVD and MD ($p > 0.05$).

Results of the influence of different drying methods on the contents of ascorbic acid, total phenolic and total flavonoids of dried beetroots are illustrated in Table 3.21. Ascorbic acid can be utilized as an indicator of the quality of dried products because it is easily destroyed during the drying process and is relatively unstable to heat, oxygen, and light [149]. The longer the drying process takes, the temperature increases, and the more ascorbic acid in dried fruits and vegetables is destroyed [150]. The findings revealed that the beetroots prepared by VD showed the greatest ascorbic acid content of 8.73 ± 0.23 mg/g, followed by those from MD, FD, and MVD. There was no significant difference in ascorbic acid content between MVD and FD ($p > 0.05$), and MVD and FD led to a relatively lower ascorbic acid content than other drying methods. This can be explained by the fact that microwave vacuum drying resulted in some higher temperature patches on the surface of the beetroots, resulting in the loss of heat-sensitive ascorbic acid [147].

Table 3.21 illustrates the total phenolic content of dried beetroots obtained using different drying methods. The highest total phenolic content was observed in VD beetroots, followed by MVD, MD, whereas FD beetroots showed the lowest content of 8.01 ± 0.11 mg GAE/g. The use of low-temperature dehydration led to more serious degradation of polyphenols, which was understandable from the long drying time of 29.67 ± 0.58 h for FD. Other researchers have observed similar findings. Freeze drying of willow was found to have a lower total phenolic content than thermal drying methods such as hot air drying, oven drying, and tray drying [151]. When compared to other drying techniques, such as hot air drying, infrared radiation drying, and hot air coupled explosion puffing drying, it was discovered that freeze drying of raspberry fruits significantly reduced polyphenol retention [152]. VD and MVD resulted in higher total phenolic content, which can be explained by higher temperature drying causing more tissue damage, allowing more phenolic compounds to be extracted or causing changes in other compounds, resulting in higher total phenols [152]. There was no significant difference in total phenolic content between MVD and VD ($p > 0.05$).

Table 3.21

Effect of drying methods on the contents of ascorbic acid, total phenolic and total flavonoids of dried beetroots

Drying method	Ascorbic acid, mg/g	Total phenolic, mg GAE/g	Total flavonoids, mg RE/g
FD	7.44 ± 0.06^{c}	8.01 ± 0.11^{d}	15.82 ± 0.15^{d}

continuation of Table 3.21

HPD	8.46 ± 0.10^{b}	9.94 ± 0.05^{b}	24.71 ± 0.47^{a}
VD	8.73 ± 0.23^{a}	10.23 ± 0.08^{a}	21.30 ± 0.34^{b}
MD	8.32 ± 0.10^{b}	9.31 ± 0.14^{c}	21.82 ± 0.17^{b}
MVD	7.17 ± 0.09^{c}	10.20 ± 0.08^{a}	19.26 ± 0.35^{c}

Flavonoids are the bioactive compounds in beetroots with numerous health benefits. The influence of different drying methods on total flavonoids content of beetroots was investigated and the results are displayed in Table 3.21. The results showed that the beetroots prepared by HPD displayed the highest total flavonoids content of 24.71 ± 0.47 mg RE/g, followed by MD, VD, MVD, and FD beetroots of 21.82 ± 0.17, 21.30 ± 0.34, 19.26 ± 0.35, and 15.82 ± 0.15 mg RE/g, respectively. Beetroots prepared by VD and MD showed relatively higher total flavonoids content than those of FD and MVD, and there was no significant difference in total flavonoids content between VD and MD ($p > 0.05$). Besides, FD led to the lowest content of total flavonoids in dried beetroots.

Numerous phytochemicals with significant antioxidant activity can be found in beetroots. At least two approaches should be used to assess total antioxidant capacity due to multiple antioxidant mechanisms such as reducing capacity, peroxide breakdown, free radical scavenging, and transition metal binding.-catalysts based on metal ions [145–146]. The antioxidant activity of dried beetroots was evaluated by three methods in this study, including DPPH radical scavenging activity, FRAP value, and ABTS radical scavenging activity. Results are presented in Table 3.22.

Table 3.22

Effect of drying methods on the antioxidant activity of beetroots

Drying method	DPPH, mg TE/g	FRAP, mg TE/g	ABTS, mg TE/g
FD	5.16 ± 0.02^{d}	9.89 ± 0.13^{c}	13.89 ± 0.29^{d}
HPD	5.65 ± 0.04^{c}	12.63 ± 0.20^{b}	15.57 ± 0.37^{c}

continuation of Table 3.22

VD	6.21 ± 0.05^{b}	13.15 ± 0.11^{a}	15.92 ± 0.08^{b}
MD	6.63 ± 0.03^{a}	12.92 ± 0.14^{b}	17.22 ± 0.35^{a}
MVD	6.62 ± 0.05^{a}	13.36 ± 0.17^{a}	16.30 ± 0.21^{b}

The beetroots carried to FD were found to display the lowest DPPH radical scavenging activity of 5.16 ± 0.02 mg TE/g. The beetroots subjected to MD and MVD demonstrated significantly ($p < 0.05$) higher DPPH radical scavenging activity than those of beetroots obtained using VD, HPD, and FD. As seen in Table 3.22, drying methods led to the degradation of bioactive compounds that were responsible for FRAP in beetroots to different degrees. MVD led to the highest FRAP value of 13.36 ± 0.17 mg TE/g, followed by VD, MD, HPD, and FD. Similar to DPPH radical scavenging activity, the beetroots prepared by FD illustrated the lowest FRAP value of 9.89 ± 0.13 mg TE/g. The beetroots dried by MD demonstrated the highest ABTS radical scavenging activity, followed by MVD, VD, HPD, and FD. The result was consistent with the outcome reported in [10] showed that betacyanin degradation resulted in other phenolic compounds, thereby increasing antioxidant activity. The beetroots processed by MD had the highest ABTS radical scavenging activity, but the lowest betacyanin content. The ABTS radical scavenging activity produced by FD was the lowest in comparison to other drying techniques. According to studies conducted under various drying settings, the ABTS radical scavenging capacity of freeze-dried sour cherries was much lower than that of vacuum microwave dried sour cherries [153].

Through analysis of the antioxidant activity data, it was discovered that FD did not outperform the other drying techniques in terms of the antioxidant activity of beetroots. This result was in agreement with results published in [152], but contradicted that of Chan et al. [154], who reported that all resulted in greater antioxidant capacity reductions than freeze drying. The decrease in antioxidant activity can be related to a number of factors. Firstly, intensive and/or long-term heat treatment during the thermal process may result in the loss of natural antioxidants, the majority of which are very unstable [155]. Furthermore, breakdown caused by enzymes or heating reduces antioxidant capacity. In addition, the antioxidant capacity may be increased by the intermediate products of the Maillard reaction and heating process [156]. The enzymatic and non-enzymatic browning reactions that occur during the drying process may also produce antioxidative properties [157].

Among different drying methods, FD required the longest drying time, while MVD led to the shortest drying time of 0.56 ± 0.01 h. There was no significant difference in final moisture content of beetroots among different drying methods. Beetroots obtained by MVD showed the highest rehydration ratio of 4.77 ± 0.11. The color results indicated that beetroots prepared by FD displayed a better color appearance. According to the microstructure results, the beetroots prepared by FD, MD and MVD displayed porous structures, while the beetroots dried by HPD were observed denser structures.

In terms of bioactive compounds, different drying methods significantly affected the bioactive compounds of beetroots. The beetroots dried by HPD exhibited the highest values of betacyanin, betaxanthin, and total flavonoids content.

The beetroots prepared by MD and MVD had considerably higher DPPH radical scavenging activity than the beetroots prepared by VD and FD in terms of antioxidant activity. Moreover, the beetroots carried to MD had the highest level of ABTS radical scavenging activity. Additionally, the MVD led to the highest FRAP value. It is worth noting that the FRAP, DPPH, and ABTS values of beetroots processed by FD were the lowest, indicating the lowest antioxidant activity. Compared to other drying methods, MVD resulted in enhance antioxidant activity of beetroot.

Considering the quality attributes and drying time, the combined drying methods (HPD+MVD) may guarantee high quality of beetroots and a short drying time.

3.2 Methods and parameters for obtaining dried beetroot, pretreated by freeze-thaw method

3.2.1 Influence of freeze-thaw cycles on quality attributes of microwave dried beetroots

Freeze-thaw technology is a non-thermophysical pretreatment method [55] that is composed of two steps, including freezing material to its freezing points, and thawing the frozen material at higher temperatures [158]. The freeze-thaw principle is based on crystallization, which occurs when free water pierces the cell membrane during the expansion of frozen water. This enables the free water to enter the cell in excess and facilitate mass transfer [159]. Freeze-thaw is an effective procedure for increasing drying rate by changing the permeability of the cell membrane and destroying the cell wall structure [56]. It has been shown that freeze-thaw pretreatment can greatly improve the performance of various thermal drying procedures by causing cell walls and cell membranes to rupture and preventing structural distortion during drying [61].

To our knowledge, the effects of freeze-thaw cycles on the microwave drying of beetroots have not been studied yet. Furthermore, only little is known about the influence of freeze-thaw cycles on the physicochemical properties and antioxidant capacity of the beetroots. Therefore, we investigated the effects of freeze-thaw cycles on drying time, physicochemical properties and antioxidant capacity of microwave dried beetroots.

3.2.1.1 Experimental conditions for freeze-thaw pretreatment and microwave drying

Freeze-thaw pretreatment: Fresh beetroot slices (300.0 ± 3.0 g) were frozen at –20 °C for 12 h, and then put them in a constant temperature water bath (25 °C) to thaw for 3 h, the pretreated process was called as freeze-thaw once (FT1). Fresh beetroot slices were subjected to freeze-thaw once (FT1), freeze-thaw two times

(FT2) and freeze-thaw three times (FT3). Beetroot slices without freeze-thaw pretreatment (FT0) were prepared as a control group. Each pretreatment was repeated three times.

In this study, a microwave drying system was used to dry frozen-thawed beetroots. Frozen-thawed beetroot slices were spread evenly on the tray as a thin layer, and then put the tray into the microwave drying system chamber. Microwave drying was carried out at microwave power of 520 W. The drying process was finished until the moisture content of beetroots was less than 6.0%.

3.2.1.2 Results and discussions on the effect of freeze-thaw cycles on quality of dried beetroots

Drying time and rehydration ratio of beetroots affected by freeze-thaw cycles are shown in Fig. 3.19. It was observed that freeze-thaw pretreatment could reduce drying time and drying time decreased with the increase of freeze-thaw cycles. Significant differences ($p < 0.05$) in drying time were noted among FT0, FT1, and FT2.

The drying time required by FT0 (without freeze-thaw pretreatment) to reach to the final moisture content (below 6.0%) was the longest of 41.3 ± 1.7 min, while FT3 resulted in the shortest drying time of 26.0 ± 1.7 min. Compared to the unpretreated beetroots (FT0), FT1, FT2, and FT3 shortened the drying time by 18.3%, 29.8%, and 37.0%, respectively.

The effect on microwave drying time was due to the changes in microstructure caused by the freeze-thaw pretreatment. As presented in Fig. 3.19, the rehydration ratio of beetroots decreased significantly ($p < 0.05$) with the increase of freeze-thaw cycles. The rehydration ratio decreased from 5.04 ± 0.07 to 4.52 ± 0.08 as the freeze-thaw cycles increasing from FT0 to FT3.

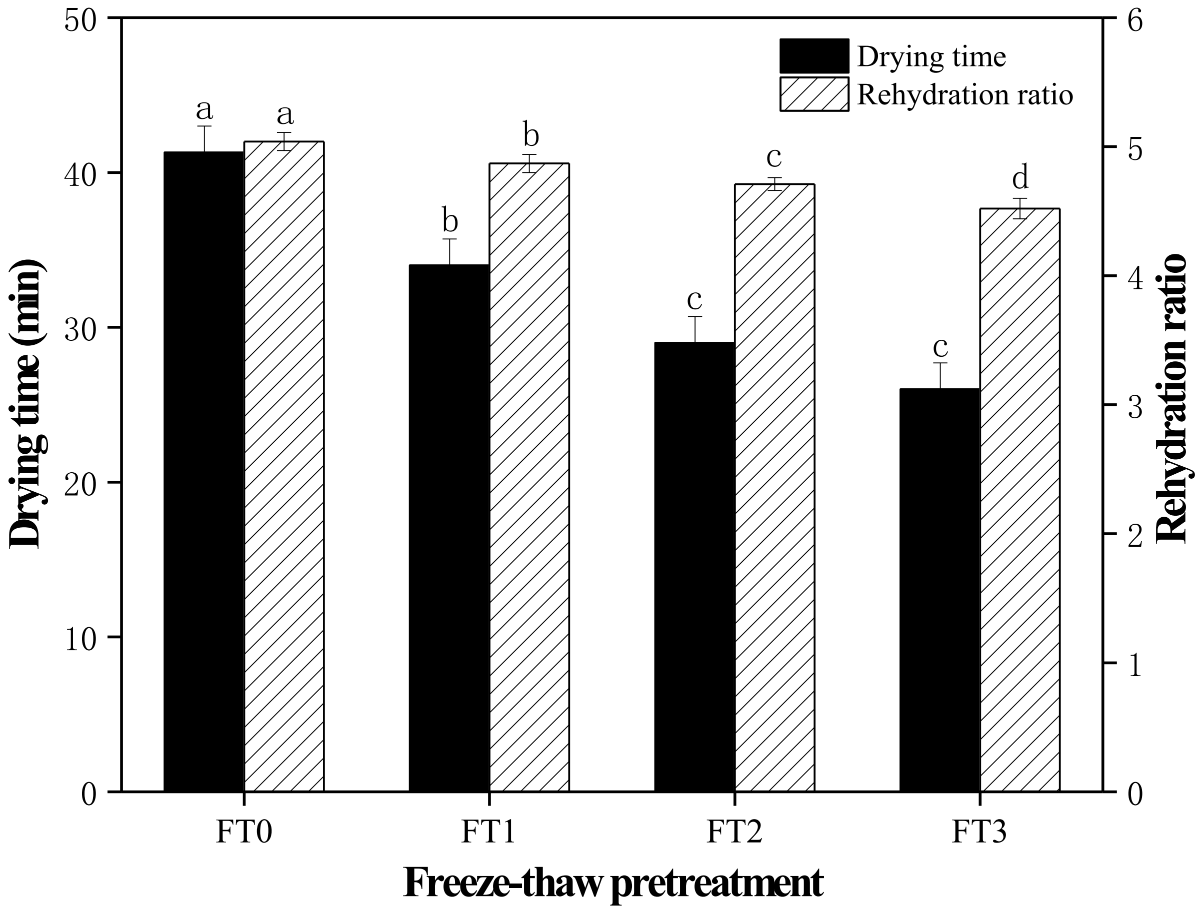


Fig. 3.19 Influence of freeze-thaw cycles on drying time and rehydration ratio of microwave dried beetroots

The highest rehydration ratio (5.04 ± 0.07) was obtained in microwave dried beetroots pretreated by FT0 (Fig. 3.19). The beetroots subjected to FT3 were characterized by the lowest rehydration ratio of 4.52 ± 0.08, indicating the most severe damage to the cell structure of beetroots.

Color is an important quality indicator of dried products, impacts the product's market value and consumer acceptance [159]. Effects of freeze-thaw cycles on the color parameters of microwave dried beetroots are displayed in Table 3.23. The brightness of microwave dried beetroots were found to be significantly higher than that of fresh beetroots ($p < 0.05$), indicating that beetroots became brighter after freeze-thaw pretreatment and drying. As can be observed in Table 3.23, the redness of microwave dried beetroots decreased with increasing freeze-thaw cycles, and was lower than that of fresh beetroots. It was found that the yellowness of beetroots were significantly lower than that of fresh beetroots ($p < 0.05$). The microwave dried beetroots with FT1 displayed the lowest yellowness of 0.79 ± 0.08.

The total color difference (ΔE) of microwave dried beetroots affected by freeze-thaw cycles were ranged from 11.18 ± 0.67 to 15.00 ± 0.55 compared to fresh beetroots. ΔE of microwave dried beetroots were increased with the increase of freeze-thaw cycles, and the microwave dried beetroots without freeze-thaw pretreatment (FT0) showed the lowest ΔE of 11.18 ± 0.67 and the microwave dried beetroots pretreated with FT3 presented the largest ΔE.

Table 3.23

Effects of freeze-thaw cycles on the color parameters of microwave dried beetroots

Freeze-thaw cycles	L	a	b	ΔE
Fresh sample	36.64 ± 0.42^{c}	28.16 ± 0.43^{a}	6.03 ± 0.30^{a}	-
FT0	40.72 ± 0.80^{b}	18.94 ± 0.60^{b}	1.25 ± 0.16^{b}	11.18 ± 0.67^{c}
FT1	42.70 ± 0.50^{a}	17.41 ± 0.70^{c}	0.79 ± 0.08^{d}	13.42 ± 0.67^{b}
FT2	41.09 ± 0.63^{b}	15.54 ± 0.68^{d}	1.17 ± 0.19^{bc}	14.24 ± 0.82^{a}
FT3	42.50 ± 0.83^{a}	15.31 ± 0.39^{d}	1.02 ± 0.07^{c}	15.00 ± 0.55^{a}

In order to better understand the effect of freeze-thaw cycles on the microstructures of microwave dried beetroots, the microstructures was observed by scanning electron microscope (SEM), and results are illustrated in Fig. 3.20.

As presented in Fig. 3.20, cell structures of microwave dried beetroots without pretreated (FT0) were relatively complete, and the cell walls were clearly visible. While the microwave dried beetroots after freeze-thaw pretreatment, the cell structure of the microwave dried beetroots ruptured and the tissue structure collapsed. This was due to the freeze-thaw process.

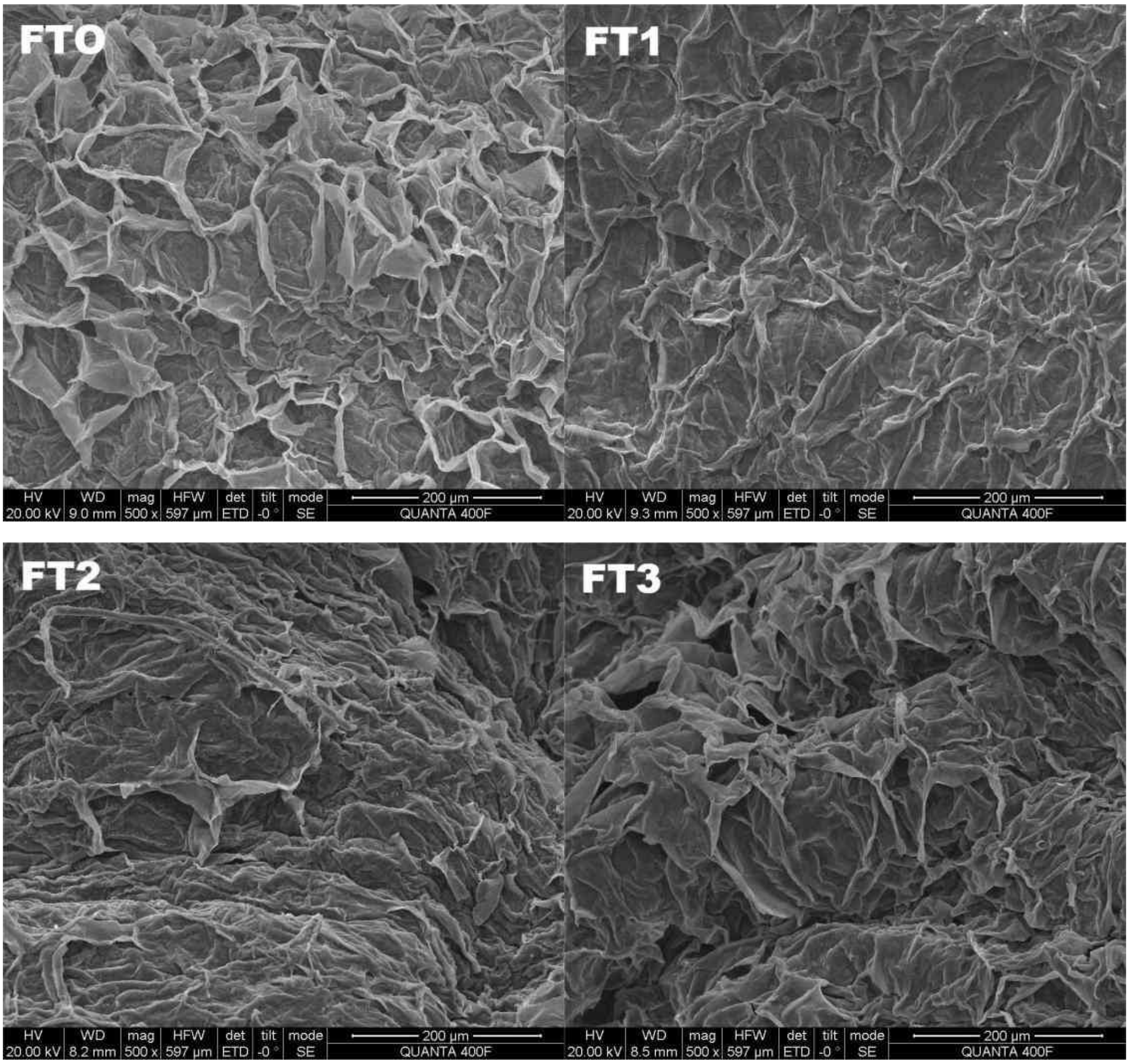


Fig. 3.20 Microstructures of microwave dried beetroots affected by freeze-thaw cycles

Effects of freeze-thaw cycles on the betalains content of microwave dried beetroots are presented in Fig. 3.21. As exhibited in Fig. 3.21, contents of betacyanins and betaxanthins decreased significantly with the increase of freeze-thaw cycles ($p < 0.05$).

The highest betacyanins content (2.81 ± 0.01 mg/g) and betaxanthins content (1.99 ± 0.01 mg/g) of microwave dried beetroots were appeared at FT0, while the lowest betacyanins content and betaxanthins content were observed at FT3.

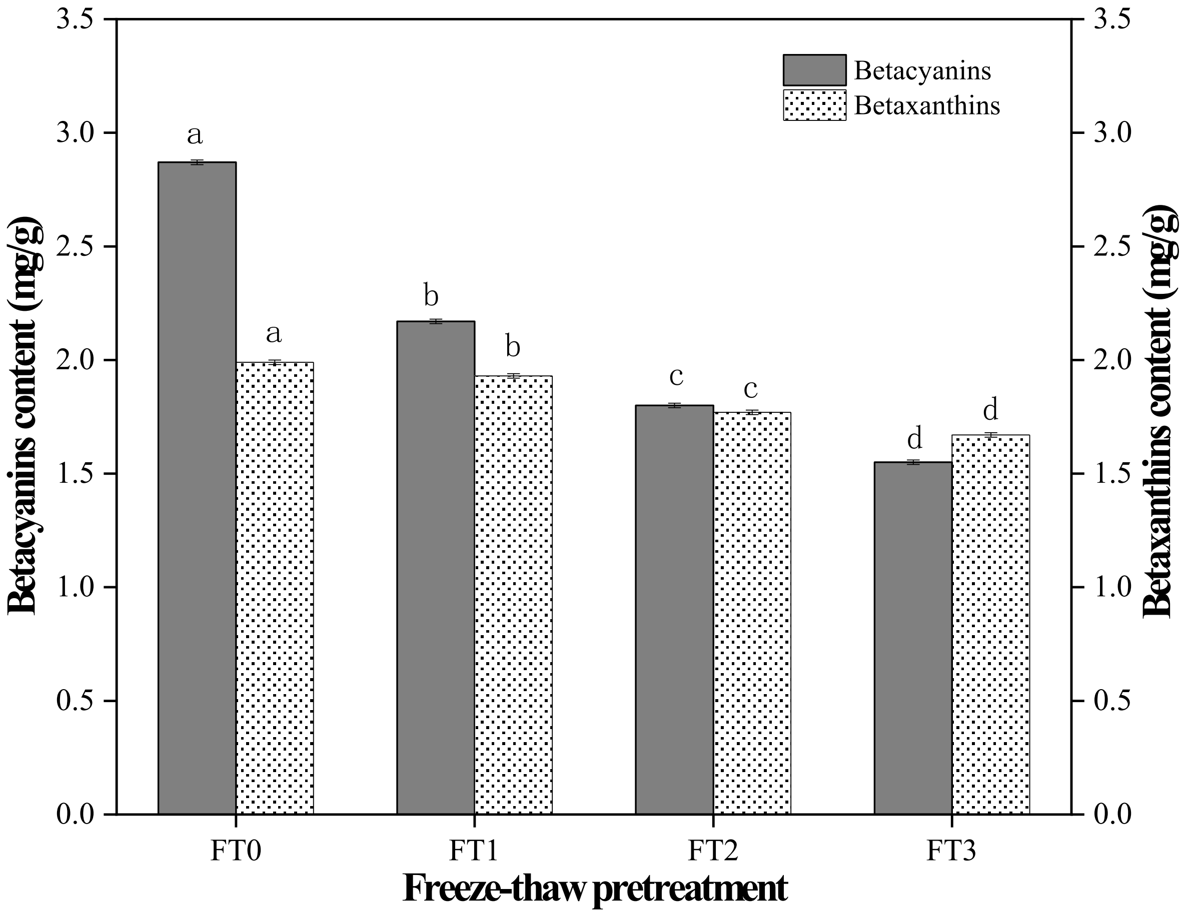


Fig. 3.21 Influence of freeze-thaw cycles on betalains content of microwave dried beetroots

The results of ascorbic acid, total phenolic and total flavonoids content of microwave dried beetroots as affected by freeze-thaw cycles are displayed in Table 3.24.

Table 3.24

Contents of ascorbic acid, total phenolic and total flavonoids of microwave dried beetroots as affected by freeze-thaw cycles

Freeze-thaw cycles	Ascorbic acid, mg/100g	Total phenolic, mg GAE/g	Total flavonoids, mg RE/g
FT0	750.78 ± 10.61^{a}	9.74 ± 0.09^{a}	19.58 ± 0.51^{a}
FT1	678.07 ± 19.02^{b}	8.13 ± 0.08^{b}	16.20 ± 0.19^{b}
FT2	571.63 ± 1.20^{c}	6.98 ± 0.08^{c}	14.22 ± 0.39^{c}
FT3	503.87± 11.37^{d}	6.54 ± 0.05^{d}	13.00 ± 0.48^{d}

It can be seen that freeze-thaw cycles significantly affected the ascorbic acid, total phenolic and total flavonoids content of microwave dried beetroots, and the contents of ascorbic acid, total phenolic and total flavonoids significantly decreased with the increase of freeze-thaw cycles ($p < 0.05$). The microwave dried beetroots without pretreated (FT0) illustrated the highest contents of ascorbic acid (750.78 ± 10.61 mg/100g), total phenolic (9.74 ± 0.09 mg GAE/g) and total flavonoids (19.58 ± 0.51 mg RE/g), while FT3 led to the lowest contents of ascorbic acid, total phenolic and total flavonoids.

As shown in Table 3.25, the microwave dried beetroots pretreated by FT1 displayed the highest DPPH radical scavenging activity of 6.86 ± 0.03 mg TE/g, while FT3 led to the lowest DPPH radical scavenging activity. FRAP value and ABTS radical scavenging activity decreased with increasing of freeze-thaw cycles. Meanwhile, the microwave dried beetroots without freeze-thaw pretreatment (FT0) showed the highest FRAP value (9.72 ± 0.09mg TE/g) and ABTS radical scavenging activity (15.01 ± 0.18 mg TE/g). This is because the antioxidant activity of beetroot is related to the content of bioactive compounds, as the content of bioactive compounds decreases with freeze-thaw cycles, the antioxidant activity of beetroots decrease at the same time.

Table 3.25

Influence of freeze-thaw cycles on the antioxidant activity of microwave dried beetroots

Freeze-thaw pretreatment	DPPH, mg TE/g	FRAP, mg TE/g	ABTS, mg TE/g
FT0	6.75 ± 0.02^{b}	9.72 ± 0.09^{a}	15.01 ± 0.18^{a}
FT1	6.86 ± 0.03^{a}	8.81 ± 0.07^{b}	14.28 ± 0.09^{b}
FT2	6.67 ± 0.02^{c}	7.92 ± 0.18^{c}	12.60 ± 0.09^{c}
FT3	6.29 ± 0.04^{d}	6.15 ± 0.21^{d}	11.27 ± 0.37^{d}

The quality properties of beetroots were significantly affected by freeze-thaw cycles. In terms of physical properties, with the increase of freeze-thaw cycles, the drying time and rehydration ratio decreased significantly, the microstructure was destroyed, and the total color difference also increased continuously compared with fresh beetroots. For bioactive compounds, contents of betalains, ascorbic acid, total phenolic and total flavonoids of microwave dried beetroots decreased with the increase of freeze-thaw cycles. The microwave dried beetroots pretreated by FT1 displayed the highest DPPH radical scavenging activity, while FRAP value and ABTS radical scavenging activity decreased with increasing of freeze-thaw cycles, and the microwave dried beetroots without freeze-thaw pretreatment (FT0) displayed the highest FRAP value and ABTS radical scavenging activity.

In comprehensive consideration, it is better to pretreat fresh beetroots by freeze-thaw once (FT1), which can not only shorten the drying time, but also better maintain the physical properties, bioactive compounds and antioxidant activity of beetroots.

3.2.2 Influence of freezing temperatures on quality attributes of heat pump dried beetroots

The freeze-thaw process consists of two stages: freezing the material and thawing the material. The ice crystals formed at different freezing temperatures have different sizes, and the degree of damage to cells is also different. The resulting ice crystals contain up to 99% solid water, and the size of the ice crystals has a considerable impact on the porosity and structure of the dried material [77]. Shock freezing stimulates the creation of a large number of little crystals, resulting in less cell damage, whereas slow freezing produces massive crystals, allowing the product to dry faster due to more intense water vapour movement [160]. In the study [161], the effect of freezing on bioaccessibility of bioactives find in beetroot during in vitro gastric digestion was investigated. It was found that although freezing caused a decrease in TPC and ascorbic acid (AA) in beetroots before in vitro digestion, but the release of TPC and AA was about 20% more in frozen beetroot than in raw samples, thus the bioaccessibility of these bioactives increased. It was concluded that in addition to extending the storage life, freezing can also effectively improve the bioavailability of bioactive substances in beetroots, and has great potential to be used as pretreatment to shorten the drying time of beetroots.

Therefore, this study aimed to investigate the influence of various freezing temperatures (–4, –20, –50, and –80 °C) before heat pump drying on the quality attributes of beetroots and to identify the optimal freezing temperatures required to achieve the best quality of beetroots.

3.2.2.1 Experimental conditions for different freezing temperatures and heat pump drying

Fresh beetroots were cut into slices with 3 mm in thicknesses and 7 mm in diameter, and packed in polyethylene bags and frozen at different freezing temperatures. The specific freezing conditions are as follows:

a. –4 °C: Fresh beetroot slices (800.0 ± 5.0 g) were placed in the refrigerator at –4 °C and frozen for 24 h.

b. –20 °C: Fresh beetroot slices (800.0 ± 5.0 g) were placed in the refrigerator at –20 °C and frozen for 12 h.

c. –50 °C: Fresh beetroot slices (800.0 ± 5.0 g) were frozen in ultra-low temperature refrigerator at –50 °C for 3 h.

d. –80 °C: Fresh beetroot slices (800.0 ± 5.0 g) were frozen in ultra-low temperature refrigerator at –80 °C for 1.5 h.

All the frozen beetroot slices were thawed with running water. When all the ice had melted, the thawing process were over.

Frozen-thawed beetroot slices were dried in a heat pump drier (L3.5AB, Guangdong IKE Industrial Co. Ltd, China) with drying temperature of 65 °C to the final moisture content under 6%.

Fresh beetroot slices (800.0 ± 5.0 g) were also were dried in the heat pump drying oven at 65 °C to the final moisture content below 6 % as the control group (CG).

3.2.2.2 Results and discussions on the influence of freezing temperatures on quality of dried beetroots

The thawing time, thawing loss rate, drying time and final moisture content of beetroots affected by freezing temperatures are displayed in Table 3.26. During the thawing process, the ice crystals melt, and the juice of the beetroot flowed out, causing a part of the weight of the beetroots to be lost. It can be seen from Table 3.26 that different freezing temperatures led to different thawing loss rates. The freezing temperature was –4 °C, the thawing loss rate of beetroots was the lowest (21.63 ± 0.15%), while the freezing temperature was –50 °C, the thawing loss rate was up to 36.02 ± 1.52%.

Table 3.26

Influence of different freezing temperatures on the thawing loss rate, drying time and final moisture content of beetroots

Freezing temperature, °C	Thawing loss rate, %	Drying time, h	Final moisture content, %
–4	21.63 ± 0.15^{d}	4.0 ± 0.0^{b}	5.04 ± 0.67^{a}
–20	32.52 ± 1.14^{b}	3.9 ± 0.3^{b}	5.06 ± 0.38^{a}
–50	36.02 ± 1.52^{a}	3.8 ± 0.3^{b}	5.31 ± 0.34^{a}
–80	25.16 ± 0.78^{c}	3.9 ± 0.3^{b}	5.51 ± 0.36^{a}
CG	-	5.3 ± 0.3^{a}	5.02 ± 0.63^{a}

Freeze-thaw pretreatment can increase the drying rate of beetroots, resulting in a reduction in drying time. Beetroots without freeze-thaw pretreatment (CG) required the longest drying time of 5.3 ± 0.3 h, while after freeze-thaw pretreatment, the drying time reduced significantly, and the drying time was shortened by about 26.4%. But there was no significant difference in drying time among the beetroots obtained at different freezing temperatures ($p > 0.05$).

The final moisture content of heat pump dried beetroots ranged from 5.02 ± 0.63 to 5.51 ± 0.36%, and different freezing temperatures had no significant effect on the final moisture content, indicating that the final moisture content had negligible effect on the quality attributes of heat pump dried beetroots.

Influence of different freezing temperatures on the hardness, rehydration ratio, shrinkage rate and apparent density of heat pump dried beetroots are illustrated in Table 3.27. As displayed in Table 3.27, freezing temperatures significantly affected ($p < 0.05$) the rehydration ratio of heat pump dried beetroots. The heat pump dried beetroots frozen at –20 °C showed the highest rehydration ratio of 6.88 ± 0.14, while the heat pump dried beetroots frozen at –80 °C illustrated the lowest rehydration ratio (5.20 ± 0.19).

Table 3.27

Effects of different freezing temperatures on the rehydration ratio, shrinkage rate, apparent density and hardness of heat pump dried beetroots

Freezing temperature, °C	Rehydration ratio	Shrinkage rate, %	Apparent density, g/mL	Hardness, g
–4	6.42 ± 0.08^{b}	93.68 ± 0.29^{c}	1.06 ± 0.04^{c}	1126.2 ± 106.6^{c}
–20	6.88 ± 0.14^{a}	95.78 ± 0.42^{b}	1.26 ± 0.07^{b}	973.1 ± 153.0^{d}
–50	6.19 ± 0.06^{c}	97.78 ± 0.21^{a}	1.65 ± 0.09^{a}	436.5 ± 70.8^{e}
–80	5.20 ± 0.19^{e}	95.17 ± 0.42^{b}	1.51 ± 0.14^{a}	1940.7 ± 180.7^{a}
CG	5.68 ± 0.16^{d}	90.54 ± 0.60^{d}	0.83 ± 0.07^{d}	1452.7 ± 98.6^{b}

During heat pump drying, the beetroot lost water and reduced its volume. The shrinkage rates of heat pump dried beetroots affected by different freezing temperatures are shown in Table 3.27. It can be seen that freeze-thaw pretreatment can significantly improved the shrinkage rate of heat pump dried beetroots compared with CG ($p < 0.05$). The heat pump dried beetroots frozen at –50 °C displayed the largest shrinkage rate of 97.78 ± 0.21%. Freeze-thaw pretreatment significantly increased the apparent density of heat pump dried beetroots in comparison with that of the CG ($p < 0.05$). Freezing temperature of –50 °C led to the highest apparent density (1.65 ± 0.09 g/mL). There was no significant difference in apparent density among the heat pump dried beetroots frozen at –50 °C and –80 °C. The hardness of heat pump dried beetroots was significantly affected by freezing temperatures ($p < 0.05$). The heat pump dried beetroots frozen at –50 °C showed the lowest hardness of 436.5 ± 70.8 g, while freezing temperature of –80 °C resulted in the highest hardness of 1940.7 ± 180.7 g.

The microstructure of heat pump dried beetroots can be seen in Fig. 3.22. The cell structures of heat pump dried beetroots without freeze-thaw pretreatment (CG) was complete and clear, and the cell wall was clearly visible. Freeze-thaw pretreatment at different freezing temperatures resulted in cell wall rupture and severe loss cell structures of beetroots.

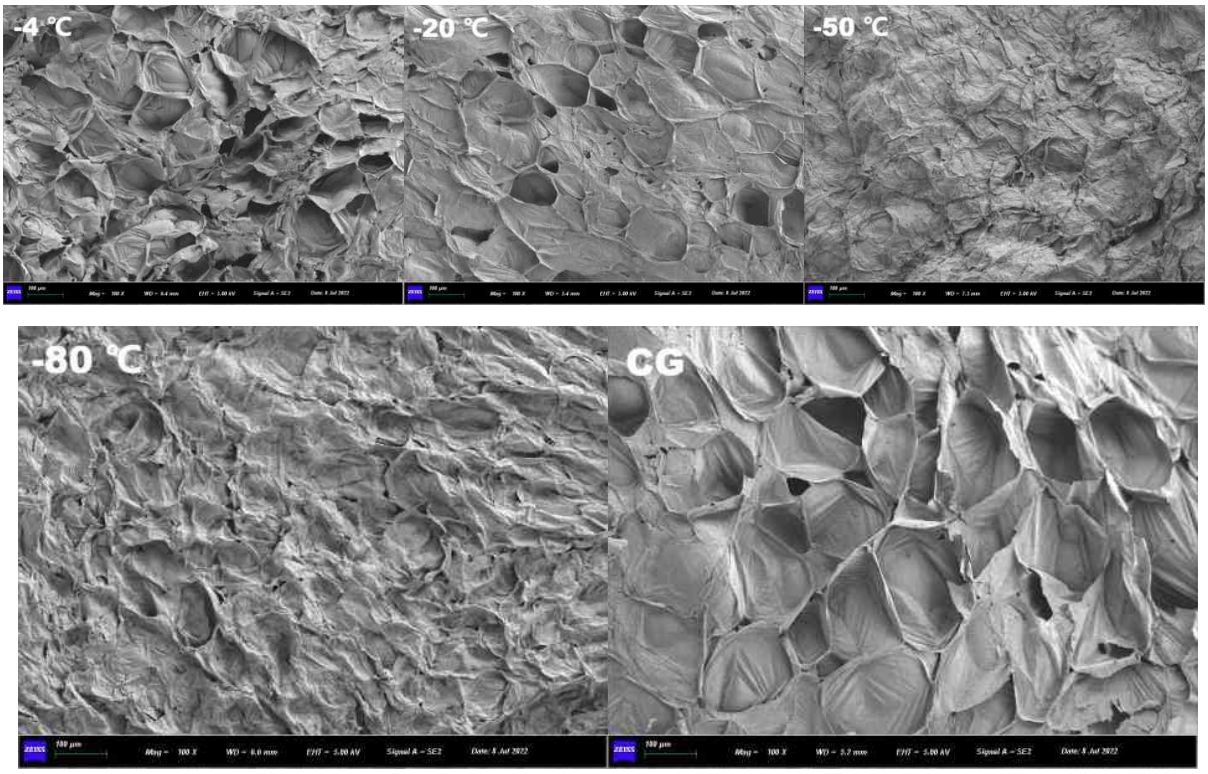


Fig. 3.22 Influence of different freezing temperatures on the microrphology (100 ×) of beetroots

The color characteristics of heat pump dried beetroots are displayed in Table 3.28. Compared with fresh beetroots (L = 27.62 ± 1.02 , a = 18.82 ± 0.75, b = 2.45 ± 0.31), heat pump dried beetroots showed higher values of L and a, indicating beetroots after drying became more brightness and redness.

The heat pump dried beetroots frozen at –50 °C had the highest *L* value of 44.20 ± 1.09, while the heat pump dried beetroots frozen at –80 °C showed the lowest *L* value of 38.38 ± 1.59. The heat pump dried beetroots without freeze-thaw pretreatment (CG) showed the highest *a* value of 28.94 ± 1.28. and *a* values of the heat pump dried beetroots frozen by different freezing temperatures significantly lower than that of CG. Freezing temperature of –50 °C led to the lowest *b* value of 0.75 ± 0.06. The *b* values of heat pump dried beetroots after freeze-thaw pretreatment were significantly lower compared with that of CG ($p < 0.05$).

Compared to CG, freeze-thaw pretreatment significantly decreased the ΔE values of heat pump dried beetroots. Heat pump dried beetroots frozen at –80 °C showed the lowest ΔE of 11.47 ± 1.24, and there was no significant difference in ΔE values among the heat pump dried beetroots frozen at –4, –20, and –80 °C ($p > 0.05$).

Table 3.28

Color parameters of heat pump dried beetroots as affected by different freezing temperatures

Color parameters	Freezing temperature, °C				
	–4	–20	–50	–80	CG
L	39.90 ±1.02^{bc}	40.47 ± 0.95^{b}	44.20 ± 1.09^{a}	38.38 ± 0.59^{c}	43.76 ± 1.09^{a}
a	22.29 ± 0.53^{c}	22.69 ± 0.62^{c}	24.86 ± 0.40^{b}	24.19 ± 0.71^{b}	28.94 ± 1.28^{a}
b	1.04 ± 0.15^{c}	1.03 ± 0.13^{c}	0.75 ± 0.06^{d}	1.99 ± 0.23^{b}	2.51 ± 0.28^{a}
ΔE	12.03 ± 0.86^{c}	13.27 ± 0.81^{c}	17.33 ± 0.94^{b}	11.47 ± 1.24^{c}	19.12 ± 0.33^{a}

Beetroots are rich in betalains, which are water soluble nitrogen-containing pigments, containing betalamic acid as a chromophore, depending upon the nature of the betalamic acid residue. Betalains can be classified as either betacyanins (red/violet coloration) or betaxanthins (yellow/orange coloration) [162]. The effects of freezing temperatures on the betalains content of heat pump dried beetroots are illustrated in Table 3.29. The heat pump dried beetroots frozen at different freezing temperatures showed significantly lower betalains content in comparison with that of CG. As displayed in Table 3.29, betacyanins content and betaxanthins content with the same trend of change, both showed the highest values in CG. After freeze-thaw pretreatment, the betacyanins content and betaxanthins content of heat pump dried beetroots were significantly reduced ($p < 0.05$), so the CG showed the highest betacyanins content (3.31 ± 0.02 mg/g) and betaxanthins content (1.98 ± 0.01 mg/g). The freezing temperature of –50 °C led to the lowest betalains content in heat pump dried beetroots.

Table 3.29

Effects of different freezing temperatures on the betalains content of heat pump dried beetroots

Freezing temperature, °C	Betacyanins, mg/g	Betaxanthins, mg/g
–4	2.82 ± 0.01^{b}	1.60 ± 0.01^{b}
–20	2.73 ± 0.01^{c}	1.55 ± 0.01^{c}
–50	2.46 ± 0.01^{e}	1.35 ± 0.00^{e}
–80	2.59 ± 0.01^{d}	1.42 ± 0.01^{d}
CG	3.31 ± 0.02^{a}	1.98 ± 0.01^{a}

The effects of freezing temperatures on the contents of ascorbic acid, total phenolic, and total flavonoids in heat pump dried beetroots are presented in Table 3.30.

Table 3.30

Influence of freezing temperatures on the contents of ascorbic acid, total phenolic, and total flavonoids in heat pump dried beetroots

Freezing temperature, °C	Ascorbic acid, mg/100g	Total phenolic, mg GAE/g	Total flavonoids, mg RE/g
–4	258.3 ± 3.8^{bc}	7.54 ± 0.21^{a}	10.90 ± 0.41^{ab}
–20	251.6 ± 5.2^{c}	7.45 ± 0.19^{a}	10.26 ± 0.22^{c}

continuation of Table 3.30

–50	239.1 ± 4.0^{d}	6.95 ± 0.21^{b}	9.94 ± 0.16^{d}
–80	249.3 ± 4.2^{c}	6.69 ± 0.12^{c}	10.60 ± 0.18^{b}
CG	287.7 ± 8.8^{a}	7.78 ± 0.24^{a}	11.15 ± 0.21^{a}

It can be found that freeze-thaw pretreatment decreased the contents of ascorbic acid, total phenolic, and total flavonoids in heat pump dried beetroots, indicating that freeze-thaw pretreatment was not conducive to the preservation of ascorbic acid, total phenolic, and total flavonoids in heat pump dried beetroots. The heat pump dried beetroots frozen at –50 °C showed the lowest ascorbic acid content (239.1 ± 4.0 mg/100g) and total flavonoids content (9.94 ± 0.16 mg RE/g), while the heat pump dried beetroots frozen at –80 °C showed the lowest total phenolic content of 6.69 ± 0.12 mg GAE/g.

The influence of freezing temperatures on the antioxidant activity of heat pump dried beetroots is displayed in Table 3.31. The antioxidant activity of heat pump dried beetroots frozen at different freezing temperatures showed lower antioxidant activity compared to those of CG, so the CG showed the highest DPPH radical scavenging activity, ABTS radical scavenging activity, and FRAP value. The heat pump dried beetroots frozen at –50 °C showed the lowest DPPH radical scavenging activity, FRAP value, and ABTS radical scavenging activity.

Table 3.31

Influence of freezing temperatures on the antioxidant activity of heat pump dried beetroots

Freezing temperatures, °C	DPPH, mg TE/g	FRAP, mg TE/g	ABTS, mg TE/g
–4	6.53 ± 0.14^{b}	10.27 ± 0.22^{a}	17.94 ± 0.49^{ab}
–20	6.43 ± 0.11^{b}	9.89 ± 0.34^{b}	17.69 ± 0.44^{b}
–50	5.59 ± 0.15^{d}	9.06 ± 0.30^{c}	16.07 ± 0.64^{c}
–80	5.99 ± 0.13^{c}	9.83 ± 0.41^{b}	17.61 ± 0.41^{b}
CG	7.01 ± 0.14^{a}	10.67 ± 0.44^{a}	18.54 ± 0.60^{a}

The beetroots were frozen at different freezing temperatures and then thawed. After that, all beetroots were dried by heat pump drying oven. The physical properties, bioactive compounds and antioxidant activity of heat pump dried beetroots were evaluated. The following conclusions were drawn:

Different freezing temperatures had significant effects on thawing loss rate, rehydration ratio, shrinkage rate, apparent density, hardness, and color parameters of heat pump dried beetroots. There was no significant difference in drying time and final moisture content of heat pump dried beetroots frozen at different freezing temperatures. Freeze-thaw pretreatment resulted in cell wall rupture and severe loss of beetroots cell structures.

Freeze-thaw pretreatment led to lower bioactive compounds in heat pump dried beetroots than those of CG. The heat pump dried beetroots frozen at –50 °C showed the lowest content of betacyanins, betaxanthins, ascorbic acid, and total flavonoids.

After freeze-thaw pretreatment at different freezing temperatures, the antioxidant activity of heat pump dried beetroots decreased compared with that of CG. The heat pump dried beetroots frozen at –50 °C demonstrated the lowest DPPH radical scavenging activity, FRAP value, and ABTS radical scavenging activity.

Considering the freezing time, physical properties, bioactive compounds, and antioxidant capacity of beetroots, it is considered that –20 °C was an economical and appropriate freezing temperature for fresh beetroots.

3.2.3 Influence of thawing methods on quality attributes of microwave dried beetroots

Freeze-thaw is a widely used pretreatment in foodstuffs. It has been demonstrated that freeze-thaw treatment can significantly shorten the drying time of agriculture products by forming ice crystals, which can cause cell separation and promote water migration during the drying process [61, 163].

Thawing is the opposite process to freezing, which aim is to maintain the original food quality as much as possible [60]. The thawing methods of water refrigerator, and air are usually adopted for food thawing [164]. Water thawing is a simple, easy and inexpensive method that involves placing frozen products in a container filled with water to absorb heat [60]. Refrigerator thawing is conducive to reducing food quality losses during production [165]. Air thawing as one of the simplest thawing methods, is based on the fact that the air temperature is higher than the temperature of the frozen product, thereby transferring heat to the frozen product to thaw it [166]. Through the rupture of cavitation bubbles, ultrasonic thawing transforms acoustic energy into thermal energy. Thermal energy speeds up the phase transition from ice to water, reducing thawing time and ensuring more uniform thawing of frozen food [167]. In the paper [168], freeze-thaw pretreatment was used to prepare hot-air drying of cooked-potato flour. Five thawing methods including air thawing (25 °C), running water thawing (25 °C), refrigerator thawing (4 °C), ultrasonic thawing, and microwave thawing were used. The results indicated that running water thawing required the largest drying rate, reduced total energy consumption by up to 32.9%, and freeze-thaw pretreatment was effective to lower drying time of potato flour, and lower energy consumption.

To the best of our knowledge, the effects of thawing methods on the microwave drying of beetroots have not been studied yet. Thawing methods have a potential impact on the quality of products. Consequently, this study investigated the effect of thawing methods, including air thawing, water thawing, ultrasonic thawing, microwave thawing, and refrigerator thawing, on the the quality characteristics of microwave dried beetroots.

3.2.3.1 Experimental conditions for thawing methods and microwave drying

Freezing treatment: Fresh beetroots were washed with tap water, peeled, cut into slices with thickness of 3 mm and diameter of 7.5 cm, and packed them in polyethylene plastic bags (each bag was 300.0 ± 3.0 g) and sealed. The sealed beetroot slices were frozen at –20 °C for 12 h. The frozen beetroot slices were thawed in different methods. The thawing methods are as follows:

Microwave thawing: Microwave thawing using a microwave oven at microwave power of 140 W. The thawing process was stopped when the beetroots were soft and the ice slush was gone.

Water thawing: The frozen beetroot slices were thawed with running tap water. The tap water temperature was 23 °C. Stopped thawing when the beetroots were soft and the ice slush was gone.

Air thawing: The frozen beetroot slices were thawed on the test table to thaw directly. The room temperature was 25 °C. Stopped thawing when the beetroots were soft and the ice slush was gone.

Refrigerator thawing: Put the frozen beetroot slices in the refrigerator to thaw at 4 °C. Stopped thawing when the beetroots were soft and the ice slush was gone.

Ultrasonic thawing: Put the frozen beetroot slices in an ultrasonic cleaning machine and thawed with an ultrasonic power of 200 W. Stopped thawing when the beetroots were soft and the ice slush was gone.

Microwave drying: The frozen-thawed beetroot slices were dried by a microwave drying system at microwave power of 360 W. When the moisture content of beetroot slices were less than 6%, the drying process stopped.

3.2.3.2 Results and discussions on the influence of freezing temperatures on quality attributes of dried beetroots

Effects of different thawing methods on the thawing time, drying time, and rehydration ratio of microwave dried beetroots are illustrated in Table 3.32. Different thawing methods had significant differences in thawing time ($p < 0.05$). Refrigerator thawing showed the longest thawing time of 364.0 ± 3.5 min, while microwave thawing required the shortest thawing time (7.3 ± 0.6 min). Although the thawing time was different, but the microwave drying time of beetroots with different thawing methods was not significantly different, indicating that different thawing methods had no significant effect on the drying time. Different thawing methods had significantly different effects on the rehydration ratio of microwave dried beetroots. The microwave dried beetroots obtained from refrigerator thawing showed the highest rehydration ratio of 4.85 ± 0.10, while air thawing led to the lowest rehydration ratio (4.23 ± 0.05). Moreover, no significant difference in rehydration ratio of microwave dried beetroots obtained from water thawing and ultrasonic thawing.

Table 3.32

Effects of thawing methods on the thawing time, drying time, and rehydration ratio of microwave dried beetroots

Thawing methods	Thawing time, min	Drying time, min	Rehydration ratio
Microwave thawing	7.3 ± 0.6[d]	39.7 ± 0.6[a]	4.67 ± 0.09[b]
Water thawing	18.0 ± 0.0[c]	39.0 ± 0.0[a]	4.59 ± 0.07[c]
Air thawing	102.3 ± 2.5[b]	38.3 ± 1.2[a]	4.23 ± 0.05[d]
Refrigerator thawing	364.0 ± 3.5[a]	39.3 ± 0.6[a]	4.85 ± 0.10[a]
Ultrasonic thawing	19.3 ± 1.2[c]	37.0 ± 1.7[a]	4.58 ± 0.08[c]

The effect of different thawing methods on the color parameters of microwave dried beetroots is displayed in Table 3.33.

Table 3.33

Influence of thawing methods on the color characteristics of microwave dried beetroots

Thawing methods	L	a	b	ΔE
Microwave thawing	43.03 ± 0.20[a]	19.85 ± 0.39[b]	3.41 ± 0.16[b]	29.22 ± 2.79[b]
Water thawing	39.51 ± 0.36[d]	17.90 ± 0.64[d]	2.80 ± 0.23[d]	16.01 ± 2.02[d]
Air thawing	42.30 ± 0.17[b]	20.89 ± 0.20[a]	5.23 ± 0.11[a]	43.23 ± 2.78[a]
Refrigerator thawing	41.69 ± 0.27[c]	19.72 ± 0.93[b]	3.23 ± 0.08[c]	26.61 ± 1.18[c]
Ultrasonic thawing	41.25 ± 0.50[c]	19.60 ± 0.19[c]	2.51 ± 0.10[e]	24.90 ± 1.00[c]
Fresh beetroots	25.90 ± 0.47[e]	16.52 ± 0.68[e]	2.47 ± 0.19[e]	-

The L values of microwave dried beetroots were significantly higher than that of fresh beetroots, indicating that the beetroots became brighter after microwave drying. Different thawing methods had different effects on the L values of the microwave dried beetroots. Meanwhile, microwave dried beetroots obtained using microwave thawing demonstrated the highest L value of 43.03 ± 0.20. Compared with fresh beetroots, a values of microwave dried beetroots obtained from different thawing methods increased, demonstrating that the microwave dried beetroots became redder. The microwave dried beetroots obtained from water thawing illustrated the highest a value (20.89 ± 0.20). The microwave dried beetroots obtained from different thawing methods exhibited higher b values in comparison with fresh beetroots. Besides, the highest b value (5.23 ± 0.11) appeared in the microwave dried beetroots thawed by water. Different thawing methods had significant effects on ΔE of microwave dried beetroots. It can be seen from Table 3.33 that water thawing resulted in the lowest ΔE (16.01 ± 2.02) of microwave dried beetroots, while air thawing led to the biggest ΔE of microwave dried beetroots. As a result, water thawing can better preserve the color of beetroots.

Results of bioactive compounds of microwave dried beetroots affected by thawing methods are presented in Table 3.34.

Table 3.34

Contents of betalains, total phenolic, and total flavonoids of microwave dried beetroots affected by thawing methods

Thawing methods	Betacyanins, mg/g	Betaxanthins, mg/g	Total phenolic, mg GAE/g	Total flavonoids, mg RE/g
Microwave thawing	2.04 ± 0.02^{c}	2.02 ± 0.01^{a}	6.06 ± 0.11^{e}	13.86 ± 0.23^{d}
Water thawing	2.20 ± 0.01^{b}	1.97 ± 0.01^{b}	8.15 ± 0.12^{a}	16.50 ± 0.40^{a}
Air thawing	2.01 ± 0.01^{c}	1.96 ± 0.01^{b}	7.40 ± 0.10^{c}	14.38 ± 0.15^{c}
Refrigerator thawing	2.20 ± 0.02^{b}	1.96 ± 0.00^{b}	7.91 ± 0.10^{b}	15.15 ± 0.26^{b}
Ultrasonic thawing	2.28 ± 0.05^{a}	1.94 ± 0.01^{b}	6.52 ± 0.08^{d}	16.59 ± 0.28^{a}

It can be found that the microwave dried beetroots obtained from ultrasonic thawing showed the highest betacyanins content of 2.28 ± 0.05 mg/g. Meanwhile, the microwave dried beetroots obtained from microwave thawing displayed the highest betaxanthins content (2.02 ± 0.01 mg/g), which was significantly higher than microwave dried beetroots obtained by other thawing methods ($p < 0.05$). There was no significant difference in betaxanthins content among the microwave dried beetroots obtained from water thawing, air thawing, refrigerator thawing, and ultrasonic thawing ($p > 0.05$).

As shown in Table 3.34, different thawing methods had significant effects on the total phenolic content of microwave dried beetroots. The microwave dried beetroots obtained from water thawing showed the highest total phenolic content of 8.15 ± 0.12 mg GAE/g, while the microwave dried beetroots obtained from microwave thawing displayed the lowest total phenolic content of 6.06 ± 0.11 mg GAE/g. There was no significant difference in total flavonoids content between the microwave dried beetroots obtained from water thawing and ultrasonic thawing, but all significantly higher than those of microwave dried beetroots obtained from other thawing methods ($p < 0.05$). Moreover, microwave thawing led to the lowest total flavonoids content of microwave dried beetroots.

Results of the effect of thawing methods on the antioxidant activity of microwave dried beetroots are shown in Table 3.35.

Table 3.35

Influence of thawing methods on the antioxidant activity of microwave dried beetroots

Thawing methods	DPPH, mg TE/g	FRAP, mg TE/g	ABTS, mg TE/g
Microwave thawing	3.21 ± 0.02^{b}	10.21 ± 0.26^{c}	12.92 ± 0.09^{d}
Water thawing	3.04 ± 0.01^{c}	13.83 ± 0.25^{a}	13.97 ± 0.18^{a}
Air thawing	3.38 ± 0.03^{a}	12.53 ± 0.22^{b}	12.31 ± 0.09^{e}
Refrigerator thawing	3.20 ± 0.01^{b}	10.08 ± 0.22^{c}	13.20 ± 0.13^{c}
Ultrasonic thawing	2.88 ± 0.01^{d}	10.48 ± 0.16^{c}	13.58 ± 0.11^{b}

As presented in Table 3.35, different thawing methods had different effects on the DPPH radical scavenging activity, FRAP value and ABTS radical scavenging activity of microwave dried beetroots. Different thawing methods significantly affected the DPPH radical scavenging activity of microwave dried beetroots, and the microwave dried beetroots obtained by air thawing showed the highest DPPH radical scavenging activity of 3.38 ± 0.03 mg TE/g, while ultrasonic thawing led to the worst DPPH radical scavenging activity (2.88 ± 0.01 mg TE/g).

Meanwhile, the microwave dried beetroots obtained from water thawing illustrated the biggest FRAP value of 13.83 ± 0.25 mg TE/g. Besides, there was no significant difference in FRAP values among the microwave dried beetroots obtained from microwave thawing, refrigerator thawing, and ultrasonic thawing ($p > 0.05$). In terms of ABTS radical scavenging activity, the highest value was 13.97 ± 0.18 mg TE/g in the microwave dried beetroots obtained from water thawing, and the microwave dried beetroots obtained from air thawing displayed the lowest value of 12.31 ± 0.09 mg TE/g. Furthermore, different thawing methods significantly affected ABTS radical scavenging activity of microwave dried beetroots ($p < 0.05$).

The thawing time was obviously different, the thawing time of refrigerator thawing was the longest, and the thawing time of microwave thawing was the shortest, but there is no significant difference in microwave drying time ($p > 0.05$). In addition, the microwave dried beetroots obtained from refrigerator thawing had the largest rehydration ratio of 4.85 ± 0.10, while air thawing resulted in the smallest rehydration ratio. Compared with other thawing methods, water thawing can better preserve the color of beetroots.

In terms of bioactive compounds, the highest content of betacyanins appeared in the microwave dried beetroots obtained from ultrasonic thawing, and the microwave dried beetroots obtained from microwave thawing illustrated the largest betaxanthins content of 2.02 ± 0.01 mg/g, and the highest total phenolic content to be appeared in the microwave dried beetroots obtained from water thawing. Furthermore, the microwave dried beetroots obtained from ultrasonic thawing presented the largest total flavonoids content of 16.59 ± 0.28 mg RE/g.

For antioxidant activity, thawing methods had different effects on the DPPH radical scavenging activity, FRAP value, and ABTS radical scavenging activity of microwave dried beetroots. The microwave dried beetroots obtained from water thawing displayed higher FRAP value and ABTS radical scavenging activity than those of microwave dried beetroots obtained from other thawing methods.

Comprehensive consideration of physical properties, bioactive compounds and antioxidant activity of beetroots, water thawing is a more suitable way to thaw frozen beetroot.

3.2.4 Influence of drying methods on quality attributes of frozen-thawed beetroots

Dehydration of thermo-sensitive materials is a highly complex process that involves the mechanisms of heat and mass transfer, and the drying methods and drying parameters used frequently cause significant changes in physical, organoleptic, biological, and chemical properties of materials, including its color, texture, aroma, vitamins, and phenolic compounds [169].

Freeze-thaw treatment prior to drying can improve the drying rate, reduce the drying time of agricultural products. The purpose was to evaluate the influence of six drying methods (microwave drying, microwave vacuum drying, freeze drying, vacuum drying, hot air drying, and sun drying) on the quality properties of freeze-thaw pretreated beetroots.

3.2.4.1 Experimental conditions for different drying methods

Before experiments, fresh beetroots were washed with tap water to remove surface impurities, peeled and then sliced crosswise into slices 7.5 cm in diameter and 4 mm in thickness using a stainless steel slicer.

Freeze-thaw pretreatment: Fresh beetroot slices were put into polyethylene bags, put them in the refrigerator (–20 °C) to freeze for 12 h, then thawed them in the refrigerator (4 °C) for 12 h.

In this study, different drying methods were designed and analyzed. Freeze-thaw pretreated beetroot slices were subjected to different drying methods as below:

Microwave drying (MD): Freeze-thaw pretreated beetroots (300.0 ± 2.0 g) were put into on a circular fiberglass tray (diameter-30 cm) of microwave drying system. The microwave power was set at 650 W and the time interval of beetroots weighing was 4 min.

Microwave vacuum drying (MVD): Freeze-thaw pretreated beetroots (900.0 ± 2.0 g) were placed uniformly on a tray of microwave vacuum dryer. The vacuum degree was –90 kPa. The microwave vacuum drying was conducted at microwave power of 1000 W. After drying for 45 min, the microwave power was switched to 500 W to continue drying.

Freeze drying (FD): Freeze-thaw pretreated beetroots (300.0 ± 2.0 g) were frozen at –20 °C for 12 h and then placed on the cavity in the freeze dryer at temperature of –80 °C and vacuum degree of 4 Pa.

Vacuum drying (VD): Freeze-thaw pretreated beetroots (300.0 ± 2.0 g) were spread evenly on a tray of vacuum drying oven. The vacuum drying conditions were temperature of 60 °C and vacuum degree of –95 kPa.

Hot air drying (HAD): Freeze-thaw pretreated beetroots (300.0 ± 2.0 g) were spread evenly in a tray of hot air tray dryer. The temperature was set at 60 °C.

Sun drying (SD): Freeze-thaw pretreated beetroots (300.0 ± 2.0 g) were placed on a tray and dried in the sun from 8 am to 6 pm. The temperature was in the range of 30 °C to 35 °C.

All drying process stopped as the final moisture content of beetroots was below 7.00%.

3.2.4.2 Results and discussions on the influence of drying methods on quality attributes of frozen-thawed beetroots

The drying time and final moisture content of freeze-thaw pretreated beetroots are displayed in Fig. 3.23. It is well known that moisture content is critical to the quality control and stability of dried products. According to the results, the final moisture content of freeze-thaw pretreated beetroots subjected to different drying methods ranged from 5.62 ± 1.00 to 6.05 ± 0.41%. As shown in Fig. 3.23, no significant difference was appeared in the final moisture content of freeze-thaw pretreated beetroots obtained by different drying methods ($p > 0.05$), indicting that the influence of moisture content on the physicochemical properties of dried beetroots could be neglected. FD required the longest drying time to dry fresh beetroots to the final moisture content (below 7.00%) of 1340.0 ± 34.6 min. MD and MVD showed faster drying rates than FD, SD, HAD, and VD, so shorter drying time were required, but there was no significant difference in drying time between MD and MVD. At the same time, drying time of VD and HAD was also not significantly different ($p > 0.05$). The drying time of MD was reduced by 96.90% compared to FD, which was only 11.86% of HAD, 11.21% of VD, and 7.28% of SD. The drying time required by MVD was about 5.25% that of FD, and reduced up to 87.67%, 81.0%, and 79.91% in comparison with SD, VD, and HAD, respectively.

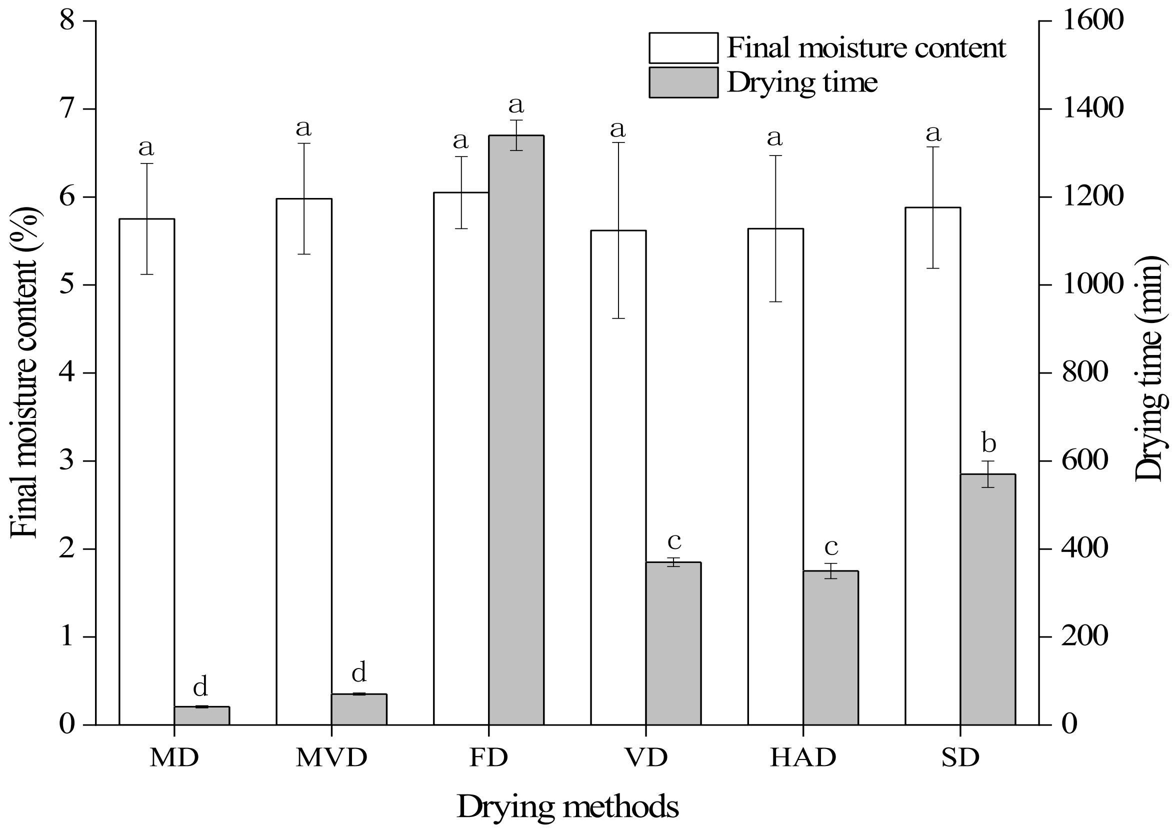


Fig. 3.23 Effects of different drying methods on drying time and final moisture content of freeze-thaw pretreated beetroots

The shrinkage rate and rehydration ratio of freeze-thaw pretreated beetroots affected by different drying methods are presented in Fig. 3.24. The shrinkage rates of freeze-thaw pretreated beetroots dried by different drying methods ranged from 74.32 ± 1.72 to 92.27 ± 1.04%. The freeze-thaw pretreated beetroots subjected to FD illustrated the smallest shrinkage rate, indicating minimal volume change compared to fresh sample. The largest shrinkage rate of freeze-thaw pretreated beetroots obtained by VD was 92.27 ± 1.04%. However, there was no significant difference in shrinkage rates among the freeze-thaw pretreated beetroots subjected to VD, MD, HAD, and SD ($p > 0.05$).

The drying process usually causes irreversible changes in the structure of material and limits its return to its original shape. Rehydration rato is a major quality parameter that can indicate the ability of material to retain its original shape, and can be used to reflect the extent of damage to cellular material during drying process [170].

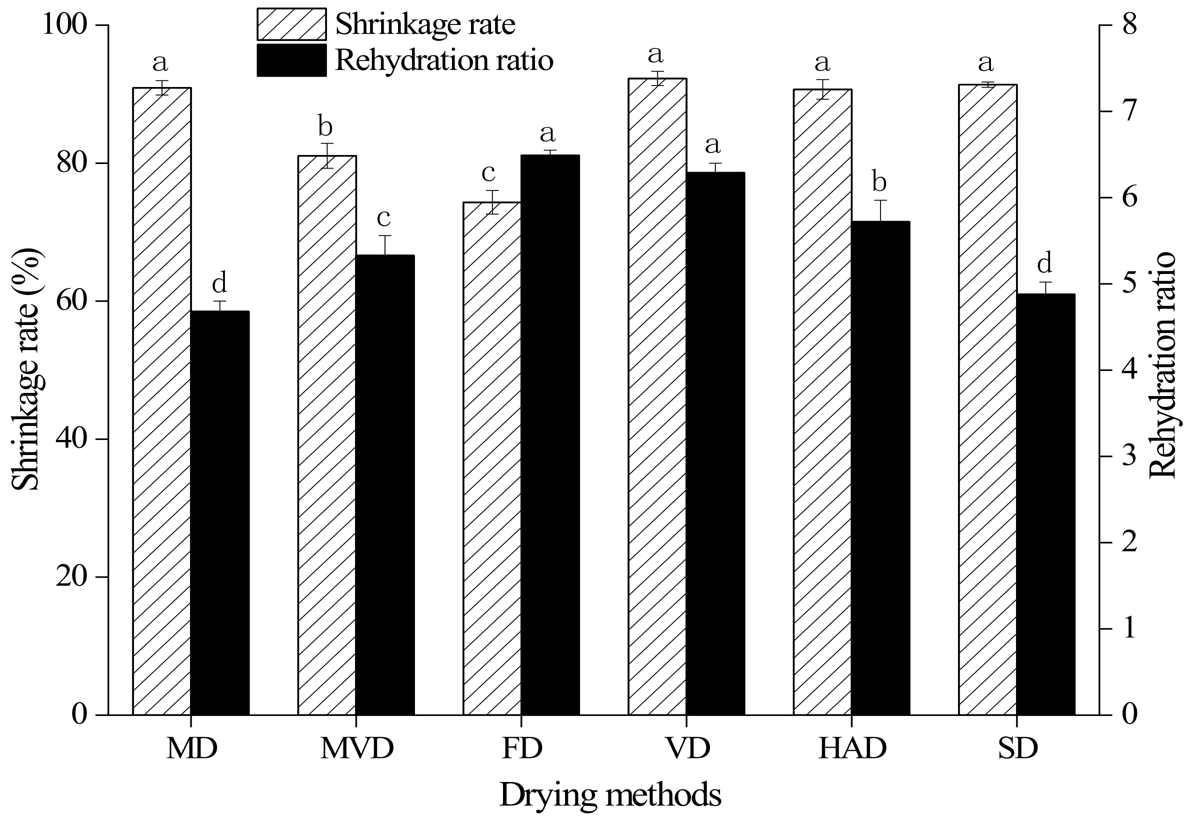


Fig. 3.24 Effects of different drying methods on shrinkage rate and rehydration ratio of freeze-thaw pretreated beetroots

It can be observed from Fig. 3.24 that rehydration ratio of freeze-thaw pretreated beetroots subjected to different drying methods ranged from 4.68 ± 0.12 to 6.49 ± 0.06. FD led to the highest rehydration ratio (6.49 ± 0.06) of freeze-thaw pretreated beetroots, while the difference was not statistically significant ($p > 0.05$) in rehydration ratio of freeze-thaw pretreated beetroots dried by FD and VD. VD resulted in high rehydration ratio of freeze-thaw pretreated beetroots can be explained by the relatively small degree of damage to the cell walls, and the damage to the tissue structure during VD process was confirmed by macroscopic characteristics, including shrinkage or rehydration [171–172]. Meanwhile, rehydration ratio of freeze-thaw pretreated beetroots obtained from MD and SD were significantly lower than that of other drying methods, indicating that MD and SD had greater damage to the cell structure of freeze-thaw pretreated beetroots.

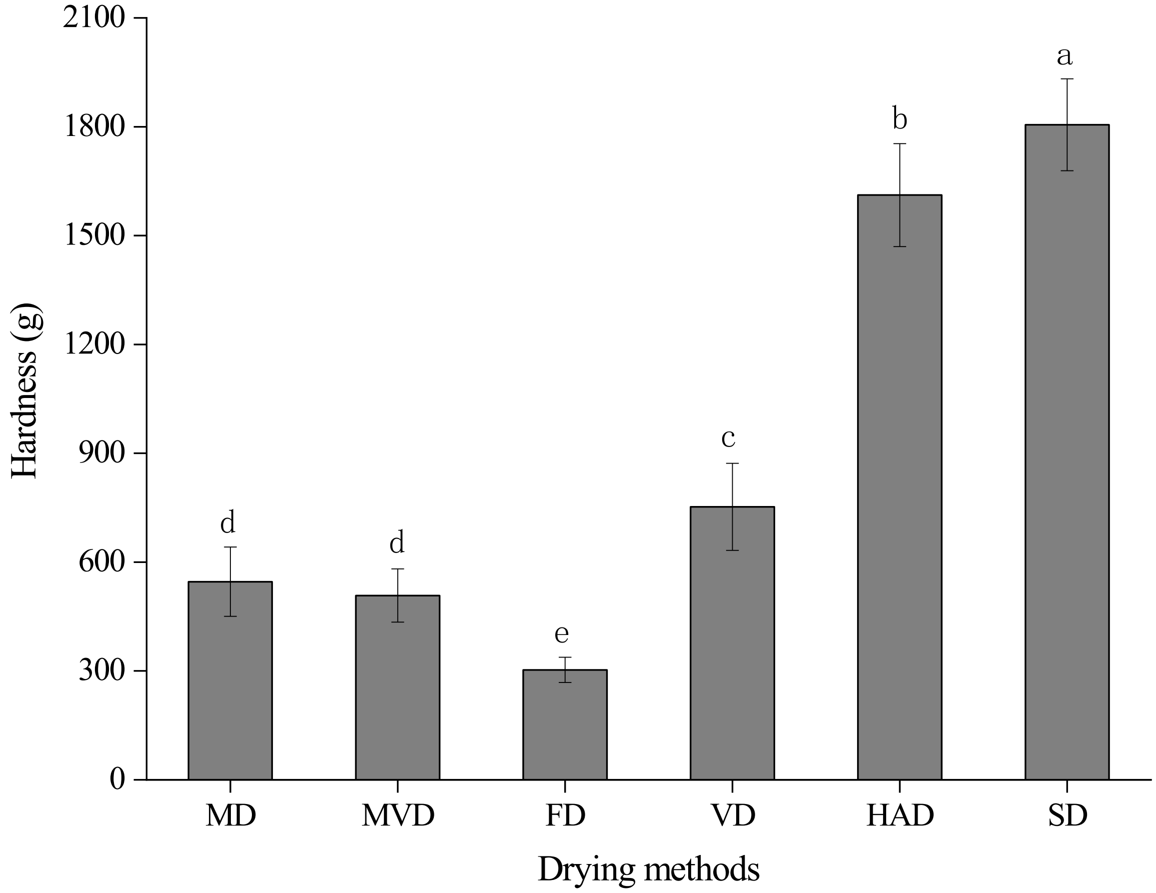


Fig. 3.25 Effects of different drying methods on hardness of freeze-thaw pretreated beetroots

Texture is a significant quality characteristic affecting the acceptability of food and is assessed by hardness. The influence of different drying methods on hardness of freeze-thaw pretreated beetroots has been presented in Fig. 3.25. The hardness of freeze-thaw pretreated beetroot was significantly affected by different drying methods ($p < 0.05$). The hardness of freeze-thaw pretreated beetroots subjected to different drying methods ranged from 303.0 ± 34.8 to 1805.4 ± 126.7 g. As observed in Fig. 3.25, the freeze-thaw pretreated beetroots obtained by SD showed the largest hardness of 1805.4±126.7 g, followed by those of HAD (1611.6 ± 141.8 g), VD (752.3 ± 119.8 g), MD (546.1 ± 95.3 g), and MVD (507.8 ± 73.4 g). FD led to the lowest hardness of freeze-thaw pretreated beetroots, indicating that the texture of freeze-thaw pretreated beetroots prepared by FD was soft. There was no significant difference in the hardness of freeze-thaw pretreated beetroots obtained using MD and MVD ($p > 0.05$).

Color is one of the important visual indicators for dried beetroot quality, due to the fact that the pigment of beetroots is typical used as a natural colorant [173]. The color parameters of freeze-thaw pretreated beetroots prepared by different drying methods are displayed in Table 3.36. As shown in Table 3.36, the *L* values of freeze-thaw pretreated beetroots dried by different drying methods were observed to be increased compared with that of fresh sample, indicating that the freeze-thaw pretreated beetroots after drying became brighter than fresh sample. Whereas, there was no significance difference in *L* values of fresh sample and freeze-thaw pretreated beetroots dried by HAD and SD ($p > 0.05$). The freeze-thaw pretreated beetroots dried by FD showed the highest *L* value of 40.47 ± 0.93.

In terms of *a* values, the freeze-thaw pretreated beetroots after drying were significantly lower than that of fresh sample ($p < 0.05$), denoting that dried beetroots became lighter red color after drying. The possible reason for the lower *a* values might be related to the degradation reactions of betacyanins during drying [174]. Compared with other drying methods, the *a* value of freeze-thaw pretreated beetroots obtained using FD was higher, which was close to that of fresh sample. Meanwhile, SD led to the lowest *a* value of freeze-thaw pretreated beetroots, which in accordance with the high degradation of betacyanins.

The results revealed that freeze-thaw pretreated beetroots after drying presented significantly lower values of *b* compared to fresh sample ($p < 0.05$). For freeze-thaw pretreated beetroots undergoing to MD, FD, and FD, no significant difference was observed in *b* values. Compared to other drying methods, SD led to the lowest *b* value (0.42 ± 0.06) of the freeze-thaw pretreated beetroots.

It is noted from Table 3.36, different drying methods had significant influences on the changes of *C* values. The *C* values of freeze-thaw pretreated beetroots prepared by different drying methods were indeed lower than that of fresh sample. *C* values of freeze-thaw pretreated beetroots decreased after drying, resulting in a lower saturation and a duller appearance. Moreover, the freeze-thaw pretreated beetroots prepared by SD displayed the lowest *C* value of 13.28 ± 0.48, indicating the smallest saturation and the dullest appearance. The *C* value was the highest in the of freeze-thaw pretreated beetroots dried by FD indicating the most vivid color. Notably, the *C* and *a* values showed similar values. This is in agreement with several authors who even considered *C* and *a* values as indicators describing the thermal degradation of betalains in beetroot products [40, 52, 76, 174].

Table 3.36

Color parameters of freeze-thaw pretreated beetroots affected by different drying methods

Drying methods	*L*	*a*	*b*	*C*	*H°*	*ΔE*
MD	39.37 ± 0.78^{b}	20.07 ± 0.45^{d}	2.63 ± 0.36^{b}	20.25 ± 0.44^{d}	7.71 ± 1.11^{d}	9.60 ± 0.45^{c}
MVD	39.18 ± 0.84^{b}	24.79 ± 0.66^{c}	2.57 ± 0.57^{b}	24.93 ± 0.61^{c}	10.06 ± 2.23^{c}	5.93 ± 0.49^{d}
FD	40.47 ± 0.93^{a}	26.93 ± 0.75^{b}	2.66 ± 0.19^{b}	27.06 ± 0.76^{b}	10.14 ± 0.63^{c}	5.61 ± 0.48^{d}
VD	40.02 ± 0.96^{ab}	20.00 ± 0.40^{d}	2.09 ± 0.23^{c}	20.11 ± 0.39^{d}	9.64 ± 1.15^{c}	10.09 ± 0.56^{c}
HAD	37.02 ± 0.85^{c}	17.60 ± 0.58^{e}	1.44 ± 0.27^{d}	17.66 ± 0.58^{e}	12.61 ± 2.57^{b}	11.95 ± 0.57^{b}
SD	37.21 ± 1.09^{c}	13.27 ± 0.47^{f}	0.42 ± 0.06^{e}	13.28 ± 0.48^{f}	31.90 ± 3.30^{a}	16.34 ± 0.48^{a}
Fresh sample	36.62 ± 0.50^{c}	28.48 ± 0.77^{a}	6.23 ± 0.38^{a}	29.16 ± 0.78^{a}	4.51 ± 0.27^{e}	-

The *a*, *b*, and *C* values of freeze-thaw pretreated beetroots after different drying methods were decreased significantly ($p < 0.05$) compared with those of fresh sample. The $H°$ values of freeze-thaw pretreated beetroots obtained by different drying methods were observed to be significantly increased in comparison with that of fresh sample ($p < 0.05$). The $H°$, with values from 7.71 ± 1.11 to 31.90 ± 3.30, was in the red range to yellow-red for freeze-thaw pretreated beetroots prepared by different drying methods. The freeze-thaw pretreated beetroots obtained by SD displayed the highest $H°$ value of 31.90 ± 3.30, demonstrating sun drying caused a great degree shift to more yellow-red color.

The greatest ΔE (16.34 ± 0.48) was seen in the freeze-thaw pretreated beetroots prepared by SD, followed by the freeze-thaw pretreated beetroots dried by HAD. It can be observed that FD led to the lowest ΔE (5.61 ± 0.48) of freeze-thaw pretreated beetroots, followed by MVD. Furthermore, there is no significant difference in ΔE values of freeze-thaw pretreated beetroots obtained from FD and VD ($p > 0.05$).

As a result, freeze-thaw pretreated beetroots dried by FD exhibited the most ideal color among the freeze-thaw pretreated beetroots subjected to different drying methods, with the lowest ΔE and the values of *L*, *a*, *b*, and *C* close to those of freshbeetroots. In addition, the worst color of freeze-thaw pretreated beetroots was prepared by SD, indicating that sun drying had a great influence on the color of final product, and was extremely unfavorable for the color retention of the freeze-thaw pretreated beetroots.

In order to explain the influence of different drying methods on the quality characteristics of freeze-thaw pretreated beetroots, the microstructures were observed by SEM as described above. The microstructures of freeze-thaw pretreated beetroots obtained using different drying methods are presented in Fig. 3.26. Obvious differences were observed in the microstructures of freeze-thaw pretreated beetroots with different drying methods. The freeze-thaw pretreated beetroots dried by FD exhibited typical homogenous porous structures, proving that FD displayed the minimal influecnce in cellular structure of beetroot tissue.

A previous study confirmed that the porous microstructure of the FD sample was formed by ice sublimation in the vacuum environment without cell shrinkage and external force collapse [148]. During the process of MD and MVD, rapid moisture evaporation caused the microscopic holes, so similar to FD, the freeze-thaw pretreated beetroots prepared by MVD and MD also had porous structures. The freeze-thaw pretreated beetroots obtained using VD were found to have thin porous walls, invisible cell boundaries, and extensive collapse of cell structures, resulting in negative effects on the texture of products. The freeze-thaw pretreated beetroots dried by HAD demonstrated tissue shrinkage and collapse of the cell structures, indicating severe damage to the cell structures of beetroots and leading to negative effects on hardness of final products. Similar results for free convection dried beetroots reported in [10]. However, SD led to a huge damage beetroots, resulting in complete breakage of cellular membrane, severe tissue shrinkage and collapse. Heating and moisture loss cause pressure in the cellular structures of the material, resulting in change and shrinkage of the microstructure. In addition, the microstructures and porosity of dried products are relevant to the migration mechanism of moisture and changes of external pressure [175].

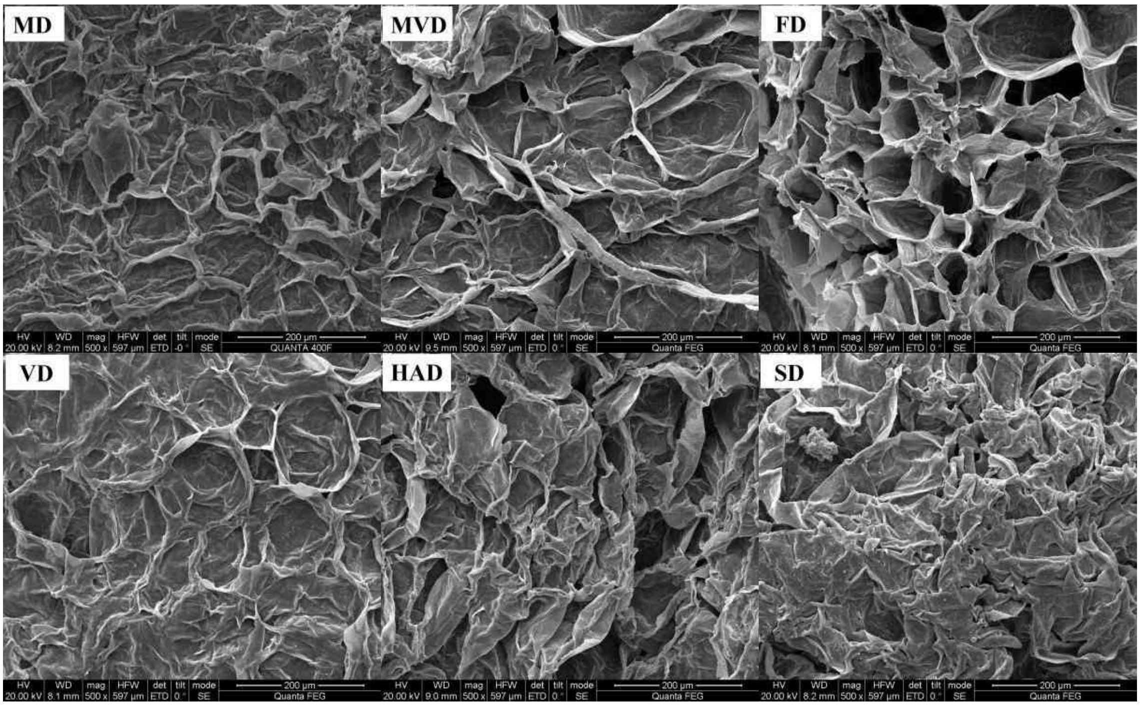


Fig. 3.26 SEM micrographs (500× magnification) of freeze-thaw pretreated beetroots obtained using different drying methods

The contents of betalain and ascorbic acid of freeze-thaw pretreated beetroots prepared by different drying methods are exhibited in Fig. 3.27. Betalains are sensitive to exposure to high temperature and long time processing [10]. Drying processing will change the content of betalains and consequently the color of the products. It can be seen from Fig. 3.27 that different drying methods significantly affected betalains content in the freeze-thaw pretreated beetroots ($p < 0.05$). The betacyanin content of freeze-thaw pretreated beetroots obtained by different drying methods ranged from 2.78 ± 0.07 to 4.38 ± 0.17 mg/g. Meanwhile, the betaxanthin content of freeze-thaw beetroots subjected to different drying methods ranged from 2.37 ± 0.05 to 3.12 ± 0.11 mg/g. Those values were obviously higher than the range reported by Wruss et al. [87] for seven beetroots varieties: 2.3 ± 0.2 to 3.9 ± 0.5 mg/g for betacyanin content, and 1.5 ± 0.2 to 2.4 ± 0.3 mg/g for betaxanthin content.

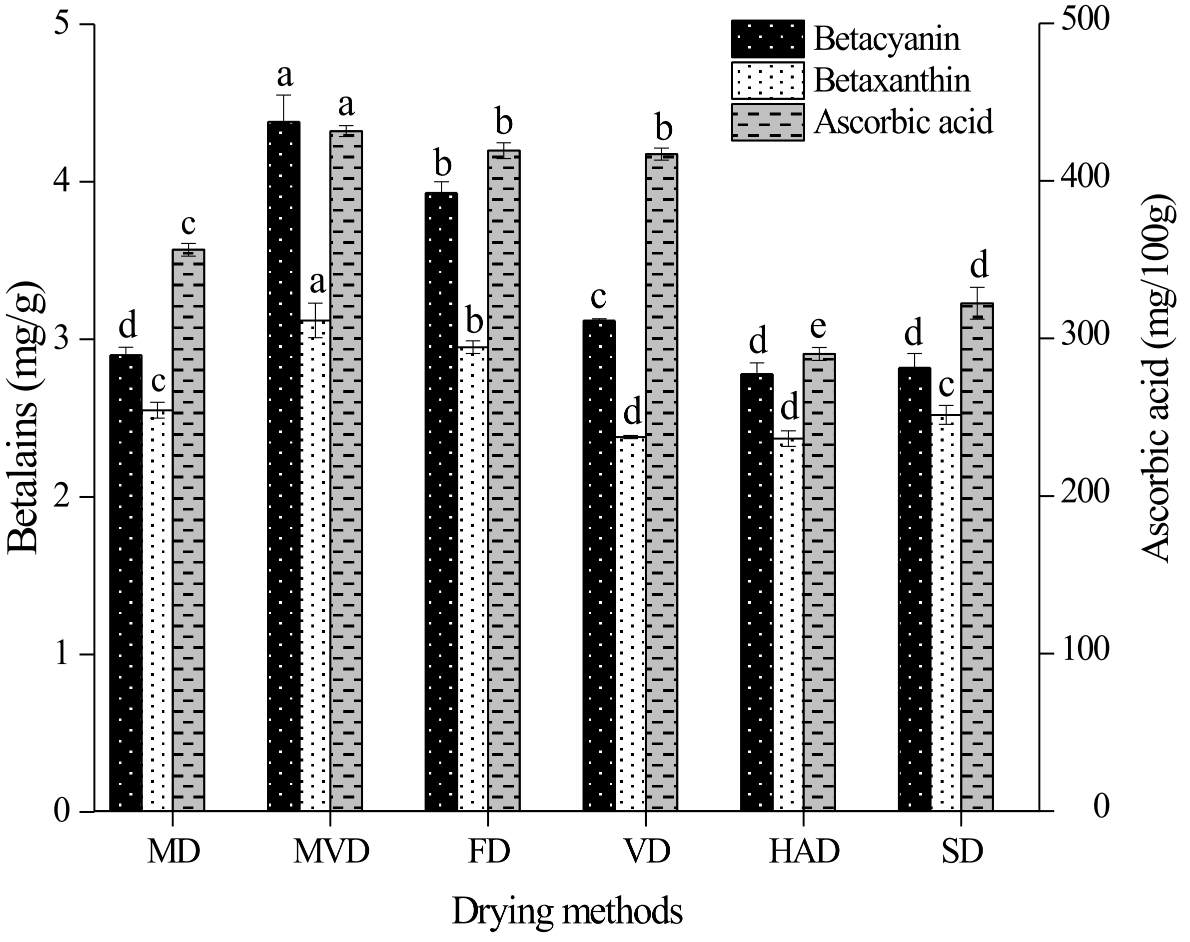


Fig. 3.27 Effects of different drying methods on betalains content and ascorbic acid content of freeze-thaw pretreated beetroots

The results showed that the betacyanin content of freeze-thaw pretreated beetroots dried by MVD was the highest (4.38 ± 0.17 mg/g), while the minimum betacyanin content of 2.78 ± 0.07 mg/g was observed in freeze-thaw pretreated beetroots dried by HAD. Furthermore, no significant difference in betacyanin content of freeze-thaw pretreated beetroots dried by SD and HAD. The betaxanthin content of beetroots obtained by MVD was significantly higher than those of freeze-thaw pretreated beetroots obtained by other drying methods ($p < 0.05$). The lowest betaxanthin content (2.37 ± 0.05 mg/g) was observed in freeze-thaw pretreated beetroots prepared by HAD, and no significant difference was observed in betaxanthin content between VD and HAD ($p > 0.05$).

Ascorbic acid is relatively unstable to heat, light and oxygen, and is easily degraded during drying process. As displayed in Fig. 3.27, different drying methods had significant effects on ascorbic acid content of freeze-thaw pretreated beetroots. The highest ascorbic acid content of 431.6 ± 3.5 mg/100g was observed in freeze-thaw pretreated beetroots obtained by MVD. Moreover, the freeze-thaw pretreated beetroots subjected to HAD showed the lowest ascorbic acid content of 290.2 ± 4.1 mg/100g, indicating that hot air drying resulted in the greatest loss of ascorbic acid in freeze-thaw pretreated beetroots, which can be explained that the higher the temperature, the longer the drying time, and the more degraded ascorbic acid in dried fruits and vegetables [150]. Besides, there was no significant difference in the ascorbic acid content of freeze-thaw pretreated beetroots obtained from FD and VD ($p > 0.05$).

Fig. 3.28 shows the total phenolic content and total flavonoids content of freeze-thaw pretreated beetroots affected by different drying methods. It can be observed from Fig. 3.28 that different drying methods had significant influences on the total phenolic content of freeze-thaw pretreated beetroots ($p < 0.05$). The freeze-thaw pretreated beetroots dried by MVD illustrated the highest total phenolic content of 8.58 ± 0.04 mg GAE/g, followed by the freeze-thaw pretreated beetroots obtained by MD (8.33 ± 0.09 mg GAE/g), VD (6.97 ± 0.10 mg GAE/g), FD (6.40 ± 0.13 mg GAE/g), and HAD (6.00 ± 0.10 mg GAE/g), respectively. MVD, VD, and MD resulted in higher total phenolic content of freeze-thaw pretreated beetroots. MVD and MD resulted in higher total phenolic content of freeze-thaw pretreated beetroots, which can be explained by the fact that the microwave irradiation treatments were very short compared to VD, FD, HAD, and VD treatments and microwave radiation leads to the release of phenolic compounds from the food matrix [176].

Moreover, the lowest total phenolic content (5.88 ± 0.09 mg GAE/g) was found in freeze-thaw pretreated beetroots prepared by SD. However, the effect of SD and HAD on the total phenolic content of freeze-thaw pretreated beetroots was not significantly different ($p > 0.05$). These values were in the range of those proposed by Székely et al. [46] for dried beetroot species ('Alto F1', 'Cylindra', 'Detroit') prepared by mospheric, vacuum and microwave vacuum drying.

The results showed that the freeze-thaw pretreated beetroots prepared by MVD displayed the highest total flavonoids content of 14.53 ± 0.44 mg RE/g, followed by the freeze-thaw pretreated beetroots obtained by FD, VD, MD, HAD, and SD with values of 12.14 ± 0.62, 12.06 ± 0.40, 11.85 ± 0.26, 10.73 ± 0.36, and 9.37 ± 0.26 mg RE/g, respectively. Those values were significantly lower than the range proposed by Hamid and Nour [86] of sun-dried, oven-dried, and freeze-dried beetroots with the values of 34.74 ± 0.54, 33.28 ± 0.72, and 36.11 ± 0.95 mg RE/g, respectively. The reason for this difference may be related to the variety and production place, and the pretreatment of beetroots.

Compared with other drying methods, SD resulted in the lowest content of total flavonoids and total phenolic in freeze-thaw pretreated beetroots, indicating that SD was not conducive to the preservation of total flavonoids and total phenolic in beetroots.

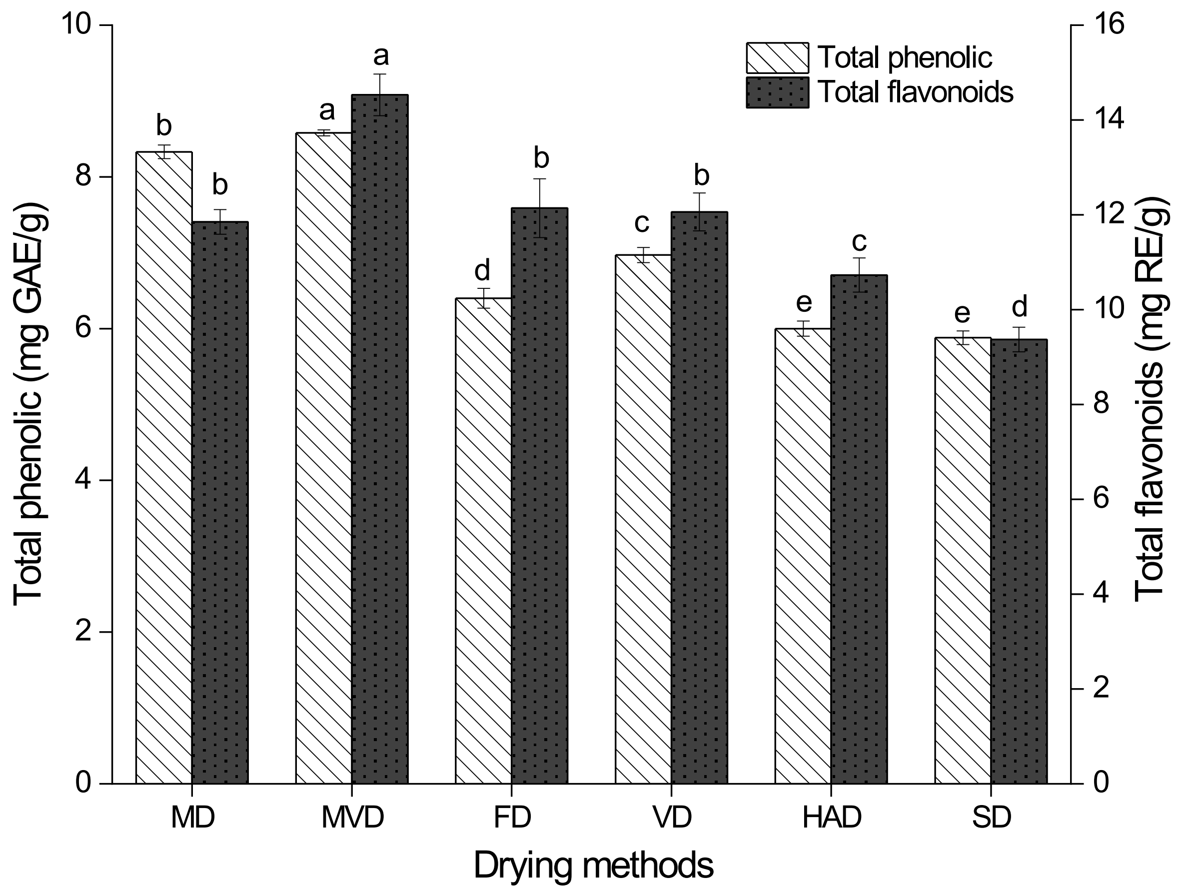


Fig. 3.28 Effects of different drying methods on total phenolic content and total flavonoids content of freeze-thaw pretreated beetroots

In this study, the antioxidant activity of freeze-thaw pretreated beetroots obtained using different drying methods was assessed by ABTS radical scavenging ability and FRAP value. Results are presented in Fig. 3.29.

It was observed that drying methods significantly affected the ABTS radical scavenging ability and FRAP values of freeze-thaw pretreated beetroots ($p < 0.05$), and the impact trend was consistent. The freeze-thaw pretreated beetroots obtained by MVD showed the highest FRAP value and ABTS radical scavenging ability, which were 16.65 ± 0.03 mg TE/g and 13.64 ± 0.26 mg TE/g, respectively. Meanwhile, the lowest FRAP value (10.87 ± 0.05 mg TE/g) and ABTS radical scavenging ability (10.24 ± 0.03 mg TE/g) were observed in freeze-thaw pretreated beetroots subjected to SD.

The results revealed that antioxidant activity is related to the content of bioactive compounds in freeze-thaw pretreated beetroots. The changes in antioxidant activity can be attributed to various reasons. It has been reported that degradation caused by enzymes or heating can lead to a loss of antioxidant capacity. In addition, the intermediate products of thermal degradation and Maillard reaction can enhance antioxidant activity [156]. Moreover, during heat treatment, intense and/or long-term heat treatment may lead to the loss of natural antioxidants that most of them are relatively unstable [155]. Besides, the enzymatic reactions and non-enzymatic browning reactions may also lead to antioxidative characteristics during drying process [157].

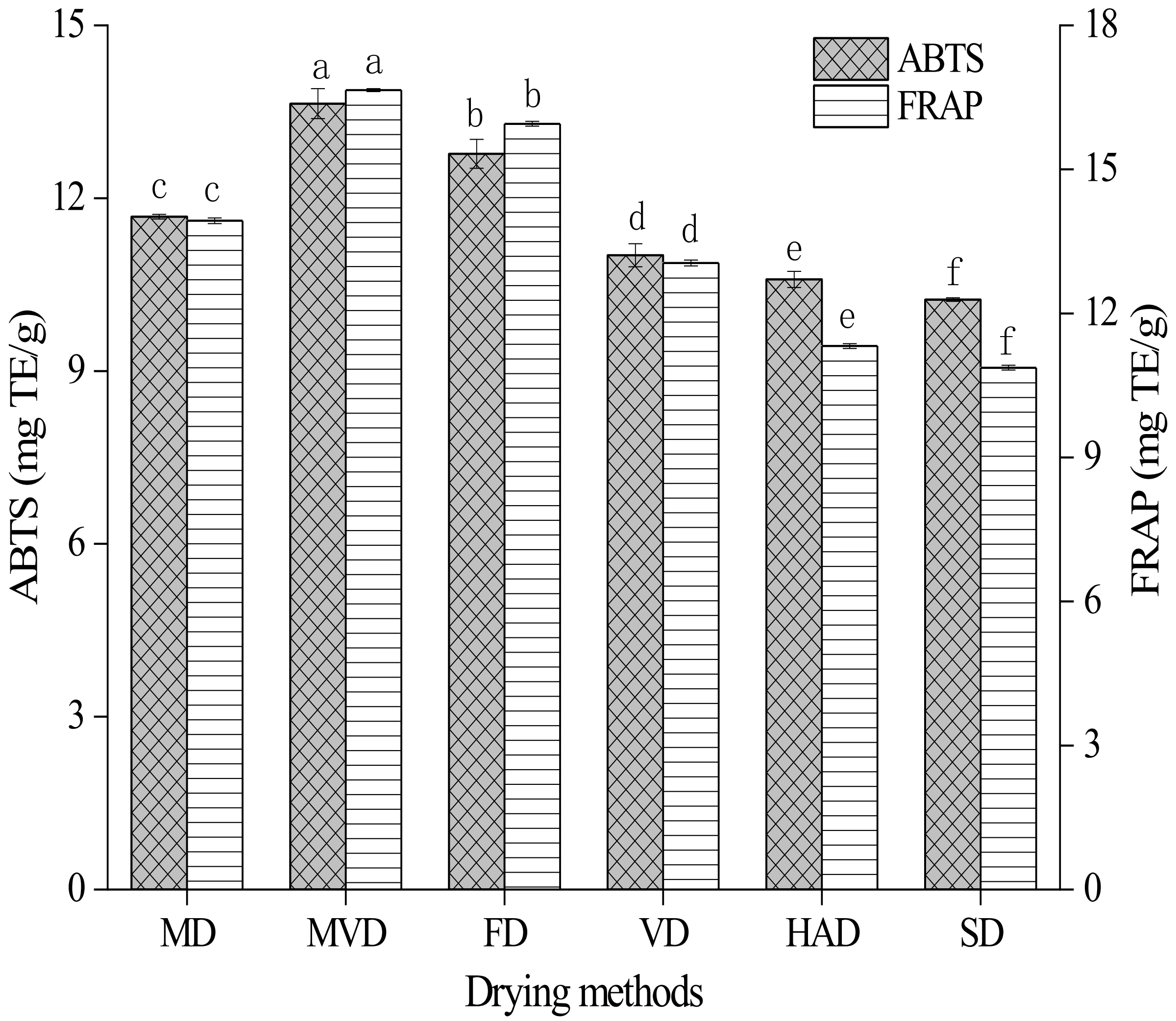


Fig. 3.29 Effects of different drying methods on ABTS radical scavenging ability and FRAP values of freeze-thaw pretreated beetroots

3.2.5 Technological scheme for obtaining dried beetroot, pretreated by freeze-thaw method

After experiments with different methods of drying frozen-thawed beetroot, a technological scheme for their production of dried beetroot, pretreated by freeze-thaw method was developed, which is presented in Figure 3.30.

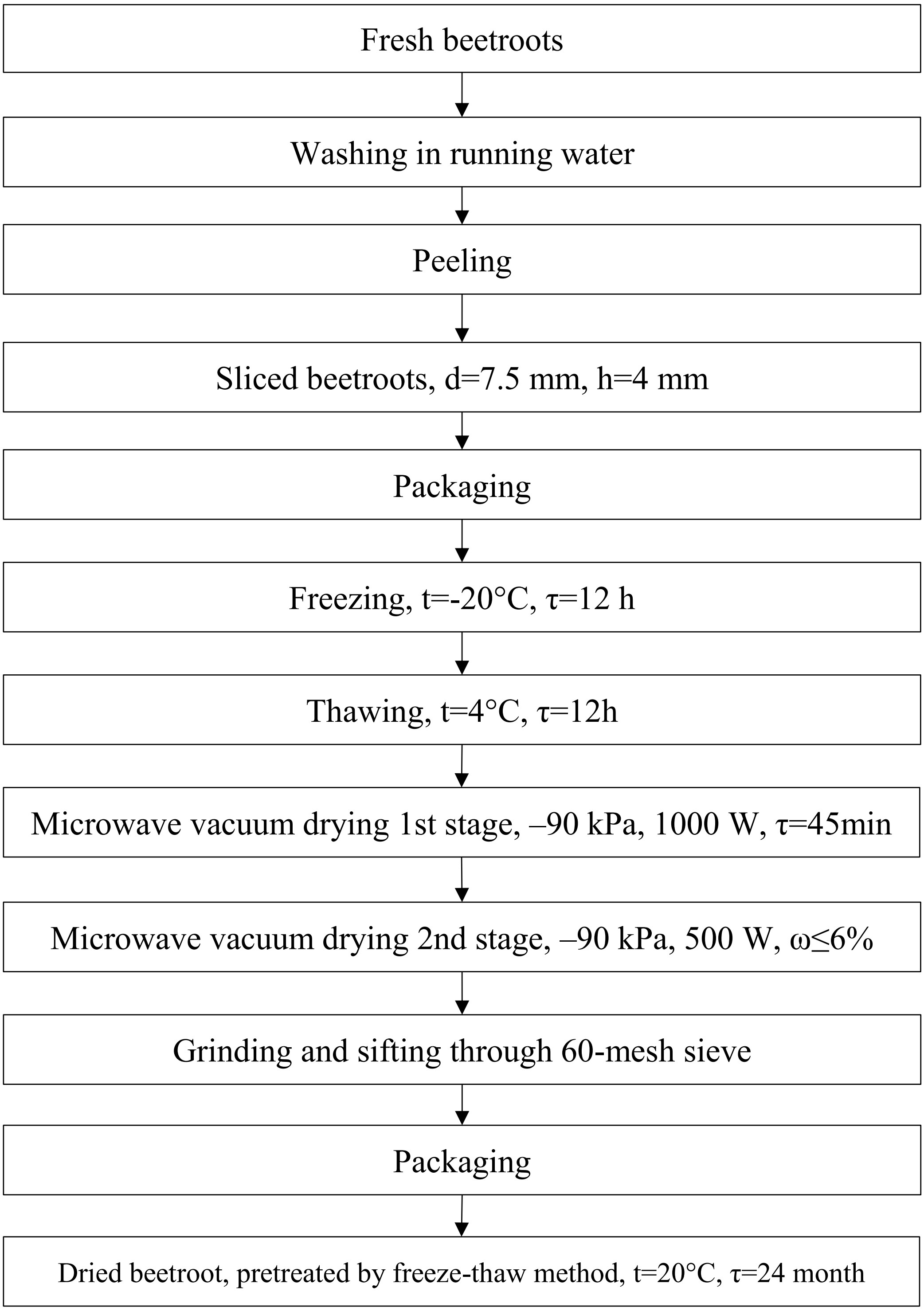


Fig. 3.30 Technological scheme for obtaining dried beetroot, pretreated by freeze-thaw method

3.2.6 Food safety of dried beetroot, pretreated by freeze-thaw method

Since protein isolate and dried beetroot, pretreated by freeze-thaw method are products with a long shelf life (up to 2 years), one of key factors affecting their quality is the ability to maintain their microbiological and toxicological characteristics during the entire manufacturing and storage period.

Dried beetroot must meet the requirements established in the technical specifications and be produced in accordance with the requirements of the technological instructions in compliance with the sanitary rules and norms approved at the enterprise in the established order. Therefore, food hygiene research is mandatory for dried beetroot, pretreated by freeze-thaw method. The study of food safety indicators was carried out according to the research methods of national standards. The concentration of toxic elements in dried beetroot, pretreated by freeze-thaw method during the three-month storage period remained at the same level as before the beginning of storage, which is shown in Table 3.37.

Table 3.37

The content of toxic elements, nitrates and radionuclides in dried beetroot, pretreated by freeze-thaw method, n=9

Chemical elements	Limit values	Storage period: 3 months
Toxic elements, mg/kg		
lead	0.50	0.08
cadmium	0.03	0.01
arsenic	0.2	0.03
mercury	0.02	0.01
copper	5.0	1.7
zinc	10	3.4
tin	200	not found
Nitrates	1400	340
Radionuclides, Bq/kg		
cesium-137	240	12
strontium-90	80	7

The values of toxicological indicators of dried beetroot are significantly influenced by growing conditions, so these values must be checked periodically to ensure food safety standards.

Microbiology of dried beetroot, pretreated by freeze-thaw method are shown in Table 3.38. The resulting colonies were subsequently counted, and the results were expressed as $\log_{10}$ CFU (colony-forming unit)/g.

Table 3.38

Microbiology of dried beetroot, pretreated by freeze-thaw method, n=9

Microbiological indicators	Limit values	Storage period: 3 months
The number of mesophilic aerobic and facultative anaerobic microorganisms, $\log_{10}$ CFU/g	6	3
Bacteria of the group of coliforms (coliforms) in 0.1 g	not allowed	not found
Pathogenic microorganisms, in particular bacteria of the genus Salmonella, in 25 g	not allowed	not found
Bacillus cereus, $\log_{10}$ CFU/g	3	2

The study of microbiological parameters of dried beetroot, pretreated by freeze-thaw method during storage showed that bacteria of the group of coliforms, as well as pathogenic microflora in dried beetroot, pretreated by freeze-thaw method were not detected.

The number of mesophilic aerobic and facultative anaerobic microorganisms and Bacillus cereus in dried beetroot, pretreated by freeze-thaw method slightly increased over time during storage, but according to the level of this microbiological indicator, after 3 months of storage, the dried beetroot met the hygienic requirements.

Physical food contamination is a hazardous yet natural accident of contaminating food with dangerous objects around the kitchen or production base when being prepared. Physical contamination of dried beetroot during 3 months of storage is shown in Table 3.39.

Table 3.39

Physical contamination of dried beetroot, pretreated by freeze-thaw method, n=9

Physical elements	Limit values	Storage period: 3 months
The mass fraction of metal impurities (the size of the mass particles should not be more than 0.3 mm in the largest dimension), %	3×10^{-4}	9×10^{-5}
Mass fraction of mineral impurities, %	0.01	0.003
Foreign impurities	forbidden	not found
Impurities of plant origin	forbidden	not found
Affected by pests of grain stocks	forbidden	not found
The presence of rotting dried beetroot and mold	forbidden	not found

After three months of storage, the indicators of physical contamination of dried beetroot, pretreated by freeze-thaw method did not change and were significantly lower than the maximum level. Prohibited physical contaminants were not found in dried beetroot. This is due to the fact that the beetroot powder was stored in polyethylene vacuum bags, which prevented the beet from coming into contact with physical contaminants.

Thus, safety indicators were studied during 3 months of storage. Based on the obtained data, it was established that dried beetroot, pretreated by freeze-thaw method can be stored at a temperature of 25°C for 3 months. Insignificant values of microbiological, toxicological and physical indicators of food hygiene confirm the effectiveness of storage at a temperature of 25°C and create prerequisites for confirming the maximum storage terms (2 years) of dried beetroot, pretreated by freeze-thaw method.

In this study, different drying methods were used to dry freeze-thaw pretreated beetroots. The results induced that the drying methods had significant influences on the quality characteristics of freeze-thaw pretreated beetroots. Among six drying methods, FD resulted in the longest drying time, while MVD and MD required shorter drying times. There was no significant difference in final moisture content of freeze-thaw pretreated beetroots obtained using different drying methods ($p > 0.05$). It has been found that the freeze-thaw pretreated beetroots obtained by FD showed the highest rehydration ratio and the lowest shrinkage rate. The color results indicated that the freeze-thaw pretreated beetroots prepared by FD displayed a better color appearance with the lowest ΔE, while SD resulted in the worst color in freeze-thaw pretreated beetroots with the biggest ΔE. According to the microstructure results, the freeze-thaw pretreated beetroots dried by FD, MD, and MVD demonstrated porous structures. SD and HAD caused great damage to the cell structure of freeze-thaw pretreated beetroots, resulting in severe tissue shrinkage and collapse.

Different drying methods significantly affected the bioactive compounds of freeze-thaw pretreated beetroots. The freeze-thaw pretreated beetroots dried by MVD exhibited the highest contents of betacyanin, betaxanthin, ascorbic acid, total phenolic, and total flavonoids, while HAD resulted in the lowest contents of betalains and ascorbic acid, and SD resulted in the lowest contents of total phenolic and total flavonoids in freeze-thaw pretreated beetroots.

Moreover, the freeze-thaw pretreated beetroots subjected to MVD showed the largest ABTS radical scavenging ability and FRAP values. Overall, higher quality properties and lower drying time suggest that MVD has greater potential as an optimal drying method for freeze-thaw pretreated beetroots.

Conclusions to Section 3

In this section, different drying methods and freeze-thaw pretreatments were used to obtained dried beetroots. The physical properties, bioactive compounds and antioxidant capacity of beetroots were investigated. Main conclusions obtained from this section are as follows:

For heat pump drying, the best drying process parameters were beetroot slices with thickness of 5 mm, drying temperature of 65 °C, and loading density of 2.0 kg/m^2. In terms of vacuum microwave drying, the most favorable conditions were microwave power of 500 W, vacuum degree of –90 kPa, and sample thickness of 2 mm.

Different microwave-assisted drying methods (HAD+LMD, HMD+HAD, HMD+LMD, HMD, LMD, HMD+VD, and VD+LMD) significantly affected the quality characteristics of beetroots. According to the results, it was demonstrated that VD+LMD was the optimal method for microwave assisted drying of beetroots.

Different drying methods (MVD, VD, MD, HPD, and FD) significantly affected the bioactive compounds of beetroots, and considering the quality attributes and drying time, the combined drying methods (HPD+MVD) guarantee high quality of beetroots and shorten drying time.

The optimal freeze-thaw pre-treatment conditions for beetroots were freeze-thaw once with freezing temperature of –20 °C and water thawing. Moreover, it was found that MVD was an optimal drying method for freeze-thaw pretreated beetroots.

SECTION 4
TECHNOLOGIES OF MEAT PRODUCTS WITH THE ADDITION OF DRIED BEETROOT, PRETREATED BY FREEZE-THAW METHOD AND BISCUITS ENRICHED WITH DRIED BEETROOT, PRETREATED BY FREEZE-THAW METHOD

4.1 Tehnology of meat products enriched with dried beetroot, pretreated by freeze-thaw method

The research of meat products was carried out at Hezhou University in China, Sumy National Agricultural University in Ukraine, the results of experiments are confirmed by relevant research protocols. Research protocols are given in the addition A. "Protocols of experimental data". Degustation of meat products with the addition of dried beetroot, pretreated by freeze-thaw method was carried out at Hezhou University in China. Degustation results were recorded in the relevant degustation protocols. Degustation protocols are given in the Addition B. "Degustation certificates".

Chicken breast is well known for its high protein and low fat content, making it a healthier food. The processing of chicken breast without any additives into sausages will lead to unattractive and colorless products. As a result, to produce an appealing sausage similar to beef sausage, chicken sausages frequently make use of food additives such as synthetic colorant [177]. Beetroot is considered as a rich source of betalains and nitrates. Betalain in beetroots is found to be a natrual coloring agent, containing two groups of red-violet (betacyanins) and yellow (betaxanthins) pigments [89]. As a source of nitrate, the intake of beetroot provides a natural way and has become a potential strategy for the prevention and management of diseases related to the reduction of NO bioavailability (especially hypertension and endothelial function) [98]. Nitrate is used in various purposes in meat products, such as providing antibacterial effect, required curing color, typical taste, and aroma, and preventing oxidation [178]. Beetroots have been proven to have important antioxidant and natural coloring properties. Some studies have been carried out on the application of beetroot powder and beetroot extract in meat products, especially sausage. In the study [177], it was evaluated the function of red beetroot powder as filler and coloring agent in meat products. The results demonstrated that color, texture profile, water-holding capacity, and sensory characteristics were impacted by the increasing level of beetroot powder ratio, and meat products with higher ratio of beetroot powder displayed good acceptability on flavor and color. It was reported in [178] that beetroot extract and beetroot extract powder as colorants were used in the production of sausages. The results showed that beetroot extract and powder had a positive impact on the sensory appearance, color, flavor, and overall acceptance of sausages. In the research of [89], beetroot powder was used to replace nitrite in Turkish fermented beef sausage. Results revealed that beetroot powder increased a^* value of samples, and led to the protection of the desired red color during storage. Turkish fermented sausage reformulated with beetroot powder instead of nitrite and stored in vacuum bags for up to 56 days at 4 °C. The usability of lyophilized red beet water extract in cemen paste and its effects on the pastırma quality (especially colour, protein and lipid oxidation, microbial and sensory properties) during storage were investigated in [91]. The results showed that during the ripening process, nitrite was generated from radish and beetroot powders, and beetroot powder altered color, pigments, and lactic acid bacteria numbers. Adding 1.0% or 1.2% lyophilized red beet water extract to cemen paste could effectively improve the color stability, lipid oxidation, microbial and sensory quality of pastırma during storage. In addition, the use of beetroot powder/extract provides a simple way to produce red-colored products to improve its nutritional value and provide decorative food for consumers [179].

The different characteristics of additives and varied contents of additive would affect the characteristics of final product. The goal of this investigation was to evaluate the effect of dried beetroot, pretreated by freeze-thaw method on the physicochemical characteristics of meat products.

4.1.1 Recipe optimization of meat products with dried beetroot, pretreated by freeze-thaw method

4.1.1.1 Materials and reagents

Materials: Fresh beetroot (Beta vulgaris L. subsp. vulgaris var. conditiva Alef.), fresh snail meat without shell (Helix pomatia) were purchased from a local market in Xuzhou, China. Beets and snail meat were stored in a refrigerator (4 °C) until further use. Ingredients for sausages are chicken breast, dried beetroot, snail powder, pork rind, potato starch, ice, salt, dried garlic, ground mustard, dried marjoram, nutmeg, white pepper, white cooking wine, tripolyphosphate, sodium isoascorbate, and casings (salted pork intestines).

Main reagents: Petroleum ether, trichloromethane, glacial acetic acid, potassium iodide, sodium thiosulfate, potassium hydroxide, sodium chloride, copper sulfate, potassium sulfate, sulfuric acid, ether, hydrochloric acid and thiobarbituric acid were all analytical reagent.

4.1.1.2 Preparation of meat products

Preparation of dried beetroot, pretreated by freeze-thaw method. Fresh beetroots slices with diameter of 7 mm and thickness of 3 mm were put into polyethylene bags, frozen in refrigerator (–20 °C) for 12 h, then thawed in the running water for 30 min, and wiped the superficial water of beetroot slices with absorbent paper to obtain frozen-thawed beetroot slices.

Dried beetroot, pretreated by freeze-thaw method were obtained by combination of heat pump drying (HPD) and microwave vacuum drying (MVD). Frozen-thawed beetroot slices were put on a polyethylene tray (74 × 50 × 4 cm) of heat pump dryer dried at 65 °C for 2.0 h, and then continue dried using microwave vacuum dryer. The microwave vacuum drying process was carried out under microwave power of 1000 W and vacuum degree of –0.09 MPa. The drying process was stopped as the final moisture content of beetroot slices below 5.0%. The dried frozen-thawed beetroot slices were ground and then sieved through a 60-mesh sieve. Beetroot powder was packed in a polyethylene bag, and then stored at 25 °C for further use.

Processing of meat products. Rinsed the pigskin with run water, boiled the pigskin in boiling water for 2 h, and then chopped the pigskin after cooling. Defrosted chicken breast, and then minced the chicken breast. Casings were cleaned by run water, then the casings were immersed by brine until for use.

Dried beets were added to the recipe in the amount of 0 % (B0), 0.5 % (B1), 1.0 % (B2), 1.5 % (B3), 2.0 % (B4), and 2.5 % (B5) from the weight of the chicken fillet. The ingredients used for the cooking of red sausages are listed in Table 4.1. Meat products processing is shown in Figure 4.1.

Table 4.1

Recipes of meat products with different additions of dried beetroot

Sustainable ingredients, g/kg	Control	Meat product samples				
	B0	B1	B2	B3	B4	B5
Chicken breast	600	600	600	600	600	600
Dried beetroot, pretreated by freeze-thaw method (powdered)	–	3	6	9	12	15
Snail powder	–	15	30	45	60	75
Pork rind	100	85	70	55	40	25
Potato starch	100	97	94	91	88	85
Ice	140	140	140	140	140	140
Salt	10	10	10	10	10	10
Dried garlic	–	4	4	4	4	4
Ground mustard	–	2	2	2	2	2
Dried marjoram	–	2	2	2	2	2
Nutmeg	6	–	–	–	–	–
White pepper	2	–	–	–	–	–
White culinary wine	40	42	42	42	42	42
Tripolyphosphate	1.5	–	–	–	–	–
Sodium isoascorbate	0.5	–	–	–	–	–

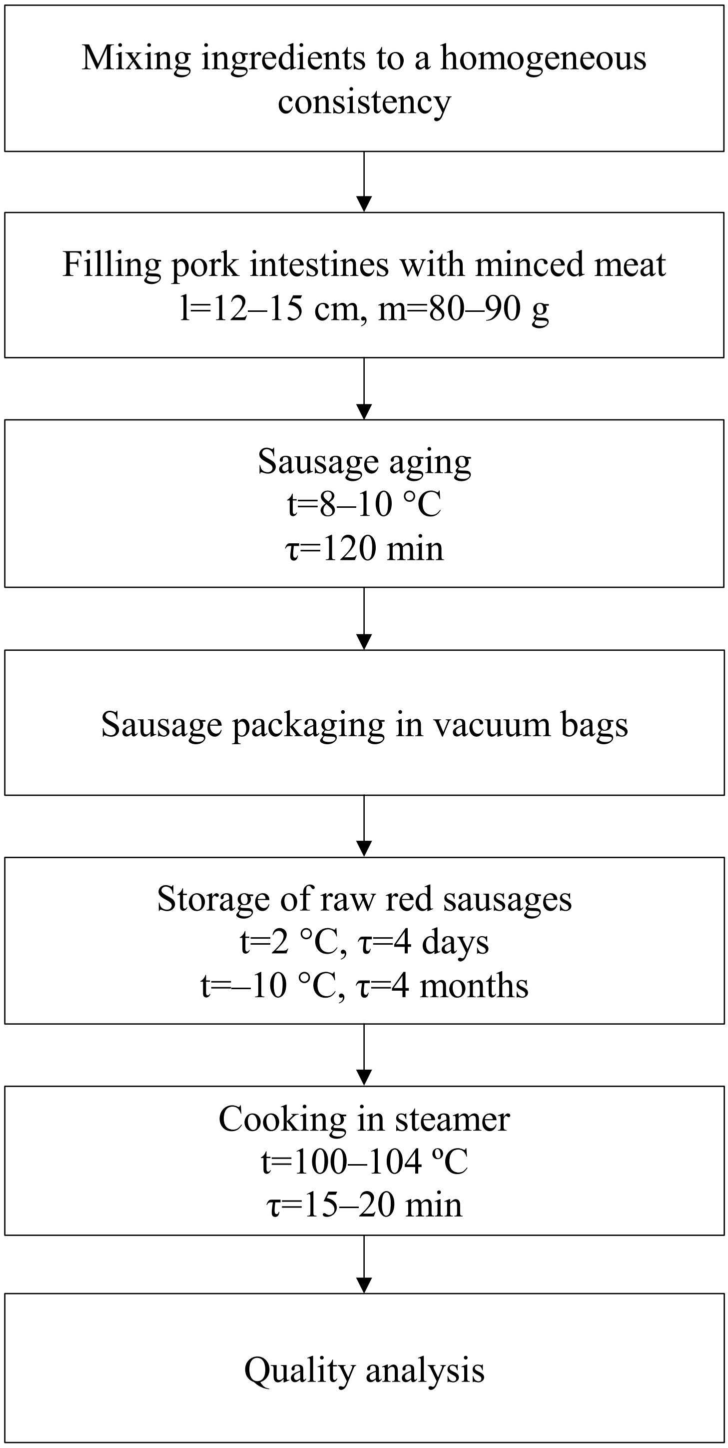


Fig. 4.1 Technological scheme of semi-finished meat products

4.1.2 Physicochemical properties of meat products fortified with dried beetroot, pretreated by freeze-thaw method

4.1.2.1 Moisture content and pH value of meat products

Moisture content and pH values of meat products are displayed in Table 4.2.

Table 4.2

Moisture content and pH value of meat products

Sample	Moisture content, %	pH
B0	51.14 ± 0.31^{c}	6.04 ± 0.01^{a}
B1	52.64 ± 0.38^{b}	5.94 ± 0.01^{b}
B2	53.31 ± 0.45^{b}	5.84 ± 0.01^{cd}
B3	57.81 ± 0.41^{a}	5.81 ± 0.03^{d}
B4	57.07 ± 0.53^{a}	5.86 ± 0.03^{c}
B5	58.00 ± 0.47^{a}	5.91 ± 0.03^{b}

As shown in Table 4.2, the moisture content of meat products were affected by the addition of dried beetroot, pretreated by freeze-thaw method. Compared with the control group (B0), the moisture content of meat products fortified with beetroot powder increased. With the addition of dried beetroot, pretreated by freeze-thaw method, the moisture content of meat products increased gradually, and there was no significant difference in moisture content among B3, B4, and B5 ($p > 0.05$).

pH value is one of commonly used physicochemical indicators to evaluate meat products quality, which can indirectly reflect the microbial characteristics and sensory quality of meat products. The pH values of meat products were significantly affected by the addition of dried beetroot, pretreated by freeze-thaw method. As shown in Table 4.2, the addition of dried beetroot, pretreated by freeze-thaw method significantly reduced the pH values of meat products. Similarly, some researchers indicated that the use of red beet caused a decrease in pH values of emulsion type sausages [180–181]. It has been reported that the pH value of the product can be affected by different factors such as product characteristics, production process, type and amount of additives [89].

4.1.2.2 Color parameters of meat products

Color characteristics of meat products affected by dried beetroot, pretreated by freeze-thaw method addition are displayed in Table 4.3. Beetroot powder has a significant impact on the color parameters of meat products. Dried dried beetroot, pretreated by freeze-thaw method addition had significant impacts on the color parameters of meat products. It can be seen from Table 4.3 that compared with B0, with the increase of dried beetroot, pretreated by freeze-thaw method, the *L* values of meat products decreased significantly ($p < 0.05$), indicating that the meat products became darkness with addition of dried beetroot, pretreated by freeze-thaw method. The addition of dried beetroot, pretreated by freeze-thaw method caused an increase in the values of *a* for the inner surfaces of meat products ($p < 0.05$). The highest *a* values were detected on the inner surface of meat products with beetroot powder addition of 2.5% (B5). The results indicated that beetroot powder was very effective in increasing the redness and maintaining the desired red color of meat products. Some academic research have already pointed out in beef sausage [89] and emulsified pork sausage [179] that redness (*a*) increased with the increased amount of frozen-thawed beetroot addition, which was attributed to the betalains content in beetroot powder. While the use of beetroot powder caused a significant increase in the yellowness (*b*) values ($p < 0.05$). With the increase of dried beetroot, pretreated by freeze-thaw method, *b* values of meat products decreased, but significantly higher than B0 ($p < 0.05$). Overall, the addition of dried beetroot, pretreated by freeze-thaw method had a significant effect on the color characteristics of meat products, and sample with 2% of dried beetroot, pretreated by freeze-thaw method (B4) exhibited better color.

Table 4.3

Color parameters of meat products

Sample	L^*	a^*	b^*
B0	62.16 ± 0.92^a	5.09 ± 0.18^f	6.24 ± 0.44^e
B1	58.69 ± 0.78^b	10.96 ± 0.36^e	11.17 ± 0.47^a
B2	54.18 ± 0.95^c	15.12 ± 0.73^d	10.38 ± 0.46^b
B3	50.06 ± 0.83^d	18.16 ± 0.40^c	8.95 ± 0.39^c
B4	48.45 ± 1.04^e	19.00 ± 0.71^b	9.46 ± 0.47^c
B5	43.43 ± 0.66^f	21.62 ± 0.52^a	7.35 ± 0.43^d

4.1.2.3 Texture profile analysis of meat products

In meat products, texture analysis can not only accurately reflect the sensory needs of consumers, but also reflect the structural integrity of protein matrix and the binding state with other components [183]. The changes of hardness, springiness, cohesiveness, gumminess, chewiness and resilience properties of meat products are shown in Table 4.4. In terms of hardness, the meat products with dried beetroot, pretreated by freeze-thaw method addition of 1.5% (B3) and 2.5% (B5) showed the higher values than that of control group (B0). The gumminess and chewiness of meat products with 2.0% of dried beetroot, pretreated by freeze-thaw method (B4) were significantly lower than those of B0, while the gumminess and chewiness of meat products with 2.5% of dried beetroot, pretreated by freeze-thaw method (B5) were higher than those of B0. However, the cohesiveness and resilience of meat products did not change much, and the differences were not significant ($p > 0.05$), which meant that addition of dried beetroot, pretreated by freeze-thaw method had no significant effect on cohesiveness and resilience of meat products.

Table 4.4

Texture profile analysis of meat products

Sample	Hardness, g	Springiness, %	Cohesiveness, %	Resilience, %	Chewiness
B0	3138.1±175.3^{c}	0.364±0.047^{ab}	0.272±0.047^{a}	0.070±0.009^{a}	319.6±54.5^{ab}
B1	2472.5±112.5^{d}	0.377±0.044^{a}	0.251±0.025^{a}	0.075±0.010^{a}	240.9±30.5^{bc}
B2	3052.0±143.3^{c}	0.316±0.027^{b}	0.260±0.020^{a}	0.071±0.007^{a}	251.6±47.2^{bcd}
B3	3640.7±131.3^{b}	0.328±0.017^{ab}	0.264±0.027^{a}	0.070±0.009^{a}	306.6±46.2^{abc}
B4	2871.2±179.4^{c}	0.304±0.022^{b}	0.235±0.016^{a}	0.064±0.005^{a}	205.2±21.0^{d}
B5	4391.3±138.4^{a}	0.335±0.020^{ab}	0.249±0.021^{a}	0.067±0.007^{a}	347.6±36.4^{a}

Overall, the addition of dried beetroot, pretreated by freeze-thaw method did not lead to significant difference in the texture characteristics of meat products, which was similar to the results from other studies [179], the addition of red beet powder (0.5% and 1.0%) into emulsified pork sausage did not result in any statistically significant difference in terms of texture properties. These results might be related to the low addition of beetroot powder used in these studies, so that no negative effect was observed on the textural characteristics of the samples [89].

4.1.2.4 Sensory quality of meat products

As displayed in Table 4.5, the color, odor, flavor, texture, and overall acceptability of meat products were affected by the addition of dried beetroot, pretreated by freeze-thaw method.

Table 4.5

Sensory analysis of meat products

Sample	Color	Odor	Flavor	Texture	Overall acceptability
B0	7.02±0.11^{e}	8.01±0.14^{a}	8.41±0.15^{ab}	8.33±0.07^{b}	7.96 ±0.16^{b}
B1	7.74±0.11^{d}	7.24±0.11^{bc}	7.93±0.12^{c}	8.02±0.08^{c}	7.75±0.11^{bc}
B2	8.30±0.16^{c}	7.44±0.11^{b}	8.19±0.09^{b}	8.21±0.07^{b}	8.00±0.10^{b}
B3	9.75±0.11^{a}	7.88±0.19^{a}	8.33±0.12^{ab}	8.64±0.11^{a}	8.67±0.08^{a}
B4	9.38±0.10^{bc}	7.98±0.12^{a}	8.52±0.10^{a}	8.67±0.12^{a}	8.72±0.13^{a}
B5	9.51±0.08^{b}	7.80±0.16^{a}	8.40±0.16^{ab}	8.62±0.13^{a}	8.69±0.07^{a}

The color and flavor scores of meat products were significantly affected by dried beetroot, pretreated by freeze-thaw method ($p < 0.05$). The sensory scores of the meat products incorporating dried beetroot, pretreated by freeze-thaw method were better than those of the control group (B0). These results might be due to the fact that the beetroot powder provided a more natural color in the chicken sausages [176]. Moreover, due to the influence of color on other sensory perceptions and preferences, a higher flavor score may actually be related to a higher color score. These results are in accordance with the research in [89], adding beetroot powder (0.12, 0.24 and 0.35%) into cooked fermented sausages resulted in a statistically significant increase in inner color scores ($p < 0.05$). The overall sensory quality of meat products depends on the formation of desired odor, color and flavor, and the addition of dried beetroot, pretreated by freeze-thaw method increased the overall acceptability scores of sausages. These results indicated that the use of dried beetroot, pretreated by freeze-thaw method provided an advantage in sensory quality of meat products. Similar results were reported from other studies [176, 179].

4.1.2.5 TBARS value and peroxide value of meat products

Lipid oxidation is one of the main factors affecting the quality characteristics of meat products, because it can lead to the development of rancidity and affect the nutritional value, color and flavor of products [181]. Peroxide is the first intermediate product after the oxidation of lipids. It is extremely unstable and can be decomposed into small molecular substances such as acids, aldehydes and ketones. Therefore, the degree of lipid oxidation can be determined from the peroxide value.

It can be seen from Table 4.6, due to the addition of dried beetroot, pretreated by freeze-thaw method, the peroxide value of meat products decreased significantly in comparison with control group (B0), demonstrating that beetroot powder could reduce the lipid oxidation of meat products.

TBARS value reflects the result of the reaction between the secondary substance produced by the oxidation and decomposition of unsaturated fatty acids in oil and malondialdehyde, and can indicate the secondary oxidation degree of fat [182]. As shown in Table 4.6, the addition of dried beetroot, pretreated by freeze-thaw method led to the TBARS values of meat products decreased significantly in comparison with that of B0. This may be due to the dried beetroot, pretreated by freeze-thaw method, which has antioxidant properties, tend to decrease lipid oxidation of meat products. Similar result has been reported in [179].

Table 4.6

TBARS and peroxide value of meat products

Sample	Peroxide value, g/100g	TBARS, mg/100g
B0	0.326 ± 0.006^{a}	0.973 ± 0.036^{a}
B1	0.301 ± 0.005^{b}	0.781 ± 0.014^{b}
B2	0.270 ± 0.007^{c}	0.720 ± 0.022^{bc}
B3	0.248 ± 0.005^{d}	0.667 ± 0.038^{c}
B4	0.249 ± 0.008^{d}	0.671 ± 0.030^{c}
B5	0.253 ± 0.009^{d}	0.673 ± 0.027^{c}

4.1.2.6 Contents of ash, fat and protein in meat products

It can be seen from Table 4.7, with the addition of dried beetroot, pretreated by freeze-thaw method, ash content increased significantly in comparison with the control group (B0), while no difference was found among samples with different additions of dried beetroot, pretreated by freeze-thaw method ($p > 0.05$), it may be due to the low addition of beetroot powder. The fat content of meat products decreased slightly with the increase of dried beetroot, pretreated by freeze-thaw method addition, but no significant differences was appeared ($p > 0.05$).

Table 4.7

Ash, fat and protein content of meat products

Sample	Ash content, g/100g	Fat content, g/100g	Protein content, g/100g
B0	3.09 ± 0.01^{b}	3.55 ± 0.05^{a}	15.23 ± 0.15^{c}
B1	3.36 ± 0.02^{a}	3.45 ± 0.05^{a}	16.10 ± 0.20^{a}
B2	3.35 ± 0.03^{a}	3.43 ± 0.09^{a}	15.69 ± 0.18^{b}
B3	3.36 ± 0.01^{a}	3.40 ± 0.06^{a}	15.72 ± 0.11^{ab}
B4	3.37 ± 0.02^{a}	3.38 ± 0.06^{a}	15.68 ± 0.17^{b}
B5	3.39 ± 0.02^{a}	3.39 ± 0.09^{a}	15.80 ± 0.10^{ab}

Compared with control group (B0), the addition of dried beetroot, pretreated by freeze-thaw method remarkably increased the protein content of meat products ($p < 0.05$). Moreover, the differences of protein content in meat products with different dried beetroot, pretreated by freeze-thaw method were not very significant. These results indicated that the addition of dried beetroot, pretreated by freeze-thaw method in meat products could slightly reduce the fat content, but increase the protein content and ash content of meat products.

4.1.3 Microbiological analyses of meat products

As shown in Table 4.8, the addition of beetroot powder led to an increase of aerobic mesophilic bacteria in meat products.

Table 4.8

Aerobic mesophilic bacteria, lactic acid bacteria, mould-yeast, and total coliforms of meat products on the fifth day of refrigeration (4 °C)

Sample	Microbiological indicators, log CFU/g			
	Aerobic mesophilic bacteria	Lactic acid bacteria	Mould-yeast	Total coliforms
B0	6.45	4.24	3.24	59.0
B1	6.59	4.39	3.35	93.5
B2	6.62	4.45	3.59	108.0
B3	6.68	4.58	3.51	123.0
B4	6.73	4.46	3.67	165.5
B5	6.79	4.27	3.48	186.0

Lactic acid bacteria are important since they limit the growth of some undesirable microorganisms, improve the physicochemical properties while contributing to the aroma and flavor of products. The lactic acid bacteria count in the present study was higher in meat products containing beetroot powder during storage. Dried beetroot, pretreated by freeze-thaw method may have acted as an additional substrate for lactic acid bacteria. Therefore, lactic acid bacteria may have used the sugar from the beetroot powder thus increasing the lactic acid amount in these samples.

Counts of yeast-mould increased with the increase of dried beetroot, pretreated by freeze-thaw method. The lowest yeast-mould counts of meat products were detected as 3.24 log CFU/g in control group (B0). Yeast-mould flora has lipolytic and proteolytic activity, and affect the odour positively up to a certain threshold, beyond which they cause bad taste and odour, so they are undesirable.

The total coliforms counts of meat products were found between 59 and 186 MPN/g. The total coliforms in samples with dried beetroot, pretreated by freeze-thaw method showed higher values than that of B0, and the total coliforms counts increased with the increase of beetroot powder addition. All samples after 15 days of storage could be consumed safely.

4.2 Dried beetroot as food coloring in sausage products

4.2.1 Materials and reagents

Materials. Chicken breast, fatty pork, bran, tapioca starch, modified tapioca starch, potato starch, ice water, salt, five-spice powder, pepper, rice wine, red yeast rice powder, beet red (the beets are crushed after vacuum microwave drying treatment and sieved (particle diameter less than 250 micron, 60 mesh), Hezhou University Laboratory, China), Phosphate (Sodium pyrophosphate 60 %, sodium tripolyphosphate 39 %, sodium hexametaphosphate 1 %), casings (commercially salt-cured fresh Pig small intestine), beet red.

Instruments and equipment. Colorimeter (CR-400, Shoufeng Instrument Technology Co., Ltd, Changzhou, China; Calibrated with a white plate, L* = +97.83, a* = -0.43, b* = +1.98). Water distribution analysis with low field nuclear magnetic resonance instrument, nuclear magnetic resonance imaging analyzer (NMI20, Shanghai Newmai Electronic Technology Co., Ltd, Shang Hai, China). Texture profile analysis was measured at room temperature with a texture analyzer (TA.XT PLUS, Stable Micro System, UK).

4.2.2 Preparation of sausage products

Defrosting chicken breast → Casing cleaning → Soaking the casing for 30min → Minced the chicken breast (including the fat) → Adding ingredients according to the ingredient list (Table 4.9) → Adding ice water and mixings The casing is put into the sausage machine → The casing is knotted at one end → Enema → Air in a ventilated place until the skin is dry → 80 °C water bath for 30 minutes → Dry the sausage skin moisture → Cool to room temperature (20 °C) → Refrigerate.

Table 4.9

Recipes of sausage products with different food coloring

Ingredient (g)	Control	L1	L2	L3	L4
Beet red	0.0	0.0	1.4	1.4	2.7
Red rice powder	0.0	2.0	0.0	2.0	2.0
Pig skin	131.4	129.4	130.0	128.0	126.7
Chicken breast	520.0	520.0	520.0	520.0	520.0
Fat (pig)	65.0	65.0	65.0	65.0	65.0
Bran (part below 80mesh)	8.0	8.0	8.0	8.0	8.0
Cassava starch	45.0	45.0	45.0	45.0	45.0
Cassava denaturant starch	25.0	25.0	25.0	25.0	25.0
Potato starch	25.0	25.0	25.0	25.0	25.0
Ice water	130.0	130.0	130.0	130.0	130.0
Salt	9.0	9.0	9.0	9.0	9.0
Phosphate	2.0	2.0	2.0	2.0	2.0
Spices	6.0	6.0	6.0	6.0	6.0
Pepper	0.6	0.6	0.6	0.6	0.6
Rice wine	33.0	33.0	33.0	33.0	33.0

4.2.3 Determination of color parameters of sausage products with dried beetroot

Adding edible red pigment can improve the color of sausages and obtain a joyful color. The test results in Table 4.10 show that the redness a* value of meat emulsion and sausage with pigment increased significantly ($P<0.05$), while the L* value and b* value showed a decreasing trend ($P<0.05$).

Table 4.10

The effect of two different food colorings on the color difference of raw meat emulsion and sausage

Sample	L*		a*		b*	
	Mashed meat	Sausage	Mashed meat	Sausage	Mashed meat	Sausage
Control	73.65±1.15[a]	73.04±0.89[b]	6.90±0.45[d]	5.50±0.48[d]	14.90±1.04[a]	13.88±0.18[a]
L1	71.12±0.53[b]	69.57±2.01[c]	12.27±0.27c	11.29±0.06[c]	14.76±0.32[a]	13.34±0.66[a]
L2	65.57±0.29[c]	67.32±1.32[c]	18.54±1.12[b]	13.27±0.23[c]	12.56±0.98[bc]	12.06±0.49[b]
L3	61.96±1.48[d]	61.89±2.87[d]	19.51±1.70[b]	19.40±2.58[b]	11.13±1.03[b]	11.60±0.84[c]
L4	59.37±0.23[e]	63.59±0.22[d]	24.21±1.17[a]	22.30±0.21[a]	8.95±0.61[c]	11.39±0.18[c]

The L2 with 1.0g beet red was more red than the L1 with 1.5g of red yeast rice, indicating that beet red can provide a higher red value than red yeast rice. Compared with the L2, there was no significant difference in the a* value of raw meat emulsion, but the a* value of L3 sausage was significantly higher than that of L2 ($P<0.05$).

The L4 continued to increase the amount of beet red, and the a* value of raw meat emulsion and sausage a* values are significantly higher than the other sample groups, and the red color is better. Liu Guoqing et al. used red yeast powder and ketchup to replace part of the sodium nitrite in frankfurter sausages. Red yeast powder and ketchup, the optimal amount of sodium nitrite is 0.001 %, 10 % and 0.0005 %, which can be substituted 70 % nitrite.

4.2.4 Cooking loss and emulsification stability of sausage products with dried beetroot

As shown in Table 4.11, compared with the control group, the cooking loss, water loss, and fat loss of the sample groups with different addition amounts of red yeast rice and beet red were significantly reduced ($P < 0.05$), this phenomenon indicates that different amounts of red yeast rice powder and beet red can reduce cooking loss, water loss and fat loss during the heating process of sausage products.

Table 4.11

The effect of two different food colorings on the cooking loss and emulsification stability of raw meat emulsion

Sample	Cooking loss	Moisture loss	Fat loss
Control	11.99 ± 1.86^{a}	11.70 ± 1.73^{a}	0.29 ± 0.13^{a}
L1	10.24 ± 1.55^{ab}	10.01 ± 1.51^{ab}	0.23 ± 0.04^{a}
L2	10.56 ± 0.77^{ab}	10.33 ± 0.81^{ab}	0.23 ± 0.04^{a}
L3	8.52 ± 0.54^{b}	8.26 ± 0.57^{b}	0.26 ± 0.08^{a}
L4	9.57 ± 0.58^{b}	9.36 ± 0.55^{b}	0.21 ± 0.04^{ab}

Gelability has a positive effect, this may be due to the fact that dried beet powder contains a lot of cellulose that can retain moisture, and red yeast rice powder contains amylopectin that helps to form a gel to retain moisture, although they are added in small amounts. In summary, the L3 group had the lowest cooking loss, water loss and fat loss ($P < 0.05$), that was, when the amount of red yeast rice powder was 1.5g and beet red was 1g, the cooking loss rate of sausage products was the lowest, and the emulsification stability of sausage products was the highest.

4.2.5 Texture profile analysis of sausage products with dried beetroot

Through the texture analyzer to measure the hardness, elasticity, cohesiveness and chewiness of sausages and other indicators, objectively evaluate the edible quality of the product, which is a key feature for evaluating the quality and acceptability of meat products. The results from Table 4.12 were shown that the addition of red yeast red and beet red two natural pigments can change the texture characteristics of raw meat emulsion and sausage products.

Table 4.12

The effect of two different food colorings on texture of raw meat emulsion and sausage products

Sample	Hardness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
Samples of raw meat emulsion						
Control	90.18 ± 38.91^{ab}	0.57 ± 0.31^{ab}	0.45 ± 0.21^{ab}	44.70 ± 37.74^{a}	33.33 ± 41.37^{a}	0.04 ± 0.01^{a}
L1	73.92 ± 14.07^{b}	0.91 ± 0.01^{a}	0.59 ± 0.03^{a}	44.09 ± 9.71^{a}	40.00 ± 9.16^{a}	0.05 ± 0.00^{a}
L2	$98.43 \pm 11.77a^{b}$	0.64 ± 0.25^{ab}	0.41 ± 0.07^{ab}	40.96 ± 11.56^{a}	27.76 ± 18.34^{a}	0.06 ± 0.02^{a}
L3	116.45 ± 14.12^{a}	0.64 ± 0.11^{ab}	0.45 ± 0.05^{ab}	53.20 ± 11.65^{a}	34.61 ± 12.65^{a}	0.05 ± 0.00^{a}
L4	60.47 ± 5.00^{b}	0.44 ± 0.09^{b}	0.35 ± 0.07^{b}	21.50 ± 5.92^{a}	19.90 ± 4.79^{a}	0.06 ± 0.01^{a}
Samples of sausage products						
Control	206.83 ± 106.43^{a}	0.79 ± 0.33^{a}	0.47 ± 0.17^{a}	108.32 ± 77.49^{a}	101.07 ± 83.17^{a}	0.13 ± 0.07^{a}
L1	103.00 ± 5.92^{ab}	0.16 ± 0.03^{a}	0.15 ± 0.01^{a}	105.64 ± 0.26^{a}	20.52 ± 0.45^{a}	0.03 ± 0.00^{b}
L2	256.31 ± 46.32^{a}	0.28 ± 0.14^{a}	0.27 ± 0.14^{a}	84.22 ± 10.05^{a}	27.99 ± 36.63^{a}	0.06 ± 0.05^{ab}
L3	115.78 ± 7.29^{ab}	$0.54 \pm 0.43a$	0.43 ± 0.33^{a}	51.30 ± 31.04^{a}	12.16 ± 7.33^{a}	0.04 ± 0.00^{b}
L4	83.89 ± 26.33^{b}	$0.71 \pm 0.43a$	0.52 ± 0.26^{a}	38.75 ± 11.46^{a}	30.83 ± 21.99^{a}	0.06 ± 0.03^{ab}

The hardness, viscosity, and chewiness of the sausage products change significantly. The L4 treated sausage products the hardness, chewiness and gumminess of the sausage products were significantly reduced, but the springiness did not change much, and the difference was not significant ($P > 0.05$). The hardness, springiness and cohesiveness of the sausage products in the L3 were moderate, but the chewiness value was the lowest. It can be seen that adding a small amount of natural plant pigments has a greater impact on the texture properties of sausage products. On the one hand, it can be seen from the data that there are some errors in the instrument, and texture parameters are only used as scientific data for sausage research. The optimal results need to be combined with sensory evaluation and color parameter comprehensive evaluation.

4.2.6 Dynamic distribution of moisture of sausage products with dried beetroot

The T2 distribution after inversion and fitting shows 3 peaks according to the relaxation time. According to the different degrees of free movement of water molecules, from left to right, it indicates bound water (T2b), non-flowing water (T21) and free water (T22). It can be seen from Figure 4.2 that compared with the control group, the relaxation time of bound water and non-flowing water in the sample groups group added with red yeast rice powder and beet red all shifted to a shorter relaxation time, while the relaxation time of free water move in the direction of the long relaxation time.

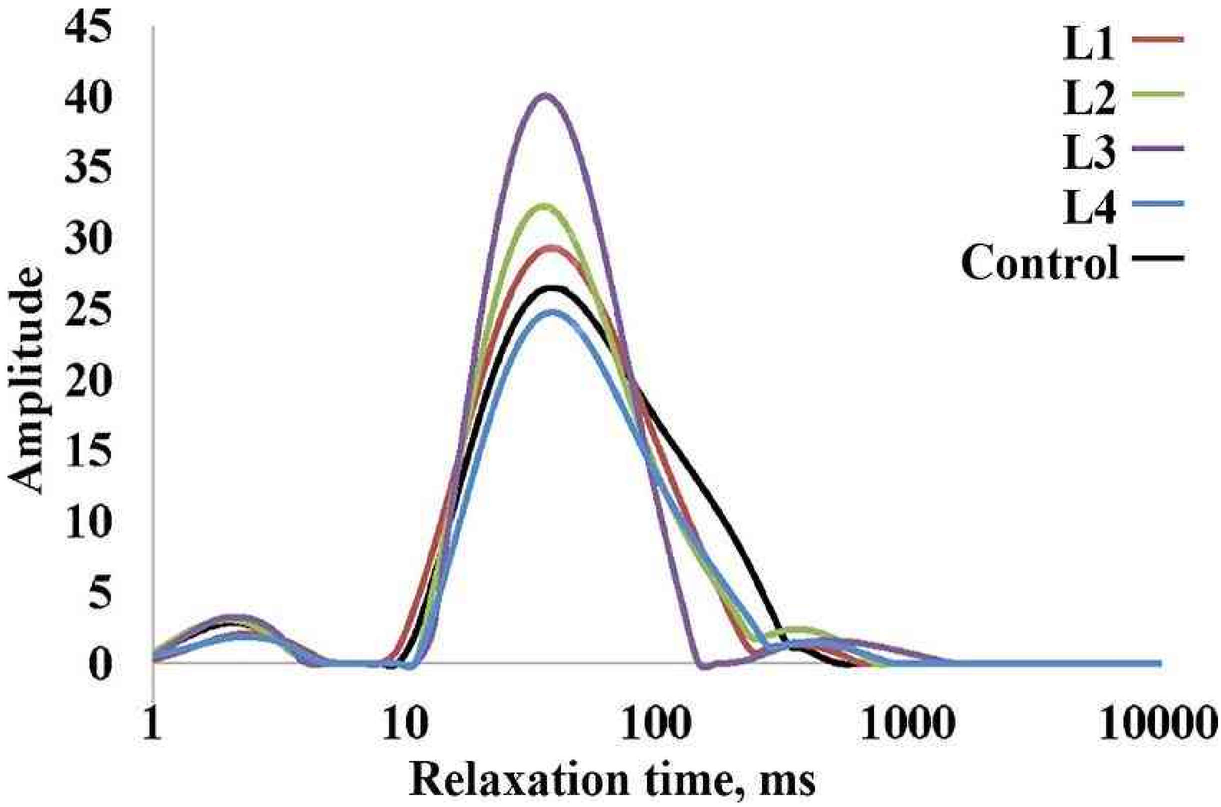


Fig. 4.2 Effects of food coloring additions on water distribution of sausage products

The relaxation time of free water has no obvious migration trend ($P > 0.05$), but the relaxation time of bound water and non-flowing water has a very obvious migration trend ($P < 0.05$), which shows that natural pigments are added and the pigments are mixed. In the sausage products meat emulsion, the flow capacity of the non-flowing water can be reduced, so that it is more closely combined with the meat chyme protein, and it is obvious in the figure that the free water is shifting to the non-flowing water (L4). The results of water distribution in Table 4.13 show that as the amount of red yeast red and beet red added to the sausage products increases gradually.

Table 4.13

Effects of food coloring additions on water distribution value of sausage products

Sample	T2b/ms	T21/ms	T22/ms	A2b	A21	A22
Control	$2.17{\pm}0.35^{a}$	$40.73{\pm}6.61^{a}$	$338.13{\pm}54.87^{a}$	$2.74{\pm}0.15^{b}$	$26.18{\pm}0.37^{d}$	$2.10{\pm}1.57^{a}$
L1	$2.56{\pm}0.42^{a}$	$40.73{\pm}6.61^{a}$	$338.13{\pm}54.87^{a}$	$2.00{\pm}0.11^{c}$	$28.87{\pm}0.49^{c}$	$1.24{\pm}0.09^{a}$
L2	$1.85{\pm}0.30^{a}$	$34.61{\pm}5.62^{a}$	$397.91{\pm}64.57^{a}$	$2.91{\pm}0.21^{ab}$	$31.62{\pm}0.70^{b}$	$2.27{\pm}0.17^{a}$
L3	$2.17{\pm}0.35^{a}$	$34.61{\pm}5.62^{a}$	$468.27{\pm}75.99^{a}$	$3.16{\pm}0.11^{a}$	$39.10{\pm}1.14^{a}$	$1.57{\pm}0.05^{a}$
L4	$2.17{\pm}0.35^{a}$	$40.73{\pm}6.61^{a}$	$397.91{\pm}64.57^{a}$	$1.78{\pm}0.10^{c}$	$33.52{\pm}0.65^{b}$	$1.42{\pm}0.05^{a}$

The A2b and A21 values both increase significantly, while the A22 value decreases significantly. This may be due to the two natural When food pigments are added to sausage products and act on the meat emulsion system, there will be a tendency for free water to change to bound water and difficult-to-flow water, so the free water is reduced.

4.2.7 Nuclear magnetic imaging analysis of sausage products with dried beetroot

Figure 4.3 shows a pseudo-color picture obtained by nuclear magnetic resonance by adding different amounts of red yeast rice powder and beet red to sausage products, which visually shows the distribution of moisture.

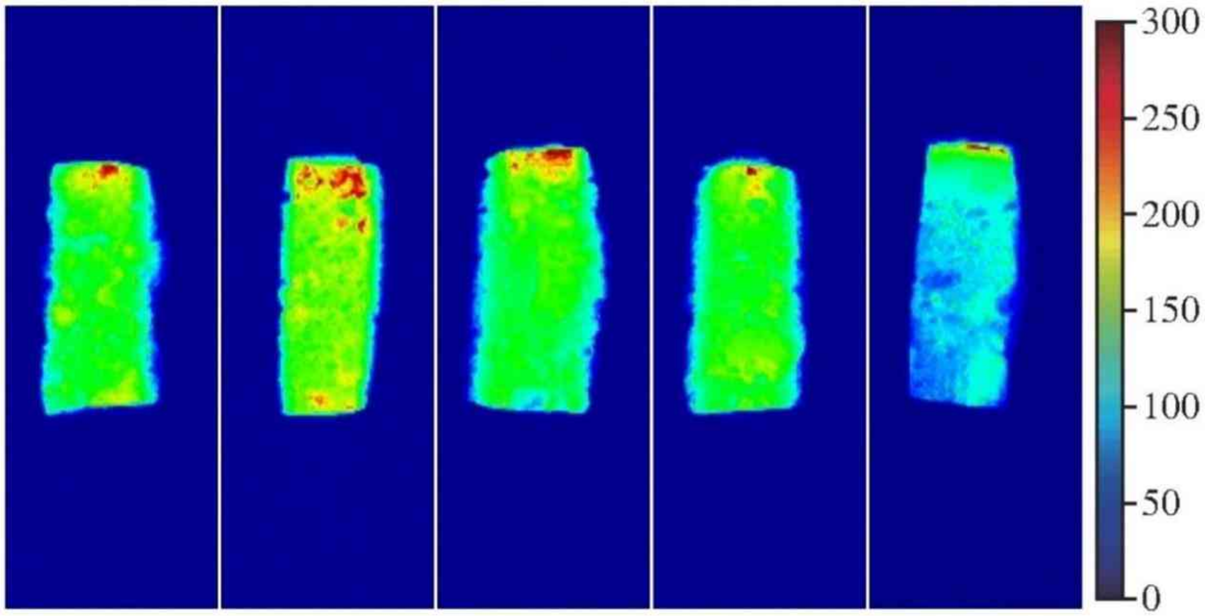


Fig. 4.3 Pseudo-color map of sausage products with dried beetroot

With the increase of the amount of pigment added, the red and yellow areas in the pseudo-color picture gradually become less, and the water molecules in the sauseges gradually decrease, and L4 is significantly reduced. This may be because excessive pigment is added to the sausage, which makes the sausage products protein cross-linked. The capacity is weakened, which reduces the water holding capacity of the sausage, so that the free water distribution of the sausage products is reduced.

4.2.8 Sensory evaluation of sausage products with dried beetroot

As shown in Table 4.14, the color score of the sample groups with added pigment was significantly higher than that of the control group.

Table 4.14

Effects of food coloring additions on sensory evaluation of sausage products

Sample	Color	Texture	Flavor	Viscosity	Overall acceptability
Control	2.80 ± 0.79^{b}	3.10 ± 0.99^{bc}	4.10 ± 1.85^{a}	4.00 ± 1.76^{a}	5.30 ± 1.06^{ab}
L1	4.30 ± 1.42^{a}	4.50 ± 1.08^{a}	5.10 ± 1.29^{a}	5.00 ± 1.56^{a}	4.50 ± 1.43^{b}
L2	4.50 ± 1.08^{a}	4.00 ± 1.05^{ab}	4.80 ± 1.55^{a}	3.90 ± 1.52^{a}	5.30 ± 1.20^{ab}

continuation of Table 4.14

L3	5.00±1.49^{a}	4.50±1.35^{a}	4.50±0.85^{a}	4.60±1.51^{a}	5.90±0.88^{a}
L4	5.20±1.48^{a}	2.70±1.25^{c}	4.20±1.55^{a}	4.10±1.20^{a}	4.10±1.37^{b}

The texture scores of the L1 and L3 were significantly higher than those of the control group. The L1 flavor score was the highest, followed by the L2 and L3. The L3 had the highest overall acceptable score and was significantly different from the control group. In addition, the color score and texture score of the L3 were significantly higher than those of the control group. Adding red yeast rice powder and beet red to sausages can make its color value more and more accepted by people, and the addition of red yeast rice powder and beet red has no effect on the flavor and viscosity of sausages, except to help increase appetite, and it is safe and has a suitable taste. The sensory scores of the L3 in all aspects are ideal.

4.3 Tehnology of biscuits enriched with dried beetroot, pretreated by freeze-thaw method

The research of biscuits was carried out at Hezhou University in China, Sumy National Agricultural University in Ukraine, the results of experiments are confirmed by relevant research protocols. Research protocols are given in the Addition A. "Protocols of experimental data". Degustation of biscuits with the addition of dried beetroot, pretreated by freeze-thaw method was carried out at Hezhou University in China. Degustation results were recorded in the relevant degustation protocols. Degustation protocols are given in the Addition B. "Degustation certificates".

Biscuits were mixture of wheat flour and water, and may contain sugar, butter, baking powder, eggs and other ingredients, and those ingredients were mixed together into dough for making biscuits [186]. Biscuit is the most popular bakery consumed by almost all levels of society, due to its low cost, good nutritional quality and longer shelf life in different varieties [187]. Conventional biscuits are high in carbohydrates, fat, sugar and calories, but low in fiber, vitamins and minerals, which make them unhealthy for daily consumption. It is required to improve nutritional quality of biscuits. Fortified biscuits have better nutritive value and healthy consumption choice [188].

Use of dried beetroot, pretreated by freeze-thaw method in bakery products have not been studied extensively. Therefore, the objective of this research work was to fortify the organoleptic and nutritional properties of biscuits with dried beetroot, pretreated by freeze-thaw method.

4.3.1 Biscuits with dried beetroot, pretreated by freeze-thaw method

4.3.1.1 The ingredients for biscuits

The ingredients for biscuits include low gluten wheat flour, corn starch, sucrose, milk powder, eggs, butter, baking soda, baking powder and salt, which were obtained from a local market of Taixing (Hezhou, China).

The reagents used in this experiment were all analytical reagents.

4.3.1.2 Preparation of dried beetroot, pretreated by freeze-thaw method

Fresh beetroots were washed, peeled and cut them into slices with diameter of 7 mm and thickness of 3 mm. Fresh beetroots slices were put into polyethylene bags, then put them in the refrigerator (–20 °C) to freeze for 12 h, then thawed them in the running water for 30 min. Finally, wiped the excess water on the surface of beetroot slices with absorbent paper to obtain frozen-thawed beetroot slices.

Frozen-thawed beetroot slices (1000 g) were placed uniformly on a tray (61 × 43 × 5 cm), and the tray was put into the microwave vacuum dryer cavity. The drying process was carried out under microwave power of 1000 W and vacuum degree of –0.09 MPa. The drying process was stopped when the final moisture content of beetroot slices was lower than 6.0% on a wet basis. The frozen-thawed beetroots were subjected to grind, then passed through 60-mesh sieve. dried beetroot, pretreated by freeze-thaw method was packed in a polyethylene bag and stored at 25 °C for further use.

4.3.1.3 Preparation of biscuits

Recipes of biscuits: Biscuits fortified with dried beetroot, pretreated by freeze-thaw method were prepared by substituting low-gluten wheat flour with beetroot powder. Various blends were prepared using low-gluten wheat flour and beetroot powder in the ratio of 100:0 (0%, T0), 95:5 (5%, T1), 90:10 (10%, T2), 85:15 (15%, T3), 80:20 (20%, T4). The ingredients used for the preparation biscuits were given in Table 4.15. Biscuits processing is shown in Figure 4.4.

Table 4.15

Recipes of biscuits with different additions of dried beetroot

Ingredients	Sample				
	T0 (100:0)	T1 (95:5)	T2 (90:10)	T3 (85:15)	T4 (80:20)
Dried beetroot, pretreated by freeze-thaw method (powdered), g	0	30	60	90	120
Low-gluten wheat flour, g	600	570	540	510	480
Sucrose, g	80	80	80	80	80
Egg liquid, g	140	140	140	140	140
Butter, g	55	55	55	55	55
Milk powder, g	50	50	50	50	50
Corn starch, g	27.5	27.5	27.5	27.5	27.5
Baking soda, g	1.5	1.5	1.5	1.5	1.5
Baking powder, g	2.5	2.5	2.5	2.5	2.5
Salt, g	1.5	1.5	1.5	1.5	1.5
Water, ml	42	42	42	42	42

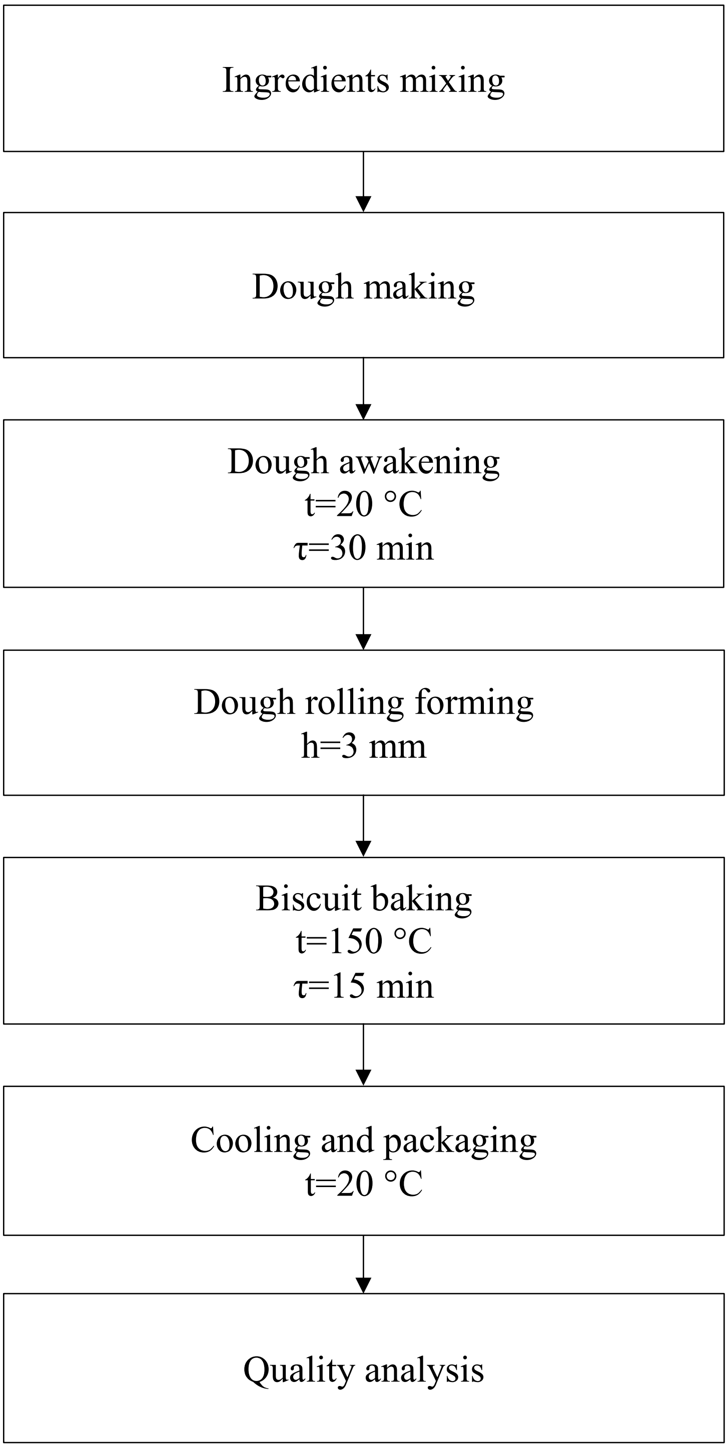


Fig. 4.4 Technological scheme of biscuits

Key operating points of technological process.

Ingredients mixing: accurately weighed each auxiliary material, preheated and melted the butter in advance, added sucrose, beetroot powder, eggs, baking soda, baking powder and salt in order, and mixed them evenly to form an emulsion.

Dough making: adding low gluten flour, milk powder and corn starch into the emulsion, fully mixed with auxiliary materials, and then knead by hand until the dough surface was smooth and the color was uniform.

Dough awakening: waking up the dough at room temperature for 30 min.

Rolling shaping: pressing the dough with a rolling pin to a thickness of 3 mm, cut with biscuit mould, and then placed them on a baking tray. The molding pattern was required to be clear, free of cracks and uniform in thickness.

Baking: the upper and lower baking temperature of baking oven were set at 150 °C, and the baking time was 15 min.

Cooling and packaging: taking out the baked biscuits from the oven, placed them at room temperature and cooled them before packaging.

4.3.2 Results and discussion on the quality properties of biscuits fortified with dried beetroot, pretreated by freeze-thaw method

4.3.2.1 Moisture content and sensory score of biscuits

The moisture content and sensory score of biscuits are illustrated in Table 4.16. With the increase of dried beetroot, pretreated by freeze-thaw method addition, the change of moisture content in biscuits was not obvious, ranged from 2.79 ± 0.63 to 3.30 ± 0.32%, and all the moisture content of biscuits was lower than 4.0%, which met the requirements of biscuit standards.

Meantime, the sensory score of biscuits increased first and then decreased, and the maximum sensory score (89.1 ± 1.9 points) occurred when the addition of dried beetroot, pretreated by freeze-thaw method was 20 g (10%, T2), demonstrating that the sample with 10% replacement of low-gluten wheat flour with beetroot powder obtained better color, taste, appearance, odor and flavor. Our findings were consistent with those of Ingle et al. [189], who stated that replacing up to 10% wheat flour with beetroot powder resulted in good acceptability of biscuits. When the addition of dried beetroot, pretreated by freeze-thaw method reached 20%, the color of biscuits was too dark that was no pleasant, and it had some rough and bitter taste, so the sensory score decreased. The sensory score reflected the effect of dried beetroot, pretreated by freeze-thaw method addition on the sensory quality of biscuits. Therefore, dried beetroot, pretreated by freeze-thaw method addition was 10%, the sensory quality of biscuits was the best.

Table 4.16

Moisture content and sensory score of biscuits

Sample	Moisture content, %	Sensory score, point
T0	3.13 ± 0.50^a	70.0 ± 2.4^d
T1	2.79 ± 0.63^a	79.6 ± 2.0^c
T2	3.02 ± 0.60^a	89.1 ± 1.9^a
T3	3.30 ± 0.32^a	84.6 ± 2.0^b
T4	3.05 ± 0.34^a	80.7 ± 1.8^c

4.3.2.2 Color parameters of biscuits

The color of biscuits is an important factor determining the acceptability of consumers. As shown in Figure 4.5, adding dried beetroot, pretreated by freeze-thaw method into the biscuits could make the biscuits appeared red color, which was easily accepted by consumers, but too much beetroot powder addition caused the color of biscuits to be too dark.

The color parameters of biscuits were displayed in Table 4.17. The *L* (lightness) and *b** (yellowness) decreased significantly with the increase of dried beetroot, pretreated by freeze-thaw method addition ($p < 0.05$), while with the increase of beetroot powder, the values of *a* (redness) first increased and then decreased. As shown in Table 4.17, the *L* value of control biscuits (T0) was 65.66 ± 2.47, and with the increase of dried beetroot, pretreated by freeze-thaw method addition, the *L* values of biscuits decreased, decreased from 48.76 ± 0.78 to 38.92 ± 0.77, indicating that the biscuits became darkness with the reduction in the proportion of low-gluten wheat flour. Moreover, the *b* values also significantly decreased with the increasing of dried beetroot, pretreated by freeze-thaw method addition, demonstrating the yellowness of biscuits kept decreasing. The change trend of *L* values and *b* values of biscuits were consistent with those of research in [9].

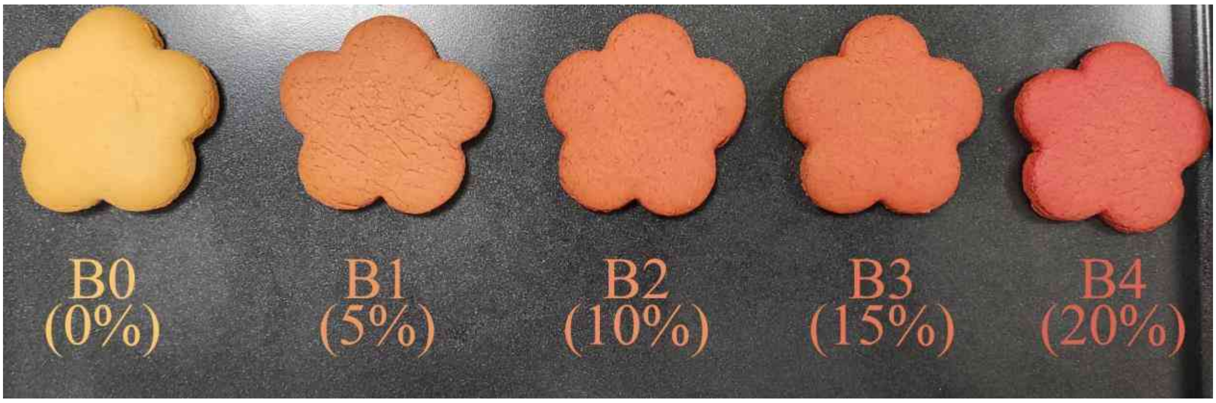


Fig. 4.5 Foto of biscuits with different additions of dried beetroot, pretreated by freeze-thaw method

The *a* value of control biscuits (T0) was 11.34 ± 0.43 and biscuits substitution with different dried beetroot, pretreated by freeze-thaw method ranged from 22.56 ± 0.29 to 25.06 ± 0.39, showing more reddish color than control. The biscuits displayed the highest *a* value (25.06 ± 0.39) with the dried beetroot, pretreated by freeze-thaw method addition of 10% (20 g, T2), indicating that the addition of beetroot powder should be appropriate, which due to too much beetroot powder will reduce the redness value and the sensory quality (see Table 2.2.2) of biscuits. The color difference is mainly caused by the pigment in the dried beetroot, pretreated by freeze-thaw method, the uneven surface area of biscuits exposed to high baking temperature, and colored compounds formed by chemical reactions such as caramelization and Maillard reaction during the baking process [190]. As a result, with addition of 10% (T2) dried beetroot, pretreated by freeze-thaw method, the biscuit displayed the best color characteristics in this study.

Table 4.17

Color parameters of biscuits

Sample	L^*	a^*	b^*
T0	65.66 ± 2.47^{a}	11.34 ± 0.43^{d}	22.32 ± 0.72^{a}
T1	48.76 ± 0.78^{b}	23.16 ± 0.24^{bc}	13.08 ± 0.46^{b}
T2	42.79 ± 0.66^{c}	25.06 ± 0.39^{a}	11.52 ± 0.51^{c}

continuation of Table 4.17

T3	40.46 ± 0.67^{d}	23.35 ± 0.58^{b}	9.61 ± 0.25^{d}
T4	38.92 ± 0.77^{e}	22.56 ± 0.29^{c}	7.67 ± 0.43^{e}

4.2.2.3 Texture parameters of biscuits

As shown in Table 4.18, the hardness of biscuits decreased with the increase of dried beetroot, pretreated by freeze-thaw method addition, but there is no significant difference between the hardness of biscuits with different beetroot powder addition ($p > 0.05$). It can be seen from Table 4.18 that the fracturability of biscuits decreased with increasing of dried beetroot, pretreated by freeze-thaw method addition. The addition amount of dried beetroot, pretreated by freeze-thaw method had no significant effect on springiness ($p > 0.05$). In terms of cohesiveness, gumminess, and chewiness, the effect of dried beetroot, pretreated by freeze-thaw method addition was not obvious, and when the beetroot powder addition of 40 g (20%, T4), the biscuits showed the lower cohesiveness, gumminess and chewiness than those of other biscuits. Overall, the effects of dried beetroot, pretreated by freeze-thaw method addition on the texture characteristics of biscuits were not obvious. When the beetroot powder addition was 10% (T2), the texture attributes of biscuits had no significant difference with those of the control group (T0), indicating that it is more appropriate to replace low-gluten wheat flour with 10% of dried beetroot, pretreated by freeze-thaw method.

Table 4.18

Texture parameters of biscuits

Sample	Hardness, g	Fracturability, g	Springiness, %	Cohesiveness, %	Chewiness
T0	228.3 ± 90.8^{a}	313.3 ± 147.1^{a}	0.967 ± 0.026^{a}	0.016 ± 0.003^{ab}	3.009 ± 0.883^{ab}
T1	215.8 ± 54.2^{a}	259.3 ± 83.8^{ab}	0.924 ± 0.056^{a}	0.018 ± 0.005^{ab}	3.443 ± 0.774^{a}
T2	209.0 ± 90.2^{a}	224.0 ± 87.4^{ab}	0.925 ± 0.060^{a}	0.021 ± 0.007^{a}	2.954 ± 0.687^{ab}
T3	182.1 ± 49.7^{a}	224.5 ± 61.1^{ab}	0.967 ± 0.036^{a}	0.020 ± 0.007^{ab}	3.285 ± 1.042^{a}
T4	165.9 ± 32.3^{a}	188.7 ± 67.8^{b}	0.965 ± 0.024^{a}	0.014 ± 0.004^{b}	2.190 ± 0.719^{b}

4.3.2.4 Contents of ash, protein and fat in biscuits

It can be seen from Table 4.19 that the ash content and protein content of biscuits increased significantly with the increase of dried beetroot, pretreated by freeze-thaw method addition ($p < 0.05$). Ash content of biscuits was significantly increased from 1.47 ± 0.18 to 3.24 ± 0.07 g/100g with addition of dried beetroot, pretreated by freeze-thaw method up to 20% (T4), as well as protein content as significantly increased from 9.85 ± 0.07 to 10.80 ± 0.14 g/100g. Results showed that higher addition of dried beetroot, pretreated by freeze-thaw method resulted in increased ash and protein content in biscuits were consistent with the result in [188], which was revealed that with increase level of beetroot powder in biscuits, where was increase in ash content and protein content of biscuits.

The addition of dried beetroot, pretreated by freeze-thaw method increased the fat content of biscuits, the result in accordance with the finding of Akanksha & Maurya [191], but was inconsistent with those results in [188–189]. There is no significant difference in fat content of biscuits with different beetroot powder additions ($p > 0.05$). The results indicated that the protein content and fat content of biscuits increased after dried beetroot, pretreated by freeze-thaw method replaced part of low-gluten wheat flour, demonstrating that the nutritional value of biscuits was improved with the addition of beetroot powder.

Table 4.19

Contents of ash, fat and protein in biscuits

Sample	Ash content, g/100g	Fat content, g/100g	Protein content, g/100g
T0	1.47 ± 0.18^{d}	7.80 ± 0.09^{b}	9.85 ± 0.07^{d}
T1	2.08 ± 0.13^{c}	8.12 ± 0.08^{a}	10.10 ± 0.08^{c}
T2	2.34 ± 0.22^{bc}	8.30 ± 0.10^{a}	10.30 ± 0.11^{bc}
T3	2.75 ± 0.11^{ab}	8.26 ± 0.09^{a}	10.52 ± 0.09^{b}
T4	3.24 ± 0.07^{a}	8.25 ± 0.07^{a}	10.80 ± 0.14^{a}

Conclusions to Section 4

This study revealed that dried beetroot, pretreated by freeze-thaw method had significant potential for use as an additive in meat products. Compared with the control group (B0), the addition of dried beetroot, pretreated by freeze-thaw method increased the moisture content and decreased the pH value of meat products. Color analysis showed that the addition of dried beetroot, pretreated by freeze-thaw method to the meat products resulted in a reduction of L^* and b^* values, while a^* values were increased compared to the control group. Texture profile analysis indicated that the addition of dried beetroot, pretreated by freeze-thaw method did not lead to significant differences in the texture characteristics of meat products. Sensory evaluation demonstrated that the addition of dried beetroot, pretreated by freeze-thaw method positively affected color, flavor and overall acceptability of the meat products. The results confirmed that the use of dried beetroot, pretreated by freeze-thaw method significantly prevented further development of lipid oxidation in meat products due to the antioxidant activities of beetroot. The addition of dried beetroot, pretreated by freeze-thaw method increased the protein content and ash content of meat products. In conclusion, dried beetroot, pretreated by freeze-thaw method could improve the physicochemical properties of meat products, not only improving color characteristics and sensory quality, and increasing protein content, but also inhibiting lipid oxidation of meat products. Dried beetroot, pretreated by freeze-thaw method could improve the physicochemical properties of meat products, not only improving sensory quality and increasing protein content, but also inhibiting lipid oxidation of meat products. The results revealed that adding 2.0% beetroot powder improve the physicochemical properties of meat products.

Sausage products with 400 g of chicken, 50 g of pig back dart, 80 g of pigskin, 6 g of bran as the main raw materials, adding 1.5g of red yeast rice and 1g of beet red, can provide the popular red color of sausages, and provide the cooking loss value of sausages. At the lowest, it helps to improve the hardness, stickiness and chewiness of sausages. Low-field NMR technology can be used to visually observe the moisture content in sausage products. The addition of natural colorants had no negative effect on hicken sausage quality. In the industrial application stage, it will be possible to reduce the amount of nitrite used when natural colorants are support for the application of natural pigments in sausage products.

It was observed that the addition of dried beetroot, pretreated by freeze-thaw method to biscuits had no significant effect on moisture content and texture attributes, but improved greater overall acceptability of biscuits. For the color characteristics, the substitution of dried beetroot, pretreated by freeze-thaw method reduced the L^* and b^* value, but increased a^* value. It may be concluded that dried beetroot, pretreated by freeze-thaw method enriched biscuits provided greater sensory properties (color, taste, odor and flavor). Nutritional analysis demonstrated that the increased dried beetroot, pretreated by freeze-thaw method addition increased the nutritional content (fat and protein) in comparison with control group (T0). The effects of dried beetroot, pretreated by freeze-thaw method addition on other macro-nutrients (carbohydrate, crude fiber), micro-nutrients (calcium, iron, zinc, phosphorus, magnesium etc.) and starch digestibility of biscuits need to be further studied. This study provided a strong theoretical basis for the comprehensive utilization of dried beetroot, pretreated by freeze-thaw method in biscuits. The results demonstrated that dried beetroot, pretreated by freeze-thaw method in biscuits provided greater sensory properties (color, taste, odor and flavor), and increased the nutritional content (fat and protein) of biscuits. It was concluded that the substitution of low-gluten wheat flour with dried beetroot, pretreated by freeze-thaw method up to 10% into the formulation of biscuits could enhance the organoleptic properties and nutritional value of biscuits.

SECTION 5
PRACTICAL IMPLEMENTATION OF DRIED BEETROOT, PRETREATED BY FREEZE-THAW METHOD AND FOOD PRODUCTS USING IT

In this section, the results of determining the socio-economic effect of the introduction of beetroot semi-finished products (dried beetroot, pretreated by freeze-thaw method) and culinary products with its use are given, the cost is calculated, and generalized data on the approval of research results are given. The economic expediency of implementing the developments in the practical activities of food industry enterprises and restaurant establishments has been proven.

5.1 Determination of the socio-economic effect of the introduction of the semi-finished beetroot production technology (dried beetroot, pretreated by freeze-thaw method)

The evaluation of the socio-economic effect of the introduction of the semi-finished beetroot technology (dried beetroot, pretreated by freeze-thaw method) was carried out with the following provisions in mind. In today's conditions, the formation of investment and current economic activity of restaurant establishments is based on the search for innovations that can be brought to the stage of industrial application. From these points of view, the technology of semi-finished beetroot (dried beetroot, pretreated by freeze-thaw method) is quite attractive. Firstly, this technology implements the main components of the innovative development strategy - marketing, technological, organizational, technical, and secondly, the technological principles of obtaining semi-finished products from root crops are determined and substantiated during the research, which allow expanding the product range, which according to marketing forecasts will be demanded by consumers.

The proposed technology involves complex processing of root crops, which was previously not used in the food industry due to the lack of industrial cultivation technologies. This approach to the processing of root crops allows to reduce the cost of production and make it affordable from an economic point of view for the broad segments of the population of Ukraine, and to increase the efficiency of production.

It is positive that as the main raw material in the technological cycle of the production of semi-finished products from dried beetroot, pretreated by freeze-thaw method are purchased from agricultural enterprises of Ukraine, which to a certain extent reduces the risks that arise under the conditions of using imported raw materials, namely, the increase in transportation costs and storage, failure to meet the delivery deadline, etc. The creation and introduction of such technologies is relevant in the conditions of the modern market economy of the state and is a priority direction of its development.

The technology of semi-finished products made from beetroot (dried beetroot, pretreated by freeze-thaw method) involves the use of natural raw materials of plant origin - root crops. Under these conditions, the creation of products with high nutritional and biological value is ensured, which helps ensure the health of consumers and increase their working capacity.

A direct quantitative assessment of the effectiveness of this technology was carried out by calculating the cost of new products in comparison with the cost of market analogues (tomato powder), which are also used as food coloring. To determine the cost of production at the first stage, the cost of raw materials and materials, which are necessary for the production of 1000 kg of semi-finished products from beetroot, was calculated. Costs at each technological stage of semi-finished beetroot production (dried beetroot, pretreated by freeze-thaw method) and equipment required for this are shown in table. 5.1.

Table 5.1

Cost modeling in the technology of semi-finished products from beetroot

Stages of production	Articles of expenditure	Equipment/storage space required
Purchase of beetroot and their storage for use in the technological process	Buying beetroot	Vegetable composition
	Electricity	
	Workforce	

continuation of Table 5.1

Washing and peeling	Water supply	Vegetable peeling machine
	Electricity	
	Workforce	
Cutting into slices	Electricity	Production slicer, Production table
	Workforce	
Freezing	Electricity	Freezer chamber Low-temperature monoblock
	Workforce	
Defrosting	Electricity	Refrigeration chamber Medium-temperature monoblock
	Workforce	
Drying	Electricity	Drying cupboard
	Workforce	
Packaging and labeling	Packaging materials	Polystyrene bags Vacuum cleaner Production table Label
	Electricity	
	Workforce	
Storage	Electricity	Dry products composition
	Workforce	

Table 5.1 data make it possible to summarize the main items of costs in the production of semi-finished products from beetroot (dried beetroot, pretreated by freeze-thaw methodroot), which is necessary for determining the total cost of production. For a better understanding of the process of making a semi-finished product from beetroot (dried beetroot, pretreated by freeze-thaw method), the costs for the purchase of the necessary equipment for starting production and the costs for its operation were calculated, according to the technical characteristics listed in the table. 5.2.

Table 5.2

Costs of the main means of production and their operation

Necessary equipment	Brand, sizes	Quantity based on 1t of manufactured products, piece	Electricity consumption per 1t, kW	Water consumption per 1t, liters	Market value as of 2023, UAH.
Vegetable peeling machine	Vektor XH 30 1020×590×590	2	12	7000	81950
Production slicer	Frosty HLC 300N 580×220×500	2	4,4	-	42870
Freezer chamber	Polair Professionale KMH100 3200×5300×2240	1	-	-	223224
Low-temperature monoblock	MXM LMN 331 1060×851×960	1	34,08	-	258988
Refrigeration chamber	Polair Standard KXC80 4060×5260×2200	1	-	-	216379
Medium-temperature monoblock	MXM MMN 344 1060×851×960	1	27	-	217036
Drying cupboard	СП-1130 904×1401×900	6	360	-	1103400
Production table	Chimneybud, 1800×700×850	2	-	-	38626
Vacuum cleaner	Vacuum packaging machine «Status SV-2000» 420×270×170	3	2,64	-	16350
In total					2198823

Table 5.2 data make it possible to calculate the cost of production, which will make it possible to determine the price range for a semi-finished beetroot (dried beetroot, pretreated by freeze-thaw methodroot).

To calculate the full cost of production, we took into account the cost of all costs for production and sales of manufactured products as of 2023 in Ukraine (Table 5.3).

Table 5.3

Calculation of the cost of semi-finished products from beetroot

Cost items for the production and sale of semi-finished products	Production factors per 1 ton of semi-finished products	Based on 1000 kg of semi-finished product as of 2023, UAH
Purchase of raw materials (60 UAH/kg)	7000 tons	14000
Labor force (number of employees and average daily wages)	16 people/8 people per shift/12 hour working day/15 working days per month	116524,8
Transportation	Delivery of 1t of raw materials once a day	7500
Electricity	440,12 kW	2090,57
Water supply	7000 liters	228,55
Rent of production premises 100 m^2	1 day	1050
Product labeling and packaging	1000 polystyrene bags (Vacuum bag PA/PE transparent food)	3200
Production cost	-	144593,92

continuation of Table 5.3

Equipment cost	2198823	-
Costs for preparation, equipment and development of production	3.5% of the equipment cost	-
Depreciation of equipment taking into account the costs of starting production (based on 10 years)	2275781,81 UAH/year	632,16
Costs for unsold products during the storage period	2.5% of the production cost	3614,85
Costs due to technical failure	1% of the production cost	1445,94
Enterprise income tax 2 group of single tax payers 20% of the minimum wage (1340 UAH/month)	Based on the production of 30 tons of semi-finished products per month	44,7
EUV of the enterprise 2 group of payers of the single tax 22% of the minimum wage (1474 UAH/month)	Based on the production of 30 tons of semi-finished products per month	49,1
The minimum payment of personal income tax is 18% of the minimum wage (1206 UAH/month) for an employee	Based on the production of 30 tons of semi-finished products per month (8 employees)	643,2
The minimum payment of social security is 22% of the minimum wage (1474 UAH/month) for an employee	Based on the production of 30 tons of semi-finished products per month (8 employees)	786,2
The cost price of 1000 kg		151810,07
Enterprise profit (minimum 15% markup)		22771,51
The total cost of 1000 kg		174581,58
VAT 20%		34916,32
Selling price 1000 kg		209497,9

The average statistical rate of output from 1 ton of raw material (beetroot) is 145 kg on average. Since the calculations are based on 1 ton of finished products, it is determined that 1 day will be spent on its production. The rent of the production premises of 150 m2 was determined on the basis of 1 working day, with a total cost of 31500 UAH for 30 days of rent.

Labor costs were calculated in accordance with the Law of Ukraine "On the State Budget of Ukraine for 2023" dated 03.11.2022 No. 2710-IX and amount to UAH 40.46/hour with a 12-hour shift work schedule. According to the tariffs for 2023, which are presented separately for each region in Ukraine, the average cost of 1 kW of electricity for enterprises of voltage class 2, which consume more than 750 kW per month, is 4.75 UAH/kW. The cost of 1m3 of water on average in Ukraine and the tariff for services for centralized water supply and drainage in the amount of UAH 32.65 are taken into account. After analyzing the freight transportation market in the sector of up to 5 tons, the cost per 1 km, on average in Ukraine, is 15 UAH/km. The maximum distance for the delivery of raw materials according to the maximum profitability of production is noted to be no more than 500 km, which is taken as a basis for calculations. The costs of preparation, equipment and development of production make 3.5 % of the cost of the equipment. Costs for unsold products during the storage period amount to 2.5 % of the production cost. Costs due to technical defects amount to 1% of production cost. Thus, the calculations made it possible to determine the selling price of 1,000 kg of the developed product, which is 209,497.9 UAH.

It was determined that the introduction of semi-finished product technology in restaurants and food industry enterprises will allow the business entity to earn a profit of 22.77...128.19 thousand UAH per ton of sold products.

To determine the selling price of a semi-finished beetroot (dried beetroot, pretreated by freeze-thaw method), the market price of an analogue, tomato powder (which is also used as a food coloring), was taken into account, which on average amounted to 350 UAH/kg (the selling price of tomato powder is quite high , taking into account the average price of fresh tomatoes in the season of their mass harvesting by farmers, which is 15 UAH/kg, which is 3 times higher than the price of beetroot) as of 2023. Therefore, taking into account that the cost price of dried beetroot, pretreated by freeze-thaw method is 151.81 UAH/kg, producers of these products can freely set the market price, determining the markup in the range from 15% (minimum markup) to 84.44% (maximum markup). At its discretion and depending on the situation in the region of sale and on the market for selling red food colorings. Such an opportunity to choose the price will allow it to be adapted to the economy of the region and create the most competitive products from dried beetroot, pretreated by freeze-thaw method while maximizing profit.

5.2 Implementation of research results into practice

Based on the implementation of the results of the innovative strategy of developing new products, conducted theoretical and experimental research, the technology of semi-finished beetroot (dried beetroot, pretreated by freeze-thaw method) and culinary products using it has been tested and implemented in the food industry.

The normative documentation of TS 10.8-04718013-007:2022 "Dried beetroot" (Addition C) and TS 10.3-04718013-008:2022 "Concentrated and dried taro products" (Addition D) was developed and approved, which regulates technical requirements and the technological process of production.

The regulatory documentation in the People's Republic of China has been developed and approved Q/YTBG-0004S-2023 «Tough biscuits fortified with beetroot powder» (Addition E); Q/YTBG-0005S-2023 «Chicken sausages fortified with beetroot powder» (Addition F), which regulates the technical requirements and the technological process of production at the food enterprise. The semi-finished product from beetroot (dried beetroot, pretreated by freeze-thaw method) has been introduced at specialized enterprises (Table 5.4). The profitability of the products from the sale of the experimental and industrial batch is shown in Fig. 5.1.

Table 5.4

Certificates of implementation of dried beetroot, pretreated by freeze-thaw method

Enterprise	Name	Addition
Individual entrepreneur "Filon A.M."	Sausage technology using dried beetroot, pretreated by freeze-thaw method	Addition G
	Biscuit technology using dried beetroot, pretreated by freeze-thaw method	Addition H
	Technology of sausage products using dried beetroot	Addition I
	Technology of chicken sausages using concentrated taro products	Addition J
Shenzhen Wah Tai Xing Foods Co., Ltd.	Tough Biscuits Fortified With Beetroot Powder	Addition K
	Chicken Sausages Fortified With Beetroot Powder	Addition L
Individual entrepreneur "Klymenko L.O."	Sausage technology using dried beetroot, pretreated by freeze-thaw method	Addition M
	Biscuit technology using dried beetroot, pretreated by freeze-thaw method	Addition N
	Technology of sausage products using dried beetroot	Addition O
	Technology of chicken sausages using concentrated taro products	Addition P

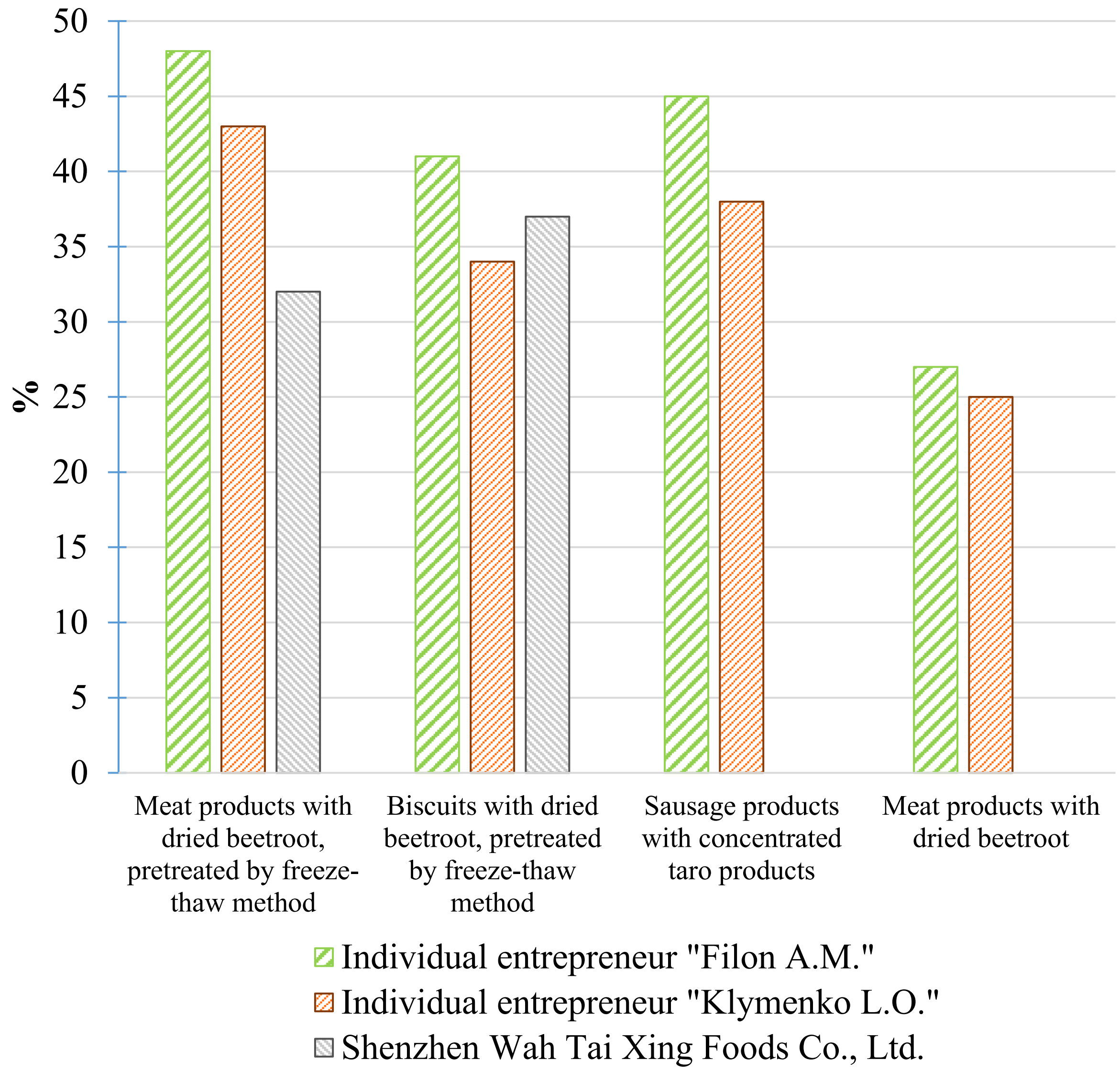


Fig. 5.1. Product profitability

According to fig. 5.1, the profitability of the products from the sale of the research and industrial batch in the amount of 30 kg of finished products is at a high level. The proposed beetroot semi-finished product (dried beetroot, pretreated by freeze-thaw method) and examples of its use in optimized recipes for confectionery and sausage products allow the economically efficient use of beetroot semi-finished products (dried beetroot, pretreated by freeze-thaw method) in any food enterprises in Ukraine and China.

Conclusions to Section 5

1. An assessment of the socio-economic effect of the development and implementation of the semi-finished beetroot (dried beetroot, pretreated by

freeze-thaw method) technology and culinary products using it at food enterprises and restaurant establishments was carried out. It is shown that the determined technological principles of production of new products allow to ensure complex processing of beetroot, which helps to reduce the cost of production, increase the efficiency of the technological process.

2. A complex of organizational and technical measures was carried out to implement new technologies at food enterprises and restaurant establishments: Individual entrepreneur "Filon A.M.", Shenzhen Wah Tai Xing Foods Co., Ltd., Individual entrepreneur "Klimenko".

3. The calculations made it possible to determine the selling price of 1,000 kg of the developed product, which is 209,497.9 UAH. It was determined that the introduction of semi-finished product technology in restaurants and food industry enterprises will allow the business entity to earn a profit of 22.77...128.19 thousand UAH per ton of sold products.

CONCLUSIONS

1. For heat pump drying, the best drying process parameters were beetroot slices with thickness of 5 mm, drying temperature of 65 °C, and loading density of 2.0 kg/m^2. The ideal conditions for vacuum microwave drying of beetroots were microwave power of 500 W, vacuum degree of –90 kPa, and sample thickness of 2 mm.

2. Different drying methods significantly affect the quality properties of beetroots. According to the results, it was demonstrated that VD+LMD was the optimal microwave-assisted drying method for beetroot drying. Different drying methods (MVD, VD, MD, HPD and FD) can significantly affect the bioactive compounds of beetroots, and considering the quality attributes and drying time, the combined drying methods (HPD+MVD) may guarantee high quality of beetroots and a short drying time.

3. The physical properties, bioactive compounds and antioxidant activity of microwave dried beetroots were significantly affected by freeze-thaw cycles. With the increase of number of freeze-thaw cycles, the drying time, rehydration ratio, bioactive compounds, FRAP value and ABTS radical scavenging decreased significantly. Freeze thaw once (FT1) was proved the best number of freeze-thaw cycles. The results demonstrated that freeze thaw once (FT1) was the best number of freeze-thaw cycles, and the optimal freezing temperature was –20 °C, and water thawing was a more suitable way to thaw the frozen beetroots.

4. Beetroot powder could improve the physicochemical properties of meat products, not only improving sensory quality and increasing protein content, but also inhibiting lipid oxidation of meat products. Also, betalain of beetroot powder is an effective antioxidant and food coloring in meat products and sausage products. The results revealed that the addition of 2.0% beetroot powder could significantly improve the physicochemical properties of meat products.

5. The results showed that the addition of dried beetroot, pretreated by freeze-thaw method to biscuits provides better sensory properties (color, taste and

smell) and increases the nutritional value of biscuits. It was concluded that the substitution of low-gluten wheat flour with dried beetroot, pretreated by freeze-thaw method up to 10% into the formulation of biscuits could enhance the organoleptic properties and nutritional value of biscuits.

6. An assessment of the socio-economic effect of the development and implementation of the semi-finished beetroot (dried beetroot, pretreated by freeze-thaw method) technology and culinary products using it at food enterprises and restaurant establishments was carried out. It is shown that the determined technological principles of production of new products allow to ensure complex processing of beetroot, which helps to reduce the cost of production, increase the efficiency of the technological process. A complex of organizational and technical measures was carried out to implement new technologies at food enterprises and restaurant establishments. It was determined that the introduction of semi-finished product technology in restaurants and food industry enterprises will allow the business entity to earn a profit of 22.77...128.19 thousand UAH per ton of sold products.

REFERENCES

1. Varshney K., & Mishra K. (2022). An Analysis of health benefits of beetroot. *International Journal of Innovative Research in Engineering and Management*, 9(1), 207–210.
2. De Oliveira, S. P. A., do Nascimento, H. M. A., Sampaio, K. B., & de Souza, E. L. (2021). A review on bioactive compounds of beet (*Beta vulgaris* L. *subsp. vulgaris*) with special emphasis on their beneficial effects on gut microbiota and gastrointestinal health. *Critical Reviews in Food Science and Nutrition*, 61(12), 2022–2033.
3. Mirmiran, P., Houshialsadat, Z., Gaeini, Z., Bahadoran, Z., & Azizi, F. (2020). Functional properties of beetroot (*Beta vulgaris*) in management of cardio-metabolic diseases. *Nutrition and Metabolism*, 17(1), 1–15.
4. Thiruvengadam, M., Chung, I. M., Samynathan, R., Chandar, S. R. H., Venkidasamy, B., Sarkar, T., Rebezov, M., Gorelik, O., Shariati, M. A., & Simal-Gandara, J. (2022). A comprehensive review of beetroot (*Beta vulgaris* L.) bioactive components in the food and pharmaceutical industries. *Critical Reviews in Food Science and Nutrition*, 1–33. https://doi.org/10.1080/10408398.2022.2108367
5. Chhikara, N., Kushwaha, K., Sharma, P., Gat, Y., & Panghal, A. (2019). Bioactive compounds of beetroot and utilization in food processing industry: A critical review. Food chemistry, 272, 192–200.
6. Dhiman, A., Suhag, R., Chauhan, D. S., Thakur, D., Chhikara, S., & Prabhakar, P. K. (2021). Status of beetroot processing and processed products: Thermal and emerging technologies intervention. *Trends in Food Science and Technology*, 114, 443–458.
7. USDA. (2019). U. S. Department of agriculture, agricultural research service, national nutrient database for standard reference, FDC ID: 169145.
8. Nemzer, B., Pietrzkowski, Z., Spórna, A., Stalica, P., Thresher, W., Michałowski, T., & Wybraniec, S. (2011). Betalainic and nutritional profiles of

pigment-enriched red beet root (*Beta vulgaris* L.) dried extracts. *Food Chemistry*, 127(1), 42–53.

9. Paciulli, M., Medina-Meza, I. G., Chiavaro, E., & Barbosa-Canovas, G. V. (2016). Impact of thermal and high pressure processing on quality parameters of beetroot (*Beta vulgaris* L.). *LWT-Food Science and Technology*, 68, 98–104.

10. Nistor, O. V., Ceclu, L. S., Andronoiu, D. G., Rudi, L., & Botez, E. (2017). Influence of different drying methods on the physicochemical properties of red beetroot (*Beta vulgaris* L. *var. Cylindra)*. *Food Chemistry*, 236, 59–67.

11. Ravichandran, K., Iryna Smetanska, I., UshaAntony, U. (2020). Chapter 19 - Red beet. Nutritional Composition and Antioxidant Properties of Fruits and Vegetables. *Academic Press*, 315–321.

12. Sawicki, T., & Wiczkowski, W. (2018). The effects of boiling and fermentation on betalain profiles and antioxidant capacities of red beetroot products. *Food Chemistry*, 259, 292–303.

13. Gasztonyi, M. N., Daood, H., Hajos, M. T., & Biacs, P. (2001). Comparison of red beet (*Beta vulgaris* var. *conditiva*) varieties on the basis of their pigment components. *Journal of the Science of Food and Agriculture*, 81(9), 932–933.

14. Sawicki, T., Martinez-Villaluenga, C., Frias, J., Wiczkowski, W., Peñas, E., Bączek, N., & Zieliński, H. (2019). The effect of processing and in vitro digestion on the betalain profile and ACE inhibition activity of red beetroot products. *Journal of Functional Foods*, 55, 229–237.

15. Ninfali, P., & Angelino, D. (2013). Nutritional and functional potential of Beta vulgaris cicla and rubra. *Fitoterapia*, 89, 188–199.

16. Pandita, D., Pandita, A., Pamuru, R. R., & Nayik, G. A. (2020). Beetroot. Antioxidants in Vegetables and Nuts - Properties and Health Benefits. *Springer Singapore*. 45–74.

17. Chen, L., Zhu, Y., Hu, Z., Wu, S., & Jin, C. (2021). Beetroot as a functional food with huge health benefits: Antioxidant, antitumor, physical

function, and chronic metabolomics activity. *Food Science and Nutrition*, 9(11), 6406–6420.

18. Vinson, J. A., Hao, Y., Su, X., & Zubik, L. (1998). Phenol antioxidant quantity and quality in foods: Vegetables. *Journal of Agricultural and Food Chemistry*, 46, 3630–3634.

19. Vijaya, D., & Thangaraj, N. (2020). A study on the antioxidant and anticancer activity of red beet pigment of betalains from Beta vulgaris. *The International journal of analytical and experimental modal analysis*, 12(2), 2436–2439.

20. Lee, C. H., Wettasinghe, M., Bolling, B. W., Ji, L. L., & Parkin, K. L. (2005). Betalains, phase II enzyme-inducing components from red beetroot (*Beta vulgaris* L.) extracts. *Nutrition and cancer*, 53(1), 91–103.

21. Varshney, K., & Mishra, K. (2022). An analysis of health benefits of beetroot. *International Journal of Innovative Research in Engineering & Management (IJIREM)*, 9(1), 207–210.

22. Lundberg, J. O., Carlström, M., & Weitzberg, E. (2018). Metabolic effects of dietary nitrate in health and disease. *Cell metabolism*, 28(1), 9–22.

23. Milton-Laskibar, I., Martínez, J. A., & Portillo, M. P. (2021). Current knowledge on beetroot bioactive compounds: Role of nitrate and betalains in health and disease. *Foods*, 10(6), 1314.

24. Domínguez, R., Cuenca, E., Maté-Muñoz, J. L., García-Fernández, P., Serra-Paya, N., Lozano-Estevan, M. D. C., Veiga-Herreros, P., & Garnacho-Castaño, M. V. (2017). Effects of beetroot juice supplementation on cardiorespiratory endurance in athletes. A systematic review. *Nutrients*, 9(1), 43.

25. Kumar, S., & Brooks, M. S. L. (2017). Use of red beet (*Beta vulgaris* L.) for antimicrobial applications-a critical review. *Food and Bioprocess Technology*, 11(1), 17–42.

26. Gong, S., Jiao, C., & Guo, L. (2022). Antibacterial mechanism of beetroot (*Beta vulgaris*) extract against Listeria monocytogenes through apoptosis-like death and its application in cooked pork. *LWT-Food Science and*

Technology, 165, 113711.

27. Lechner, J. F., & Stoner, G. D. (2019). Red beetroot and betalains as cancer chemopreventative agents. *Molecules*, 24(8), 1602.

28. Bangar, S. P., Sharma, N., Sanwal, N., Lorenzo, J. M., & Sahu, J. K. (2022). Bioactive potential of beetroot (*Beta vulgaris*). *Food Research International*, 158, 111556.

29. Paula, R. R., Vimercati, W. C., Araújo, C. D. S., Macedo, L. L., Teixeira, L. J. Q., & Saraiva, S. H. (2020). Drying kinetics and physicochemical properties of whey dried by foam mat drying. *Journal of Food Processing and Preservation*, 44(10). e14796.

30. Vallespir, F., Cárcel, J. A., Marra, F., Eim, V. S., & Simal, S. (2018). Improvement of mass transfer by freezing pre-treatment and ultrasound application on the convective drying of beetroot (*Beta vulgaris* L.). *Food and Bioprocess Technology*, 11, 72–83.

31. Nowak, D., & Jakubczyk, E. (2020). The freeze-drying of foods—The characteristic of the process course and the effect of its parameters on the physical properties of food materials. *Foods*, 9(10), 1488.

32. Janiszewska-Turak, E., Rybak, K., Grzybowska, E., Konopka, E., & Witrowa-Rajchert, D. (2021). The influence of different pretreatment methods on color and pigment change in beetroot products. *Molecules*, 26(12), 3683.

33. Marfil, P. H. M., Santos, E. M., & Telis, V. R. N. (2008). Ascorbic acid degradation kinetics in tomatoes at different drying conditions. *LWT-Food Science and Technology*, 41(9), 1642–1647.

34. Figiel, A. (2010). Drying kinetics and quality of beetroots dehydrated by combination of convective and vacuum-microwave methods. *Journal of Food Engineering*, 98(4), 461–470.

35. Dalmau, M. E., Eim, V., Rosselló, C., Cárcel, J. A., & Simal, S. (2019). Effects of convective drying and freeze-drying on the release of bioactive compounds from beetroot during in vitro gastric digestion. *Food and Function*, 10(6), 3209–3223.

36. Chua, K. J., Chou, S. K., Ho, J. C., & Hawlader, M. N. A. (2002). Heat pump drying: Recent developments and future trends. *Drying Technology*, 20(8), 1579–1610.

37. Liu, Y., Sabadash, S. M., Duan, Z. (2021). Effect of heat pump temperature on the physical properties, bioactive compounds and antioxidant capacity of beetroots. *Journal of Chemistry and Technologies*, 29(4), 595–604.

38. Hentabli, M., Belhadj, A. E., Benimam, H., Dahmoune, F., & Keskes, S. (2021). Vacuum drying of the Terbinafine HCl powder: A kinetics study and mathematical modeling. *Powder Technology*, 383, 220–232.

39. Kuma, P. S., & Sagar, V. R. (2014). Drying kinetics and physico-chemical characteristics of osmo- dehydrated mango, guava and aonla under different drying conditions. *Journal of Food Science and Technology*, 51, 1540–1546.

40. Mella, C., Vega-Gálvez, A., Uribe, E., Pastena, A., Mejias, N., & Quispe-Fuentes, I. (2022). Impact of vacuum drying on drying characteristics and functional properties of beetroot (*Beta vulgaris*). *Applied Food Research*, 2(1), 100120.

41. Székely, D., Illés, B., Stéger-Máté, M., & Monspart-Sényi, J. (2016). Effect of drying methods for inner parameters of red beetroot (*Beta vulgaris* L.). *Acta Universitatis Sapientiae, Alimentaria*, 9(1), 60–68.

42. Kerr, W. L., & Varner, A. (2020). Chemical and physical properties of vacuum-dried red beetroot (*Beta vulgaris*) powders compared to other drying methods. *Drying Technology*, 38(9), 1165–1174.

43. Lin, T. M., Durance, T. D., & Scaman, C. H. (1998). Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Research International*, 31(2), 111–117.

44. Sham, P. W. Y., Scaman, C. H., & Durance, T. D. (2001). Texture of vacuum microwave dehydrated apple chips as affected by calcium pretreatment, vacuum level, and apple variety. *Journal of Food Science*, 66(9), 1341–1347.

45. Lech, K., Figiel, A., Wojdyło, A., Korzeniowska, M., Serowik, M., &

Szarycz, M. (2015). Drying kinetics and bioactivity of beetroot slices pretreated in concentrated chokeberry juice and dried with vacuum microwaves. *Drying Technology*, 33(13), 1644–1653.

46. Székely, D., Vidák, K., Furulyás, D., Ribárszki, Á., & Stéger-Máté, M. (2019). Effect of drying methods on physicochemical parameters of different red beetroots (*Beta vulgaris* L.) species. *Periodica Polytechnica Chemical Engineering*, 63(3), 485–490.

47. Ng, M. L., & Sulaiman, R. (2018). Development of beetroot (*Beta vulgaris*) powder using foam mat drying. *LWT-Food Science and Technology*, 88, 80–86.

48. Hajiaghaei, M., & Sharifi, A. (2022). Physicochemical properties of red beetroot and quince fruit extracts instant beverage powder: Effect of drying method and maltodextrin concentration. *Journal of Food Quality*, https://doi.org/10.1155/2022/7499994

49. Bunkar, D. S., Anand, A., Meena, K. K., Goyal, S. K., & Paswan, V. K. (2020). Development of production technology for preparation of beetroot powder using different drying methods. *Annals of Phytomedicine*, 9(2), 293–301.

50. Malakar, S., Alam, M., & Arora, V. K. (2022). Evacuated tube solar and sun drying of beetroot slices: Comparative assessment of thermal performance, drying kinetics, and quality analysis. *Solar Energy*, 233, 246–258.

51. Kaur, K., & Singh, A. K. (2014). Drying kinetics and quality characteristics of beetroot slices under hot air followed by microwave finish drying. *African Journal of Agricultural Research*, 9(16), 1238–1243.

52. Seremet, L., Nistor, O. V., Andronoiu, D. G., Mocanu, G. D., Barbu, V. V., Maidan, A., Rudi, L., & Botez, E. (2020). Development of several hybrid drying methods used to obtain red beetroot powder. *Food chemistry*, 310, 125637.

53. Bassey, E. J., Cheng, J.-H., & Sun, D.-W. (2021). Novel nonthermal and thermal pretreatments for enhancing drying performance and improving quality of fruits and vegetables. *Trends in Food Science & Technology*, 112, 137–148.

54. Sripinyowanich, J., & Noomhorm, A. (2013). Effects of freezing pretreatment, microwave-assisted vibro-fluidized bed drying and drying temperature on instant rice production and quality. *Journal of Food Processing and Preservation*, 37(4), 314–324.

55. Deng, L. Z., Mujumdar, A. S., Zhang, Q., Yang, X. H., Wang, J., Zheng, Z. A., Gao, Z. J., & Xiao, H. W. (2019). Chemical and physical pretreatments of fruits and vegetables: Effects on drying characteristics and quality attributes – a comprehensive review. *Critical Reviews in Food Science and Nutrition*, 59(9), 1408–1432.

56. Ando, Y., Maeda, Y., Mizutani, K., Wakatsuki, N., Hagiwara, S., & Nabetani, H. (2016). Impact of blanching and freeze-thaw pretreatment on drying rate of carrot roots in relation to changes in cell membrane function and cell wall structure. *LWT-Food Science and Technology*, 71, 40–46.

57. Liu, Y.-Y., Wang, Y., Lv, W.-Q., Li, D., Wang, L.-J. (2021). Freeze-thaw and ultrasound pretreatment before microwave combined drying affects drying kinetics, cell structure and quality parameters of *Platycodon grandiflorum*. *Industrial Crops and Products*, 164, 113391.

58. Lan, W., Hu, X., Sun, X., Zhang, X., & Xie, J. (2020). Effect of the number of freeze-thaw cycles number on the quality of Pacific white shrimp (*Litopenaeus vannamei*): An emphasis on moisture migration and microstructure by LF-NMR and SEM. *Aquaculture and Fisheries*, 5(4), 193–200.

59. Li, M., Guan, Z. Q., & Xie, D. J. (2016). Experimental study of freeze-thaw cycles placement in heat pump drying of tilapia fillets. *Chemical Engineering Transactions*, 55, 241–246.

60. Ge, X., Wang, H., Yin, M., & Wang, X. (2022). Effect of different thawing methods on the physicochemical properties and microstructure of frozen instant sea cucumber. *Foods*, 11(17), 2616.

61. Feng, Y., Tan, C. P., Zhou, C., Yagoub, A. E. A., Xu, B., Sun, Y., Ma, H., Xu, X., & Yu, X. (2020). Effect of freeze-thaw cycles pretreatment on the vacuum freeze-drying process and physicochemical properties of the dried garlic

slices. *Food chemistry*, 324, 126883.

62. Junqueira, J. R. D. J., Corrêa, J. L. G., Oliveira, H. M. D., Avelar, R. I. S., & Pio, L. A. S. (2017). Convective drying of cape gooseberry fruits: Effect of pretreatments on kinetics and quality parameters. *LWT-Food Science and Technology*, 82, 404–410.

63. Hajji, W., Bellagha, S., & Allaf, K. (2020). Effect of partial drying intensity, frozen storage and repeated freeze-thaw cycles on some quality attributes of dehydrofrozen quince fruit. *Journal of Food Measurement and Characterization*, 14(1), 353–365.

64. Madhu, B., Srinivas, M. S., Srinivas, G., & Jain, S. K. (2019). Ultrasonic technology and its applications in quality control, processing and preservation of food: A review. *Current Journal of Applied Science and Technology*, 32(5), 1–11.

65. Fuente-Blanco, S., Sarabia, E. R. F., Acosta-Aparicio, V. M., Blanco-Blanco, A., & Gallego-Juárez, J. A. (2006). Food drying process by power ultrasound. *Ultrasonics*, 44 (Suppl), e523–e527.

66. Szadzińska, J., Mierzwa, D., Pawłowski, A., Musielak, G., Pashminehazar, R., & Kharaghani, A. (2019). Ultrasound- and microwave-assisted intermittent drying of red beetroot. *Drying Technology*, 38(1–2), 93–107.

67. Soquetta, M. B., Schmaltz, S., Righes, F. W., Salvalaggio, R., & Terra, L. de M. (2017). Effects of pretreatment ultrasound bath and ultrasonic probe, in osmotic dehydration, in the kinetics of oven drying and the physicochemical properties of beet snacks. *Journal of Food Processing and Preservation*, 42(1), e13393.

68. Torreggiani, D. (1993). Osmotic dehydration in fruit and vegetables. *Food Research International*, 26(1), 59–68.

69. Ciurzyńska, A., Kowalska, H., Czajkowska, K. & Lenart, A. (2016). Osmotic dehydration in production of sustainable and healthy food. *Trends in Food Science and Technology*, 50, 186–192.

70. Peters, A. P., Tullio, L. T., Lima, R. F. D., Carvalho, C. B. O. D.,

Barros, Z. M. P., Fraga, E., & Ferreira, S. M. R. (2021). Physicochemical properties and sensory acceptability of beetroot chips pre-treated by osmotic dehydration and ultrasound. *Brazilian Journal of Food Technology*, 24(3), 20–68.

71. Ramos, J. A., Furlaneto, K. A., Lundgren, G. A., Mariano-nasser, F. A. D. C., Mendonca, V. Z., Nasser, M. D., & Vieites, R. L. (2018). Stability of bioactive compounds in minimally processed beet according to the cooking methods. *Food Science and Technology*, 38, 643–646.

72. Lin, S., & Brewer, M. S. (2005). Effects of blanching method on the quality characteristics of frozen peas. *Journal of Food Quality*, 28(4), 350–360.

73. Ndiaye, C., Xu, S. Y., & Wang, Z. (2009). Steam blanching effect on polyphenoloxidase, peroxidase and colour of mango (*Mangifera indica* L.) slices. *Food Chemistry*, 113(1), 92–95.

74. Del Bo', C., Riso, P., Brambilla, A., Gardana, C., Rizzolo, A., Simonetti, P., Bertolo, G., Klimis-Zacas, D., & Porrini, M. (2012). Blanching improves anthocyanin absorption from highbush blueberry (*Vaccinium corymbosum* L.) puree in healthy human volunteers: A pilot study. *Journal of Agricultural and Food Chemistry*, 60(36), 9298–9304.

75. Kaur, S., Kaur, N., Aggarwal, P., & Grover, K. (2021). Bioactive compounds, antioxidant activity and color retention of beetroot (*Beta vulgaris* L.) powder: Effect of steam blanching with refrigeration and storage. *Journal of Food Processing and Preservation*, 45(3), e15247.

76. Zhang, Y., Sun, B. H., Pei, Y. P., Vidyarthi, S. K., & Xiao, H. W. (2021). Vacuum-steam pulsed blanching (VSPB): An emerging blanching technology for beetroot. *LWT-Food Science and Technology*, 147(5), 111532.

77. Ciurzyńska, A., Falacińska, J., Kowalska, H., Kowalska, J., Galus, S., Marzec, A., Domian, E. (2021). The effect of pre-treatment (blanching, ultrasound and freezing) on quality of freeze-dried red beets. *Foods*, 10(1), 132.

78. Janiszewska-Turak, E., Rybak, K., Grzybowska, E., Konopka, E., & Witrowa-Rajchert, D. (2021). The influence of different pretreatment methods on color and pigment change in beetroot products. *Molecules*, 26(12), 3683.

79. Alonzo-Macías, M., Cardador-Martínez, A., Besombes, C., Allaf, K., Tejada-Ortigoza, V., Soria-Mejía, M. C., Vazquez-Garcia, R., & Téllez-Pérez, C. (2020). Instant controlled pressure drop as blanching and texturing pre-treatment to preserve the antioxidant compounds of red dried beetroot (*Beta vulgaris* L.). *Molecules*, 25(18), 4132.

80. Shirsat, N., Lyng, J. G., Brunton, N. P., & McKenna., B. (2004). Ohmic processing: Electrical conductivities of pork cuts. *Meat Science*, 67(3), 507–514.

81. Darvishi, H., Hosainpour, A., Nargesi, F., & Fadavi, A. (2015). Exergy and energy analyses of liquid food in an Ohmic heating process: A case study of tomato production. *Innovative Food Science and Emerging Technologies*, 31, 73–82.

82. Shynkaryk, M. V., Lebovka, N. I., & Vorobiev, E. (2008). Pulsed electric fields and temperature effects on drying and rehydration of red beetroots. *Drying Technology*, 26(6), 695–704.

83. Varshney, K., & Mishra, K. (2022). An analysis of health benefits of beetroot. *International Journal of Innovative Research in Engineering & Management* (IJIREM), 9(1), 207–210.

84. Krejčová, A., Černohorský, T., & Meixner, D. (2007). Elemental analysis of instant soups and seasoning mixtures by ICP–OES. *Food Chemistry*, 105(1), 242–247.

85. Kumar, S., & Brooks, M. S. L. (2017). Use of red beet (*Beta vulgaris* L.) for antimicrobial applications-a critical review. *Food and Bioprocess Technology*, 11(1), 17–42.

86. Hamid, M. G., & Nour, A. A. A. M. (2018). Effect of different drying methods on quality attributes of beetroot (*Beta vulgaris*) slices. *World Journal of Science Technology and Sustainable Development*, 15(3), 287–298.

87. Wruss, J., Waldenberger, G., Huemer, S., Uygun, P., Lanzerstorfer, P., Müller, U., Höglinger, O., & Weghuber, J. (2015). Compositional characteristics of commercial beetroot products and beetroot juice prepared from seven beetroot

varieties grown in Upper Austria. *Journal of Food Composition and Analysis*, 42, 46–55.

88. Guldiken, B., Toydemir, G., Nur Memis, K., Okur, S., Boyacioglu, D., & Capanoglu, E. (2016). Home-processed red beetroot (*Beta vulgaris* L.) products: Ehanges in antioxidant properties and bioaccessibility. *International Journal of Molecular Sciences*, 17(6), 858.

89. Sucu, C., & Turp, G. Y. (2018). The investigation of the use of beetroot powder in Turkish fermented beef sausage (sucuk) as nitrite alternative. *Meat Science*, 140, 158–166.

90. Chandran, J., Nisha, P., Singhal, R. S., & Pandit, A. B. (2014). Degradation of colour in beetroot (*Beta vulgaris* L.): A kinetics study. *Journal of Food Science and Technology*, 51(10), 2678–2684.

91. Ozaki, M. M., Munekata, P. E. S., Jacinto-Valderrama, R. A., Efraim, P., Pateiro, M., Lorenzo, J. M., & Pollonio, M. A. R. (2021). Beetroot and radish powders as natural nitrite source for fermented dry sausages. *Meat Science*, 171, 108275.

92. Kohajdová, Z., Karovičová, J., Kuchtová, V., & Lauková, M. (2018). Utilisation of beetroot powder for bakery applications. *Chemical Papers*, 72(6), 1507–1515.

93. Lucky, A. R., Al-Mamun, A., Hosen, A., Toma, M. A., & Mazumder, M. A. R. (2020). Nutritional and sensory quality assessment of plain cake enriched with beetroot powder. *Food Research*, 4(6), 2049–2053.

94. Cui, R., Fei, Y., & Zhu, F. (2022). Physicochemical, structural and nutritional properties of steamed bread fortified with red beetroot powder and their changes during breadmaking process. *Food Chemistry*, 383, 132547.

95. Astuti, P., Zumar, H. A., Fathonah, S., & Ansori, M. (2022). Differences in preferences, water content, anddietary fibre of jackfruit seed crackers enriched with red beetroot (*Beta vulgaris*). *IOP Conference Series: Earth and Environmental Science*, 969, 012009.

96. Aksu, M. İ., Erdemir, E., Turan, E., & Sat, İ. G. (2020). Effects of red

beet extracts on protein and lipid oxidation, colour, microbial, sensory properties and storage stability of Turkish pastırma. *Journal of Stored Products Research*, 89, 101721.

97. Chhikara, N., Kushwaha, K., Jaglan, S., Sharma, P., & Panghal, A. (2019). Nutritional, physicochemical, and functional quality of beetroot (*Beta vulgaris* L.) incorporated Asian noodles. *Cereal Chemistry*, 96(1), 154–161.

98. Clifford, T., Howatson, G., West, D. J., & Stevenson, E. J. (2015). The potential benefits of red beetroot supplementation in health and disease. *Nutrients*, 7(4), 2801–2822.

99. Raikos, V., McDonagh, A., Ranawana, V., & Duthie, G. (2016). Processed beetroot (*Beta vulgaris* L.) as a natural antioxidant in mayonnaise: Effects on physical stability, texture and sensory attributes. *Food Science and Human Wellness*, 5, 191–198.

100. Rahimi, P., Abedimanesh, S., Mesbah-Namina, S. A., & Ostadrahimi, A. (2019). Betalains, the nature-inspired pigments, in health and diseases. *Critical Reviews in Food Science and Nutrition*, 59(18), 2949–2978.

101. Kusznierewicz, B., Mróz, M., Koss-Mikołajczyk, I., & Namieśnik, J. (2021). Comparative evaluation of different methods for determining phytochemicals and antioxidant activity in products containing betalains-Verification of beetroot samples. *Food Chemistry*, 362, 130132.

102. Bozkir, H., & Ergün, A. R. (2020). Effect of sonication and osmotic dehydration applications on the hot air drying kinetics and quality of persimmon. *LWT-Food Science and Technology*, 131, 109704.

103. Zielinska, M., Sadowski, P., & Błaszczak, W. (2015). Freezing/thawing and microwave-assisted drying of blueberries (*Vaccinium corymbosum* L.). *LWT-Food Science and Technology*, 62(1), 555-563.

104. Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology*, 6, 36–60.

105. Jiang, S., Chen, Y., Cao, C., Zhang, S., Kong, B., & Liu, Q. (2018).

Effect of curdlan and water addition on quality characteristics of frankfurters. *Food Science*, 39(14), 57–66.

106. Stintzing, F. C., Herbach, K. M., Mosshammer, M. R., Carle, R., Yi, W., Sellappan, S., Akoh, C. C., Bunch, R., & Felker, P. (2005). Color, betalain pattern, and antioxidant properties of cactus pear (*Opuntia spp*.) clones. *Journal of Agricultural and Food Chemistry*, 53(2), 442–451.

107. Alvarez-Parrilla, E., de la Rosa, L. A., Amarowicz, R., & Shahidi, F. (2011). Antioxidant activity of fresh and processed Jalapeño and Serrano peppers. *Journal of Agricultural and Food Chemistry*, 59(1), 163–173.

108. Souza, V. R. D., Pereira, P. A. P., Silva, T. L. T. D., Lima, L. C. D. O., Pio, R., & Queiroz, F. (2014). Determination of the bioactive compounds, antioxidant activity and chemical composition of Brazilian blackberry, red raspberry, strawberry, blueberry and sweet cherry fruits. *Food Chemistry*, 156, 362–368.

109. Brand-Williams, W., Cuvelier, M. E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology*, 28(1), 25–30.

110. Benzie, I. F. F., & Strain, J. J. (1996). The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. *Analytical biochemistry*, 239(1), 70–76.

111. Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, 26(9–10), 1231–1237.

112. State Administration for Market Regulation of China, China National Standardization Administration. National Standards of the People's Republic of China: GB/T 20980-2021 General quality of biscuits. Beijing: China Standards Press.

113. Wu, J. Y., Yao, W. J., Cao C. A., Wang, M. J., Kong B. H., & Liu, Q. (2023). Effect of seaweed dietary fiber on the quality profiles of low-fat and low-salt chicken frankfurters. *Food Science*, 44(02), 87–93.

114. Bruna, J. M., Ordóñez, J. A., Fernández, M., Herranz, B., & de la Hoz, L. (2001). Microbial and physico-chemical changes during the ripening of dry fermented sausages superficially inoculated with or having added an intracellular cell-free extract of *Penicillium aurantiogriseum*. *Meat Science*, 59(1), 87–96.

115. National Health and Family Planning Commission of China. National standard for food safety of the People's Republic of China: GB 5009.227-2016 Determination of peroxide value in foods. Beijing: China Standards Press.

116. AOAC (2000). Official methods of analysis (17th ed.). Maryland, USA: Association of Official Analytical Chemistry.

117. AOAC (2006). Official methods of analysis (18th ed.). Washington, DC: Association of Official Analytical Chemists.

118. Madhava, N. M. M., Vedashree, M., Satapathy, P., Khanum, H., Ramsamy, R., & Hebbar, H. U. (2016). Effect of drying methods on the quality characteristics of dill (*Anethum graveolens*) greens. *Food Chemistry*, 192, 849–856.

119. Jin, W., Zhang, M., & Shi, W. (2018). Evaluation of ultrasound pretreatment and drying methods on selected quality attributes of bitter melon (*Momordica charantia* L.). *Drying Technology*, 37(3), 387–396.

120. Monteiro, R. L., Link, J. V., Tribuzi, G., Carciofi, B. A. M., & Laurindo, J. B. (2018). Microwave vacuum drying and multi-flash drying of pumpkin slices. J*ournal of Food Engineering*, 232, 1–10.

121. Nguyen, T.-V.-L., Nguyen, Q.-N., Nguyen, P.-B.-D., Tran, B.-L., & Huynh, P.-T. (2020). Effects of drying conditions in low-temperature microwave-assisted drying on bioactive compounds and antioxidant activity of dehydrated bitter melon (*Momordica charantia* L.). *Food Science and Nutrition*, 8(7), 3826–3834.

122. Macedo, L. L., Vimercati, W. C., da Silva Araújo, C., Saraiva, S. H., & Teixeira, L. J. Q. (2020). Effect of drying air temperature on drying kinetics and physicochemical characteristics of dried banana. *Journal of Food Process Engineering*, 43(9), e13451.

123. Lund, M. N., & Ray, C. A. (2017). Control of Maillard reactions in foods: Strategies and chemical mechanisms. *Journal of Agricultural and Food Chemistry*, 65(23), 4537–4552.

124. Gokhale, S. V., & Lele, S. S. (2011). Dehydration of red beet root (*Beta vulgaris*) by hot air drying: Process optimization and mathematical modeling. *Food Science and Biotechnology*, 20(4), 955–964.

125. Hu, Q. G., Zhang, M., Mujumdar, A. S., Du, W. H., & Sun, J. C. (2006). Effect of different drying methods on the quality changes of the granular fruits and vegetables. *Journal of Food Science and Biotechnology*, 2(8), 28–32.

126. Ravichandran, K., Saw, N. M. M. T., Mohdaly, A. A. A., Gabr, A. M. M., Kastell, A., Riedel, H., Cai, Z. Z., Knorr, D., & Smetanska, I. (2013). Impact of processing of red beet on betalain content and antioxidant activity. *Food Research International*, 50(2), 670–675.

127. Herbach, K. M., Stinzing, F. C., & Carle, R. (2004). Impact of thermal treatment on color and pigment pattern of red beet (*Beta vulgaris* L.) preparations. *Journal of Food Science*, 69(6), C491–C498.

128. Gokhale, S. V., & Lele, S. S. (2014). Betalain content and antioxidant activity of *Beta vulgaris*: Effect of hot air convective drying and storage. *Journal of Food Processing and Preservation*, 38(1), 585–590.

129. Neha, P., Jain, S. K., Jain, N. K., Jain, H. K., & Mittal, H. K. (2018). Chemical and functional properties of beetroot (*Beta vulgaris* L.) for product development: A review. *International Journal of Chemical Studies*, 6(3), 3190–3194.

130. Kubra, I. R., & Rao, L. J. M. (2012). Microwave drying of ginger (*Zingiber officinaleRosco*) and its effects on polyphenolic content and antioxidant activity. *International Journal of Food Science and Technology*, 47(11), 2311–2317.

131. Salima, C., Lila, B. M., Javed I., Sabrina, Z., Sait, S., & Gavin, W. (2019). Effect of different drying temperatures on the composition and antioxidant activity of ginger powder. *The Annals of the University Dunarea de Jos of Galati.*

Fascicle VI–Food Technology, 43(2), 125–142.

132. Scaman, C. H., & Durance, T. D. (2005). 19 - Combined microwave vacuum-drying. *Emerging Technologies for Food Processing*, 507–533.

133. Abers, J. E., & Wrolstad, R. E. (1979). Causative factors of color deterioration in strawberry preserves during processing and storage. *Journal of Food Science*, 44(1), 75–78.

134. Dudley, G. B., Richert, R., & Stiegman A. (2015). On the existence of and mechanism for microwave-specific reaction rate enhancement. *Chemical Science*, 46(21), 2144–2152.

135. Zielinska M., & Zielinska D. (2019). Effects of freezing, convective and microwave-vacuum drying on the content of bioactive compounds and color of cranberries. *LWT-Food Science and Technology*, 104, 202–209.

136. Köprüalan, Ö., Altay, Ö., Bodruk, A., & Kaymak-Ertekin, F. (2021). Effect of hybrid drying method on physical, textural and antioxidant properties of pumpkin chips. *Journal of Food Measurement and Characterization*, 15(4), 2995–3004.

137. Handwerk, R. L., & Coleman, R. L. (1988). Approaches to the citrus browning problem. A review. *Journal of Agricultural and Food Chemistry*, 36 (1), 231–236.

138. Qin, J., Wang, Z., Wang, X., & Shi, W. (2020). Effects of microwave time on quality of grass carp fillets processed through microwave combined with hot-air drying. *Food Science and Nutrition*, 8(8), 4159–4171.

139. Li, X., Liu, J., Cai, J., Xue, L., Wei, H., Zhao, M., & Yang, Y. (2021). Drying characteristics and processing optimization of combined microwave drying and hot air drying of *Termitomyces albuminosus* mushroom. *Journal of Food Processing and Preservation*, 45 (12), e16022.

140. Zhao, G., Hu, C., & Luo, H. (2020). Effects of combined microwave-hot-air-drying on the physicochemical properties and antioxidant activity of Rhodomyrtus tomentosa berry powder. *Journal of Food Measurement and Characterization*, 14 (3), 1433–1442.

141. Kaymak-Ertekin, E. (2002). Drying and rehydration kinetics of green and red peppers. *Journal of Food Science*, 67(1), 168–175.

142. Preethi, R., Deotale, S. M., Moses, J. A., & Anandharamakrishnan, C. (2020). Conductive hydro drying of beetroot (*Beta vulgaris* L) pulp: Insights for natural food colorant applications. *Journal of Food Process Engineering*, 43(12), e13557.

143. Huang, T., Feng, X., Feng, Z., Bai Y., & Fu, W. (2021). Comparison of microstructure and quality of instant noodle prepared with different drying methods. *Modern Food Science and Technology*, 37(4), 207–216.

144. Horuz, E., Bozkurt, H., Karatas, H., & Maskan, M. (2017). Effects of hybrid (microwave-convectional) and convectional drying on drying kinetics, total phenolics, antioxidant capacity, vitamin C, color and rehydration capacity of sour cherries. *Food Chemistry*, 230, 295–305.

145. Mao, L. C., Pan, X., Que, F., & Fang, X. H. (2006). Antioxidant properties of water and ethanol extracts from hot air-dried and freeze-dried daylily flowers. *European Food Research and Technology*, 222(3), 236–241.

146. Inchuen, S., Narkrugsa, W., & Pornchaloempong, P. (2010). Effect of drying methods on chemical composition, color and antioxidant properties of Thai red curry powder. *Kasetsart Journal (Nature Science)*, 44(1), 142–151.

147. Wei, Q., Huang, J., Zhang, Z., Lia, D., Liu, C., Xiao, Y., Lagnika, C., & Zhang, M. (2019). Effects of different combined drying methods on drying uniformity and quality of dried taro slices. *Drying Technology*, 37(3), 322–330.

148. Chen, Q., Li, Z., Bi, J., Zhou, L., Yi, J., & Wu, X. (2017). Effect of hybrid drying methods on physicochemical, nutritional and antioxidant properties of dried black mulberry. *LWT-Food Science and Technology*, 80(3), 178–184.

149. Hu, Q., Zhang, M., Arun, S. M., Du, W., Sun, J. (2006). Effects of different drying methods on the quality changes of granular edamame. *Drying Technology*, 24(8), 1025–1032.

150. Cui Z.-W., Xu S.-Y., & Sun D.-W. (2004). Effect of microwave-vacuum drying on the carotenoids retention of carrot slices and chlorophyll

retention of Chinese chive leaves. *Drying Technology*, 22(3), 563–575.

151. Harbourne, N., Marete, E., Jacquier, J. C., & O'Riordan D. (2009). Effect of drying methods on the phenolic constituents of meadowsweet (*Filipendula ulmaria*) and willow (*Salix alba*). *LWT-Food Science and Technology*, 42(9), 1468–1473.

152. Si, X., Chen, Q., Bi, J., Wu, X., Yi, J., Zhou, L., & Li, Z. (2016). Comparison of different drying methods on the physical properties, bioactive compounds and antioxidant activity of raspberry powders. *Journal of the Science of Food and Agriculture*, 96(6), 2055–2062.

153. Wojdyło A., Figiel A., Lech K., Nowicka P., Oszmiański J. (2014). Effect of convective and vacuum–microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. *Food and Bioprocess Technology*, 7(3), 829–841.

154. Chan, E. W. C., Lim, Y. Y., Wong, S. K., Lim, K. K, Tan, S. P., Lianto, F. S., & Yong, M. Y. (2009). Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. *Food Chemistry*, 113(1), 166–172.

155. Lim, Y. Y., & Murtijaya, J. (2007). Antioxidant properties of Phyllanthus amarus extracts as affected by different drying methods. *LWT-Food Science and Technology*, 40(9), 1664–1669.

156. Cheigh, H. S., Um, S. H., & Lee, C. Y. (1995). Antioxidant characteristics of melanin-related products from enzymatic browning reaction of catechin in a model system. *ACS Symposium Series*, 600, 200–208.

157. Samoticha, J., Wojdyło, A., & Lech, K. (2016). The influence of different the drying methods on chemical composition and antioxidant activity in chokeberries. *LWT-Food Science and Technology*, 66, 484–489.

158. Wu, X. F., Zhang, M., Adhikari, B., & Sun, J. C. (2017). Recent developments in novel freezing and thawing technologies applied to foods. *Critical Reviews in Food Science and Nutrition*, 57(17), 3620–3631.

159. Xu, X., Zhang, L., Feng, Y., Zhou, C., Yagoub, A. E. A., Wahia, H.,

Ma, H., Zhang, J., & Sun, Y. (2021). Ultrasound freeze-thawing style pretreatment to improve the efficiency of the vacuum freeze-drying of okra (*Abelmoschus esculentus* (L.) Moench) and the quality characteristics of the dried product. *Ultrasonics Sonochemistry*, 70, 105300.

160. Ceballos, A. M., Giraldo, G. I., & Orrego, C. E. (2012). Effect of freezing rate on quality parameters of freeze dried soursop fruit pulp. *Journal of Food Engineering*, 111(2), 360–365.

161. Dalmau, M. E., Llabr´es, P. J., Eim, V. S., Rossell´o, C., & Simal, S. (2019). Influence of freezing on the bioaccessibility of beetroot (*Beta vulgaris*) bioactive compounds during in vitro gastric digestion. *Journal of the Science of Food and Agriculture*, 99(3), 1055–1065.

162. Carrillo, C., Wilches-Pérez, D., Halman, E., Kazimierczak, R., & Rembiakowska, E. (2019). Organic versus conventional beetroot. Bioactive compounds and antioxidant properties. *LWT-Food Science and Technology*, 116, 108552.

163. Ando, Y., Hagiwara, S., Nabetani, H., Sotome, I., Okunishi, T., Okadome, H., Orikasa, T., & Tagawa, A. (2019). Effects of prefreezing on the drying characteristics, structural formation and mechanical properties of microwave-vacuum dried apple. *Journal of Food Engineering*, 244, 170–177.

164. Qian, S. Y., Li, X., Wang, H., Mehmood, W., Zhong, M., Zhang, C. H., & Blecker, C. (2019). Effects of low voltage electrostatic field thawing on the changes in physicochemical properties of myofibrillar proteins of bovine *Longissimus dorsi* muscle. *Journal of Food Engineering*, 261, 140–149.

165. Okamoto, A., & Suzuki, A. (2002). Effects of high hydrostatic pressure-thawing on pork meat. *Progress in Biotechnology*, 19, 571–576.

166. Li, F. F., Wang, B., Liu, Q., Chen, Q., Zhang, H. W., & Xia, X. F. (2019). Changes in myofibrillar protein gel quality of porcine *longissimus* muscle induced by its stuctural modification under different thawing methods. *Meat Science*, 147, 108–115.

167. Shi, Z. J., Zhong, S. Y., Yan, W. J., Liu, M., Yang, Z., & Qiao, X. L.

(2019). The effects of ultrasonic treatment on the freezing rate, physicochemical quality, and microstructure of the back muscle of grass carp (*Ctenopharyngodon idella*). *LWT-Food Science and Technology*, 111, 301–308.

168. Shen, G., Zhang, L., Hu, T., Li, Z., Chen, A., Zhang, Z., Wu, H., Li, S., & Hou, X. (2020). Preparation of potato flour by freeze-thaw pretreatment: Effect of different thawing methods on hot-air drying process and physicochemical properties. *LWT-Food Science and Technology*, 133, 110157.

169. An, K., Zhao, D., Wang, Z., Wu, J., Xu, Y., & Xiao, G. (2016). Comparison of different drying methods on Chinese ginger (*Zingiber officinale* Roscoe): Changes in volatiles, chemical profile, antioxidant properties, and microstructure. *Food Chemistry*, 197, 1292–1300.

170. Srikanth, K. S., Sharanagat, V. S., Kumar, Y., Bhadra, R., Singh, L., Nema, P. K., & Kumar V. (2019). Convective drying and quality attributes of elephant foot yam (*Amorphophallus paeoniifolius*). *LWT-Food Science and Technology*, 99(15), 8–16.

171. Xie, L., Zheng, Z. A., Mujumdar, A. S., Fang, X. M., Wang, J., Zhang, Q., Ma, Q., Xiao, H. W., Yan-Hong Liu, Y. H., & Gao Z. J. (2018). Pulsed vacuum drying (PVD) of wolfberry: Drying kinetics and quality attributes. *Drying Technology, 36*(12), 1501–1514.

172. Piotrowski, D., Kostyra, E., Grzegory, P., & Janiszewska-Turak, E. (2021). Influence of drying methods on the structure, mechanical and sensory properties of strawberries. *European Food Research and Technology, 247*(8), 1859–1867.

173. Bazaria, B., & Kumar, P. (2018). Optimization of spray drying parameters for beetroot juice powder using response surface methodology (RSM). *Journal of the Saudi Society of Agricultural Sciences*, 17(4), 408–415.

174. Prieto-Santiago, V., Cavia, M., Alonso-Torre, S., & Carrillo, C. (2020). Relationship between color and betalain content in different thermally treated beetroot products. *Journal of Food Science and Technology*, 57(9), 3305–3313.

175. Vadivambal R. & Jayas D. S. (2007). Changes in quality of

microwave-treated agricultural products—a review. *Biosystems Engineering*, 98(1), 1–16.

176. Valadez-Carmona, L., Cortez-García, R. M., Plazola-Jacinto, C. P., Necoechea-Mondragón, H., & Ortiz-Moreno, A. (2016). Effect of microwave drying and oven drying on the water activity, color, phenolic compounds content and antioxidant activity of coconut husk (*Cocos nucifera* L.). *Journal of food science and technology,* 53(9), 3495–3501.

177. Swastike, W., Suryanto, E., Rusman, R., Hanim, C., & Jumari, J. (2020). The substitution effects of tapioca starch and beetroot powder as filler on the physical and sensory characteristics of chicken sausage. *Jurnal Ilmu dan Teknologi Hasil Ternak*, 15(2), 97–107.

178. Sebranek, J. G., & Bacus, J. N. (2007). Cured meat products without direct addition of nitrate or nitrite: what are the issues? Meat Science, 77(1), 136–147.

179. Aykin-Dincer, E., Güngör, K. K., Çağlar, E., & ErbaÇ, M. (2021). The use of beetroot extract and extract powder in sausages as natural food colorant. *International Journal of Food Engineering*, 17(1), 75–82.

180. Choi, Y. S., Kim, T. K., Jeon, K. H., Park, J. D., Kim, H. W., Hwang, K. E., & Kim, Y. B. (2017). Effects of pre-converted nitrite from red beet and ascorbic acid on quality characteristics in meat emulsions. *Korean Journal for Food Science of Animal Resources*, 37(2), 288–296.

181. Hwang, K. E., Kim, T. K., Kim, H. W., Oh, N. S., Kim, Y. B., Jeon, K. H., & Choi, Y. S. (2017). Effect of fermented red beet extracts on the shelf stability of low-salt frankfurters. *Food Science and Biotechnology*, 26(4), 929–936.

182. Jin, S. K., Choi, J. S., Moon, S. S., Jeong, J. Y., & Kim, G. D. (2014). The assessment of red beet as a natural colorant, and evaluation of quality properties of emulsified pork sausage containing red beet powder during cold storage. Korean *Journal for Food Science of Animal Resources*, 34(4), 472–481.

183. Souissi, N., Jridi, M., Nasri, R., Slama, R. B., Njeh, M., & Nasri, M.

(2016). Effects of the edible cuttlefish gelatin on textural, sensorial and physicochemical quality of octopus sausage. *LWT-Food Science and Technology*, 65, 18–24.

184. Kim, H. W., Hwang, K. E., Song, D. H., Kim, Y. J., Ham, Y. K., Yeo, E. J., & Kim, C. J. (2015). Effect of pre-rigor salting levels on physicochemical and textural properties of chicken breast muscles. *Korean Journal for Food Science of Animal Resources*, 35(5), 577–584.

185. Ercoşkun, H., & Özkal, S. G. (2011). Kinetics of traditional Turkish sausage quality aspects during fermentation. *Food Control*, 22(2), 165–172.

186. Alshehry, G., Abdelazez, A., Abdelmotaal, H., & Abdel-Aleem, W. (2021). Investigating antioxidant and antibacterial activity of functional cookies enriched with beetroot during storage. *Czech Journal of Food Sciences*, 39(6), 479–486.

187. Amnah, & Alsuhaibani, M. A. (2013). Nutritional, sensory and biological study of biscuits fortified with red beetroots. *Life Science Journal*, 10(3), 1579–1584.

188. Srivastava, S., & Singh, K. (2016). Physical, sensory and nutritional evaluation of biscuits prepared by using beetroot (*Beta vulgaris*) powder. *International Journal of Innovative Research and Advanced Studies*, 3(7), 281–283.

189. Ingle, M., Thorat, S. S., Kotecha, P. M., & Nimbalkar, C. A. (2017). Nutritional assessment of beetroot (*Beta vulgaris* L.) powder cookies. *Asian Journal of Dairy and Food Research*, 36(3), 222–228.

190. Purlis, E., & Salvadori, V. O. (2007). Bread browning kinetics during baking. *Journal of Food Engineering*, 80(4), 1107–1115.

191. Akanksha, & Maurya, P. (2019). Development of baked products by using beetroot powder and their quality evaluation. *Trends in Biosciences*, 12(23), 1492–1497.

ADDITIONS

Addition A

"Protocols of experimental data"

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 1
from July 29, 2020

Indicators of quality attributes of dried beetroots affected by heat pump drying conditions*

1. Color results of dried beetroots affected by heat pump drying conditions

Indicators	*L*	*a*	*b*	Δ*E*	Method name and number
Loading density of 1.5 kg/m^2	38.56±1.17	21.62±0.71	0.82±0.20	7.40±0.11	Color measurement
Loading density of 2.0 kg/m^2	37.44±0.60	23.11±0.24	1.47±0.09	5.95±0.32	Color measurement
Loading density of 2.5 kg/m^2	37.75±0.86	24.77±0.31	2.37±0.30	4.10±0.12	Color measurement
Loading density of 3.0 kg/m^2	38.95±1.01	25.28±0.44	1.23±0.05	3.82±0.09	Color measurement
Drying temperature of 45 °C	36.27±0.27	25.43±0.22	1.91±0.14	4.22±0.30	Color measurement
Drying temperature of 50 °C	39.20±0.95	25.04±1.18	1.55±0.23	4.05±0.34	Color measurement
Drying temperature of 55 °C	37.44±0.60	23.11±0.24	1.47±0.09	5.95±0.32	Color measurement
Drying temperature of 60 °C	36.39±1.56	23.03±0.34	1.44±0.13	6.47±0.19	Color measurement
Drying temperature of 65 °C	39.10±0.62	24.99±1.29	1.22±0.23	4.17±0.27	Color measurement
Slice thickness of 2 mm	38.24±1.14	26.63±0.76	1.70±0.10	2.44±0.12	Color measurement
Slice thickness of 5 mm	37.44±0.60	23.11±0.24	1.47±0.09	5.95±0.32	Color measurement
Slice thickness of 8 mm	39.92±1.12	24.68±0.72	1.40±0.07	4.48±0.20	Color measurement
Freeze-dried beetroots	38.71±0.90	28.73±0.16	2.86±0.07	—	Color measurement

2. Results of betalains content and ascorbic acid content in dried beetroots affected by heat pump drying conditions

Indicators	Betacyanins (mg/g)	Betaxanthins (mg/g)	Method name and number	Ascorbic acid (mg/100g)	Method name and number
Loading density of 1.5 kg/m^2	2.69±0.02	1.56±0.05	Colorimetric method	309.93±5.21	Ascorbic acid determination kit
Loading density of 2.0 kg/m^2	2.81±0.03	1.67±0.02	Colorimetric method	302.16±3.14	Ascorbic acid determination kit
Loading density of 2.5 kg/m^2	2.67±0.02	1.59±0.01	Colorimetric method	296.55±1.95	Ascorbic acid determination kit
Loading density of 3.0 kg/m^2	2.50±0.06	1.41±0.01	Colorimetric method	290.29±5.97	Ascorbic acid determination kit
Drying temperature of 45 °C	1.96±0.02	1.17±0.01	Colorimetric method	230.61±2.57	Ascorbic acid determination kit
Drying temperature of 50 °C	2.44±0.02	1.57±0.02	Colorimetric method	272.48±1.53	Ascorbic acid determination kit
Drying temperature of 55 °C	2.81±0.03	1.67±0.02	Colorimetric method	302.16±3.41	Ascorbic acid determination kit
Drying temperature of 60 °C	3.17±0.03	1.93±0.02	Colorimetric method	313.17±6.82	Ascorbic acid determination kit
Drying temperature of 65 °C	3.59±0.09	2.09±0.05	Colorimetric method	365.83±1.78	Ascorbic acid determination kit
Slice thickness of 2 mm	2.35±0.02	2.00±0.02	Colorimetric method	287.27±2.77	Ascorbic acid determination kit
Slice thickness of 5 mm	2.81±0.03	1.67±0.02	Colorimetric method	302.16±3.41	Ascorbic acid determination kit
Slice thickness of 8 mm	2.01±0.03	1.12±0.01	Colorimetric method	229.96±3.61	Ascorbic acid determination kit

3. Results of total phenolic and total flavonoids contents in dried beetroots affected by heat pump drying conditions

Indicators	Total phenolic (mg GAE/g)	Method name and number	Total flavonoids (mg CE/g)	Method name and number
Loading density of 1.5 kg/m^2	9.77±0.26	Folin-Ciocalteu method	7.57±0.16	Colorimetric method
Loading density of 2.0 kg/m^2	9.83±0.17	Folin-Ciocalteu method	8.06±0.22	Colorimetric method
Loading density of 2.5 kg/m^2	9.86±0.20	Folin-Ciocalteu method	8.15±0.01	Colorimetric method
Loading density of 3.0 kg/m^2	9.76±0.20	Folin-Ciocalteu method	8.30±0.13	Colorimetric method
Drying temperature of 45 °C	8.39±0.06	Folin-Ciocalteu method	6.96±0.14	Colorimetric method
Drying temperature of 50 °C	8.97±0.13	Folin-Ciocalteu method	7.71±0.26	Colorimetric method
Drying temperature of 55 °C	9.83±0.17	Folin-Ciocalteu method	8.06±0.22	Colorimetric method
Drying temperature of 60 °C	10.41±0.17	Folin-Ciocalteu method	9.14±0.34	Colorimetric method
Drying temperature of 65 °C	11.07±0.60	Folin-Ciocalteu method	9.50±0.38	Colorimetric method
Slice thickness of 2 mm	9.75±0.18	Folin-Ciocalteu method	7.59±0.11	Colorimetric method
Slice thickness of 5 mm	9.83±0.17	Folin-Ciocalteu method	8.06±0.22	Colorimetric method
Slice thickness of 8 mm	8.42±0.13	Folin-Ciocalteu method	6.24±0.31	Colorimetric method

4. Results of antioxidant activities in dried beetroots affected by heat pump drying conditions

Indicators	DPPH (mg TE/g)	ABTS (mg TE/g)	FRAP (mg TE/g)	Method name and number
Loading density of 1.5 kg/m^2	1.28±0.04	22.75±0.42	15.98±0.13	Colorimetric method
Loading density of 2.0 kg/m^2	1.11±0.01	20.89±0.68	15.33±0.36	Colorimetric method
Loading density of 2.5 kg/m^2	1.08±0.02	21.82±0.46	15.06±0.08	Colorimetric method
Loading density of 3.0 kg/m^2	1.02±0.02	22.48±0.52	14.81±0.23	Colorimetric method
Drying temperature of 45 °C	1.56±0.03	20.49±0.16	12.74±0.45	Colorimetric method
Drying temperature of 50 °C	1.25±0.01	20.74±0.13	14.21±0.35	Colorimetric method
Drying temperature of 55 °C	1.11±0.01	20.89±0.56	15.62±0.66	Colorimetric method
Drying temperature of 60 °C	0.84±0.01	23.17±0.45	16.46±0.08	Colorimetric method
Drying temperature of 65 °C	0.40±0.02	24.10±0.16	17.81±0.04	Colorimetric method
Slice thickness of 2 mm	0.98±0.02	20.96±0.26	14.29±0.24	Colorimetric method
Slice thickness of 5 mm	1.11±0.01	20.89±0.68	15.62±0.66	Colorimetric method
Slice thickness of 8 mm	1.75±0.00	20.00±0.31	12.29±0.22	Colorimetric method

*Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor Ph.D., Associate Professor	(signature)	Anna O. Helikh
Responsible executor Ph.D. student	(signature)	Yan Liu
Head of the laboratory Ph.D., Associate Professor	(signature, seal) 食品与生物工程学院 4511020091352	Jinfeng Yang

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 2
from November 29, 2020

Indicators of quality attributes of dried beetroots affected by microwave vacuum drying conditions*

1. Color results of dried beetroots affected by microwave vacuum drying conditions

Indicators	*L*	*a*	*b*	Δ*E*	Method name and number
Microwave power of 500 W	40.92±1.22	22.92±0.42	2.83±0.08	7.35±0.37	Color measurement
Microwave power of 1000 W	43.44±0.56	23.81±0.55	3.51±0.20	7.95±0.33	Color measurement
Microwave power of 1500 W	40.58±0.66	23.36±0.54	3.56±0.22	6.46±0.42	Color measurement
Vacuum degree of −50 kPa	41.17±0.90	22.73±0.45	2.67±0.13	7.61±0.37	Color measurement
Vacuum degree of −70 kPa	38.62±1.02	23.25±0.63	3.00±0.06	6.20±0.33	Color measurement
Vacuum degree of −90 kPa	40.46±1.09	23.99±0.35	3.73±0.11	5.90±0.27	Color measurement
Sample thickness of 2 mm	40.58±0.66	23.36±0.54	3.56± 0.22	6.46±0.42	Color measurement
Sample thickness of 4 mm	42.73±0.53	21.05±0.21	2.48±0.12	9.74±0.37	Color measurement
Sample thickness of 6 mm	42.15±0.67	21.97±0.26	2.67±0.10	8.67±0.49	Color measurement
Fresh beetroots	37.52±1.03	28.47±0.74	6.02±0.22	-	Color measurement

2. Results of betalains content and ascorbic acid content in dried beetroots affected by microwave vacuum drying conditions

Indicators	Betacyanin (mg/g)	Betaxanthin (mg/g)	Method name and number	Ascorbic acid (mg/100g)	Method name and number
Microwave power of 500 W	4.65±0.03	3.34±0.06	Colorimetric method	939.1±3.3	Ascorbic acid determination kit
Microwave power of 1000 W	4.29±0.07	2.85±0.04	Colorimetric method	794.4±11.7	Ascorbic acid determination kit
Microwave power of 1500 W	4.02±0.04	2.82±0.01	Colorimetric method	789.5±5.6	Ascorbic acid determination kit
Vacuum degree of −50 kPa	3.38±0.02	2.57±0.01	Colorimetric method	730.2±1.9	Ascorbic acid determination kit
Vacuum degree of −70 kPa	3.65±0.02	2.79±0.01	Colorimetric method	835.4±9.4	Ascorbic acid determination kit
Vacuum degree of −90 kPa	4.09±0.03	2.91±0.01	Colorimetric method	870.2±12.3	Ascorbic acid determination kit
Sample thickness of 2 mm	4.02±0.04	2.82±0.01	Colorimetric method	789.5±5.6	Ascorbic acid determination kit
Sample thickness of 4 mm	3.44±0.02	2.52±0.01	Colorimetric method	676.8±7.3	Ascorbic acid determination kit
Sample thickness of 6 mm	3.97±0.00	2.83±0.00	Colorimetric method	869.4±3.8	Ascorbic acid determination kit

3. Results of total phenolic and total flavonoids contents in dried beetroots affected by microwave vacuum drying conditions

Indicators	Total phenolic (mg GAE/g)	Method name and number	Total flavonoids (mg RE/g)	Method name and number
Microwave power of 500 W	11.26±0.18	Folin-Ciocalteu method	28.34± 0.44	Colorimetric method
Microwave power of 1000 W	8.19±0.08	Folin-Ciocalteu method	25.92±0.49	Colorimetric method

Microwave power of 1500 W	11.37±0.08	Folin-Ciocalteu method	26.04±0.49	Colorimetric method
Vacuum degree of −50 kPa	12.47±0.09	Folin-Ciocalteu method	25.49±0.57	Colorimetric method
Vacuum degree of −70 kPa	9.56±0.11	Folin-Ciocalteu method	22.37±0.56	Colorimetric method
Vacuum degree of −90 kPa	9.64±0.06	Folin-Ciocalteu method	20.09±0.56	Colorimetric method
Sample thickness of 2 mm	11.26±0.18	Folin-Ciocalteu method	26.04±0.49	Colorimetric method
Sample thickness of 4 mm	8.40±0.10	Folin-Ciocalteu method	22.81±0.98	Colorimetric method
Sample thickness of 6 mm	8.64±0.10	Folin-Ciocalteu method	21.53±0.24	Colorimetric method

4. Results of FRAP values in dried beetroots affected by microwave vacuum drying conditions

Indicators	Rehydration ratio	Method name and number	FRAP (mg TE/g)	Method name and number
Microwave power of 500 W	4.70±0.03	Gravimetric method	14.70±0.17	Colorimetric method
Microwave power of 1000 W	4.53±0.07	Gravimetric method	13.07±0.21	Colorimetric method
Microwave power of 1500 W	4.32±0.12	Gravimetric method	11.31±0.10	Colorimetric method
Vacuum degree of −50 kPa	4.35±0.10	Gravimetric method	10.93±0.04	Colorimetric method
Vacuum degree of −70 kPa	4.57±0.28	Gravimetric method	10.38±0.05	Colorimetric method
Vacuum degree of −90 kPa	4.60±0.12	Gravimetric method	10.23±0.15	Colorimetric method
Sample thickness of 2 mm	4.32±0.12	Gravimetric method	11.31±0.10	Colorimetric method
Sample thickness of 4 mm	3.87±0.06	Gravimetric method	10.62±0.08	Colorimetric method
Sample thickness of 6 mm	3.55±0.05	Gravimetric method	11.40±0.08	Colorimetric method

*Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor Ph.D., Associate Professor	(signature)	Anna O. Helikh
Responsible executor Ph.D. student	Yan Liu (signature)	Yan Liu
Head of the laboratory Ph.D., Associate Professor	Jinfeng Yang (signature, seal) 食品与生物工程学院 4511020091352	Jinfeng Yang

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 3
from January 20, 2021

Results of microwave-assisted drying methods on quality attributes of dried beetroots*

1. Results of moisture content, rehydration ratio and hardness of beetroots affected by different microwave-assisted drying methods

Indicators	Moisture content (%)	Method name and number	Rehydration ratio	Method name and number	Hardness (g)	Method name and number
HMD+LMD	6.23±0.63	Moisture analyzer	3.90±0.13	Gravimetric method	868.4±105.2	Texture analyzer
HMD	6.17±0.74	Moisture analyzer	4.22±0.17	Gravimetric method	803.9 ±103.2	Texture analyzer
LMD	6.19±0.59	Moisture analyzer	3.88±0.22	Gravimetric method	840.0±105.9	Texture analyzer
HMD+HAD	6.20±0.75	Moisture analyzer	3.95±0.11	Gravimetric method	1332.0±109.2	Texture analyzer
HAD+LMD	6.29±0.76	Moisture analyzer	4.15±0.05	Gravimetric method	932.6±118.2	Texture analyzer
HMD+VD	6.40±0.27	Moisture analyzer	3.81±0.08	Gravimetric method	1237.7±81.2	Texture analyzer
VD+LMD	6.48±0.40	Moisture analyzer	3.55±0.14	Gravimetric method	910.9±100.2	Texture analyzer

2. Color results of dried beetroots affected by microwave-assisted drying methods

Indicators	L	a	b	ΔE	Method name and number
HMD+LMD	43.55±0.75	22.79±0.35	3.82±0.15	9.36±0.67	Color measurement
HMD	40.84±1.02	22.20±0.19	3.47±0.13	8.26±0.60	Color measurement
LMD	42.05±1.02	21.76±0.67	3.54±0.29	9.22±1.01	Color measurement
HMD+HAD	42.78±1.08	21.48±0.47	2.09±0.25	10.36±0.87	Color measurement
HAD+LMD	42.12±1.26	23.37±0.85	3.55±0.40	8.08±1.50	Color measurement
HMD+VD	41.19±0.55	21.86±0.91	2.20±0.25	9.18±0.91	Color measurement

VD+LMD	41.87±1.05	23.80±0.77	3.19±0.31	7.77±1.25	Color measurement
Fresh beetroots	36.83±0.94	28.78±0.79	6.34±0.54	-	Color measurement

3. Results of betalains content in dried beetroots affected by microwave-assisted drying methods

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
HMD+LMD	3.08±0.05	2.73±0.04	Colorimetric method
HMD	3.18±0.06	2.74±0.05	Colorimetric method
LMD	2.81±0.05	2.43±0.04	Colorimetric method
HMD+HAD	3.52±0.09	2.51±0.07	Colorimetric method
HAD+LMD	2.97±0.03	2.56±0.02	Colorimetric method
HMD+VD	3.78±0.09	2.81±0.08	Colorimetric method
VD+LMD	4.09±0.05	3.45±0.04	Colorimetric method

4. Results of ascorbic acid and total flavonoids of dehydrated beetroots at different microwave-assisted drying methods

Indicators	Ascorbic acid (mg/100g)	Method name and number	Total flavonoids (mg RE/g)	Method name and number
HMD+LMD	262.1±1.0	Ascorbic acid determination kit	14.94±0.39	Colorimetric method
HMD	272.3±4.4	Ascorbic acid determination kit	13.91±0.31	Colorimetric method
LMD	239.3±3.8	Ascorbic acid determination kit	12.86±0.21	Colorimetric method
HMD+HAD	254.6±2.0	Ascorbic acid determination kit	12.91±0.18	Colorimetric method
HAD+LMD	253.5±4.4	Ascorbic acid determination kit	15.64±0.09	Colorimetric method
HMD+VD	222.1±1.9	Ascorbic acid determination kit	12.76±0.08	Colorimetric method
VD+LMD	265.4±4.6	Ascorbic acid determination kit	16.74±0.26	Colorimetric method

5. Results of FRAP and ABTS values in dried beetroots affected by different microwave-assisted drying methods

Indicators	FRAP (mg TE/g)	Method name and number	ABTS (mg TE/g)	Method name and number
HMD+LMD	14.38±0.09	Colorimetric method	15.85±0.68	Colorimetric method
HMD	14.90±0.19	Colorimetric method	16.56±0.34	Colorimetric method
LMD	12.57±0.49	Colorimetric method	14.95±0.23	Colorimetric method
HMD+HAD	12.79±0.31	Colorimetric method	13.27±0.12	Colorimetric method
HAD+LMD	13.85±0.07	Colorimetric method	16.88±0.66	Colorimetric method
HMD+VD	11.60±0.06	Colorimetric method	13.79±0.26	Colorimetric method
VD+LMD	14.95±0.18	Colorimetric method	16.92±0.21	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor ____________ (signature) Anna O. Helikh

Responsible executor
Ph.D. student ____________ (signature) Yan Liu

Head of the laboratory
Ph.D., Associate Professor ____________ (signature, seal) Jinfeng Yang

食品与生物工程学院
4511020081352

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 4
from March 25, 2021

Results of different drying methods on quality attributes of beetroots*

1. Results of moisture content and rehydration ratio of beetroots affected by different microwave-assisted drying methods

Indicators	Moisture content (%)	Method name and number	Rehydration ratio	Method name and number
FD	4.31±0.61	Moisture analyzer	4.16±0.08	Gravimetric method
HPD	4.64±0.78	Moisture analyzer	4.10±0.07	Gravimetric method
VD	4.41±0.81	Moisture analyzer	4.37±0.01	Gravimetric method
MD	4.82±0.60	Moisture analyzer	3.26±0.07	Gravimetric method
MVD	5.44±0.68	Moisture analyzer	4.77±0.11	Gravimetric method

2. Color results of dried beetroots affected by microwave-assisted drying methods

Indicators	L	a	b	ΔE	Method name and number
Fresh beetroot	37.54±0.69	28.62±0.61	6.09±0.20	–	Color measurement
FD	43.52±0.62	27.76±0.68	4.02±0.16	6.43±0.53	Color measurement
HPD	39.65±0.53	21.92±0.69	1.07±0.08	8.65±0.68	Color measurement
VD	41.00±0.60	25.46±0.45	1.95±0.11	6.28±0.46	Color measurement
MD	41.82±0.91	21.94±0.44	3.49±0.24	8.38±0.66	Color measurement
MVD	40.97±0.99	22.79±0.33	2.93±0.13	7.50±0.69	Color measurement

3. Results of betalains content in dried beetroots affected by microwave-assisted drying methods

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
FD	3.97±0.01	2.57±0.01	Colorimetric method
HPD	5.48±0.03	3.57±0.20	Colorimetric method
VD	4.05±0.05	2.51±0.03	Colorimetric method
MD	2.98±0.02	2.41±0.02	Colorimetric method
MVD	3.13±0.02	2.40±0.02	Colorimetric method

4. Results of ascorbic acid content and total phenolic content of dehydrated beetroots at different microwave-assisted drying methods

Indicators	Ascorbic acid (mg/g)	Method name and number	Total phenolic (mg GAE/g)	Method name and number
FD	7.44±0.06	Ascorbic acid determination kit	8.01±0.11	Folin-Ciocalteu method
HPD	8.46±0.10	Ascorbic acid determination kit	9.94±0.05	Folin-Ciocalteu method
VD	8.73±0.23	Ascorbic acid determination kit	10.23±0.08	Folin-Ciocalteu method
MD	8.32±0.10	Ascorbic acid determination kit	9.31±0.14	Folin-Ciocalteu method
MVD	7.17±0.09	Ascorbic acid determination kit	10.20±0.08	Folin-Ciocalteu method

5. Results of total flavonoids content and DPPH values in dried beetroots affected bydifferent microwave-assisted drying methods

Indicators	Total flavonoids (mg RE/g)	Method name and number	DPPH (mg TE/g)	Method name and number
FD	15.82±0.15	Colorimetric method	5.16±0.02	Colorimetric method
HPD	24.71±0.47	Colorimetric method	5.65±0.04	Colorimetric method
VD	21.30±0.34	Colorimetric method	6.21±0.05	Colorimetric method
MD	21.82±0.17	Colorimetric method	6.63±0.03	Colorimetric method
MVD	19.26±0.35	Colorimetric method	6.62±0.05	Colorimetric method

6. Results of FRAP and ABTS values in dried beetroots affected by different drying methods

Indicators	FRAP (mg TE/g)	Method name and number	ABTS (mg TE/g)	Method name and number
FD	9.89±0.13	Colorimetric method	13.89±0.29	Colorimetric method
HPD	12.63±0.20	Colorimetric method	15.57±0.37	Colorimetric method
VD	13.15±0.11	Colorimetric method	15.92±0.08	Colorimetric method
MD	12.92±0.14	Colorimetric method	17.22±0.35	Colorimetric method
MVD	13.36±0.17	Colorimetric method	16.30±0.21	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor Ph.D., Associate Professor	(signature)	Anna O. Helikh
Responsible executor Ph.D. student	(signature)	Yan Liu
Head of the laboratory Ph.D., Associate Professor	(signature, seal) 食品与生物工程学院 4511020091352	Jinfeng Yang

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 5
from May 28, 2021

Results of freeze-thaw cycles on quality attributes of microwave dried beetroots *

1. Results of rehydration ratio of beetroots affected by freeze-thaw cycles

Indicators	Drying time (min)	Method name and number	Rehydration ratio	Method name and number
FT0	41.3±1.7	Timing method	5.04±0.07	Gravimetric method
FT1	33.0± 0.7	Timing method	4.89±0.05	Gravimetric method
FT2	28.5± 1.7	Timing method	4.67±0.04	Gravimetric method
FT3	26.0 ± 1.7	Timing method	4.52±0.08	Gravimetric method

2. Color results of dried beetroots affected by freeze-thaw cycles

Indicators	*L*	*a*	*b*	Δ*E*	Method name and number
Fresh sample	36.64±0.42	28.16±0.43	6.03±0.30	/	Color measurement
FT0	40.72±0.80	18.94±0.60	1.25±0.16	11.18±0.67	Color measurement
FT1	42.70±0.50	17.41±0.70	0.79±0.08	13.42±0.67	Color measurement
FT2	41.09±0.63	15.54±0.68	1.17±0.19	14.24±0.82	Color measurement
FT3	42.50±0.83	15.31±0.39	1.02±0.07	15.00±0.55	Color measurement

3. Results of betalains content in dried beetroots affected by freeze-thaw cycles

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
FT0	2.81±0.01	1.99±0.01	Colorimetric method
FT1	2.12±0.01	1.93±0.01	Colorimetric method
FT2	1.80±0.01	1.77±0.01	Colorimetric method
FT3	1.55±0.01	1.67±0.01	Colorimetric method

4. Results of ascorbic acid content and total phenolic content of dehydrated beetroots carried to different freeze-thaw cycles

Indicators	Ascorbic acid (mg/100g)	Method name and number	Total phenolic (mg GAE/g)	Method name and number
FT0	750.78±10.61	Ascorbic acid determination kit	9.74±0.09	Folin-Ciocalteu method
FT1	678.07±19.02	Ascorbic acid determination kit	8.13±0.08	Folin-Ciocalteu method
FT2	571.63±1.20	Ascorbic acid determination kit	6.98±0.08	Folin-Ciocalteu method
FT3	503.87±11.37	Ascorbic acid determination kit	6.54±0.05	Folin-Ciocalteu method

5. Results of total flavonoids content and DPPH values in dried beetroots affected by freeze-thaw cycles

Indicators	Total flavonoids (mg RE/g)	Method name and number	DPPH (mg TE/g)	Method name and number
FT0	19.58±0.51	Colorimetric method	6.75±0.02	Colorimetric method
FT1	16.20±0.19	Colorimetric method	6.86±0.03	Colorimetric method
FT2	14.22±0.39	Colorimetric method	6.67±0.02	Colorimetric method
FT3	13.00±0.48	Colorimetric method	6.29±0.04	Colorimetric method

6. Results of FRAP and ABTS values in dried beetroots affected by freeze-thaw cycles

Indicators	FRAP (mg TE/g)	Method name and number	ABTS (mg TE/g)	Method name and number
FT0	9.72±0.09	Colorimetric method	15.01±0.18	Colorimetric method
FT1	8.81±0.07	Colorimetric method	14.28±0.09	Colorimetric method
FT2	7.92±0.18	Colorimetric method	12.60±0.09	Colorimetric method
FT3	6.15±0.21	Colorimetric method	11.27±0.37	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor ______ (signature) ______ Anna O. Helikh

Responsible executor
Ph.D. student ______ (signature) ______ Yan Liu

Head of the laboratory
Ph.D., Associate Professor ______ (signature, seal) ______ Jinfeng Yang

食品与生物工程学院
4511020091352

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 6
from October 27, 2021

Results of different freezing temperatures on quality attributes of heat pump dried beetroots*

1. Results of thawing time, thawing loss rate and drying time of beetroots affected by freezing temperatures

Indicators	Thawing time (min)	Drying time (h)	Method name and number	Thawing loss rate (%)	Method name and number
–4 °C	38.3±2.5	4.0±0.0	Timing method	21.63±0.15	Gravimetric method
–20 °C	36.3±1.5	3.9±0.3	Timing method	32.52±1.14	Gravimetric method
–50 °C	32.0±2.6	3.8±0.3	Timing method	36.02±1.52	Gravimetric method
–80 °C	28.7±2.3	3.9±0.3	Timing method	25.16±0.78	Gravimetric method
CG	—	5.3±0.3	Timing method		Gravimetric method

2. Results of moisture content and rehydration ratio of beetroots affected by different freezing temperatures

Indicators	Moisture content (%)	Method name and number	Rehydration ratio	Method name and number
–4 °C	5.04±0.67	Moisture analyzer	6.42±0.08	Gravimetric method
–20 °C	5.06±0.38	Moisture analyzer	6.88±0.14	Gravimetric method
–50 °C	5.31±0.34	Moisture analyzer	6.19±0.06	Gravimetric method
–80 °C	5.51±0.36	Moisture analyzer	5.20±0.19	Gravimetric method
CG	5.02±0.63	Moisture analyzer	5.68±0.16	Gravimetric method

3. Results of shrinkage rate, apparent density and hardness of heat pump dried beetroots affected by freezing temperatures

Indicators	Shrinkage rate (%)	Method name and number	Apparent density (g/mL)	Method name and number	Hardness (g)	Method name and number
–4 °C	93.68±0.29	Volumetric method	1.06±0.04	Gravimetric and volumetric methods	1126.2±106.6	Texture analyzer
–20 °C	95.78±0.42	Volumetric method	1.26±0.07	Gravimetric and volumetric methods	973.1±153.0	Texture analyzer
–50 °C	97.78±0.21	Volumetric method	1.65±0.09	Gravimetric and volumetric methods	436.5±70.8	Texture analyzer
–80 °C	95.17±0.42	Volumetric method	1.51±0.14	Gravimetric and volumetric methods	1940.7±180.7	Texture analyzer
CG	90.54±0.60	Volumetric method	0.83±0.07	Gravimetric and volumetric methods	1452.7±98.6	Texture analyzer

4. Color results of dried beetroots affected by freezing temperatures

Indicators	Freezing temperature (°C)					Method name and number
	–4	–20	–50	–80	CG	
L	39.90±1.02	40.47±0.95	44.20±1.09	38.38±1.59	43.76±1.09	Color measurement
a	22.29±0.53	22.69±0.62	24.86±0.40	24.19±0.71	28.94±1.28	Color measurement
b	1.04±0.15	1.03±0.13	0.75±0.06	1.99±0.23	2.51±0.28	Color measurement
ΔE	12.03±0.86	13.27±0.81	17.33±0.94	11.47±1.24	19.12±0.33	Color measurement

5. Results of betalains content in dried beetroots affected by freezing temperatures

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
–4 °C	2.82 ±0.01	1.60±0.01	Colorimetric method
–20 °C	2.73±0.01	1.55±0.01	Colorimetric method
–50 °C	2.46±0.01	1.35±0.00	Colorimetric method
–80 °C	2.59±0.01	1.42±0.01	Colorimetric method
CG	3.31±0.02	1.98±0.01	Colorimetric method

6. Results of ascorbic acid content and total phenolic content of dehydrated beetroots at different freezing temperatures

Indicators	Ascorbic acid (mg/100g)	Method name and number	Total phenolic (mg GAE/g)	Method name and number
–4 °C	258.3±3.8	Ascorbic acid determination kit	7.54±0.21	Folin-Ciocalteu method
–20 °C	251.6±5.2	Ascorbic acid determination kit	7.45±0.19	Folin-Ciocalteu method
–50 °C	239.1±4.0	Ascorbic acid determination kit	6.95±0.21	Folin-Ciocalteu method
–80 °C	249.3±4.2	Ascorbic acid determination kit	6.69±0.12	Folin-Ciocalteu method
CG	287.7±8.8	Ascorbic acid determination kit	7.78±0.24	Folin-Ciocalteu method

7. Results of total flavonoids content and DPPH values in dried beetroots affected by different freezing temperatures

Indicators	Total flavonoids (mg RE/g)	Method name and number	DPPH (mg TE/g)	Method name and number
–4 °C	10.90±0.41	Colorimetric method	6.53±0.14	Colorimetric method
–20 °C	10.26±0.22	Colorimetric method	6.43±0.11	Colorimetric method
–50 °C	9.94±0.16	Colorimetric method	5.59±0.15	Colorimetric method
–80 °C	10.60±0.18	Colorimetric method	5.99±0.13	Colorimetric method
CG	11.15±0.21	Colorimetric method	7.01±0.14	Colorimetric method

8. Results of FRAP and ABTS values in dried beetroots affected by different freezing temperatures

Indicators	FRAP (mg TE/g)	Method name and number	ABTS (mg TE/g)	Method name and number
–4 °C	10.27±0.22	Colorimetric method	17.94±0.49	Colorimetric method
–20 °C	9.89±0.34	Colorimetric method	17.69±0.44	Colorimetric method
–50 °C	9.06±0.30	Colorimetric method	16.07±0.64	Colorimetric method
–80 °C	9.83±0.41	Colorimetric method	17.61±0.41	Colorimetric method
CG	10.67±0.44	Colorimetric method	18.54±0.60	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor Ph.D., Associate Professor	(signature)	Anna O. Helikh
Responsible executor Ph.D. student	(signature)	Yan Liu
Head of the laboratory Ph.D., Associate Professor	(signature, seal)	Jinfeng Yang

食品与生物工程学院
4511020081352

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 7
from November 5, 2021

Results of different thawing methods on quality attributes of microwave-dried beetroots*

1. Results of thawing time and drying time of beetroots affected by thawing methods

Indicators	Thawing time (min)	Drying time (h)	Method name and number
Microwave thawing	7.3±0.6	39.7±0.6	Timing method
Water thawing	18.0±0.0	39.0±0.0	Timing method
Air thawing	102.3±2.5	38.3±1.2	Timing method
Refrigerator thawing	364.0±3.5	39.3±0.6	Timing method
Ultrasonic thawing	19.3±1.2	37.0±1.7	Timing method

2. Results of moisture content and rehydration ratio of beetroots affected by different thawing methods

Indicators	Rehydration ratio	Method name and number
Microwave thawing	4.67±0.09	Gravimetric method
Water thawing	4.59±0.07	Gravimetric method
Air thawing	4.23±0.05	Gravimetric method
Refrigerator thawing	4.85±0.10	Gravimetric method
Ultrasonic thawing	4.58±0.08	Gravimetric method

3. Color results of dried beetroots affected by thawing methods

Indicators	*L*	*a*	*b*	Δ*E*	Method name and number
Microwave thawing	43.03±0.20	19.85±0.39	3.41±0.16	29.22±2.79	Color measurement
Water thawing	39.51±0.36	17.90±0.64	2.80±0.23	16.01±2.02	Color measurement
Air thawing	42.30±0.17	20.89±0.20	5.23±0.11	43.23±2.78	Color measurement
Refrigerator thawing	41.69±0.27	19.72±0.93	3.23±0.08	26.61±1.18	Color measurement
Ultrasonic thawing	41.25±0.50	19.60±0.19	2.51±0.10	24.90±1.00	Color measurement
Fresh beetroots	25.90±0.47	16.52±0.68	2.47±0.19	—	Color measurement

4. Results of betalains content in dried beetroots affected by thawing methods

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
Microwave thawing	2.04±0.02	2.02±0.01	Colorimetric method
Water thawing	2.20±0.01	1.97±0.01	Colorimetric method
Air thawing	2.01±0.01	1.96±0.01	Colorimetric method
Refrigerator thawing	2.20±0.02	1.96±0.00	Colorimetric method
Ultrasonic thawing	2.28±0.05	1.94±0.01	Colorimetric method

5. Results of ascorbic acid content and total phenolic content of dehydrated beetroots at different thawing methods

Indicators	Total flavonoids (mg RE/g)	Method name and number	Total phenolic (mg GAE/g)	Method name and number
Microwave thawing	13.86±0.23	Colorimetric method	6.06±0.11	Folin-Ciocalteu method
Water thawing	16.50±0.40	Colorimetric method	8.15±0.12	Folin-Ciocalteu method

Air thawing	14.38±0.15	Colorimetric method	7.40±0.10	Folin-Ciocalteu method
Refrigerator thawing	15.15±0.26	Colorimetric method	7.91±0.10	Folin-Ciocalteu method
Ultrasonic thawing	16.59±0.28	Colorimetric method	6.52±0.08	Folin-Ciocalteu method

6. Results of FRAP, DPPH and ABTS values in dried beetroots affected by different thawing methods

Indicators	FRAP (mg TE/g)	DPPH (mg TE/g)	ABTS (mg TE/g)	Method name and number
Microwave thawing	10.21±0.26	3.21±0.02	12.92±0.09	Colorimetric method
Water thawing	13.83±0.25	3.04±0.01	13.97±0.18	Colorimetric method
Air thawing	12.53±0.22	3.38±0.03	12.31±0.09	Colorimetric method
Refrigerator thawing	10.08±0.22	3.20±0.01	13.20±0.13	Colorimetric method
Ultrasonic thawing	10.48 ± 0.16	2.88±0.01	13.58±0.11	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor ______ (signature) ______ Anna O. Helikh

Responsible executor
Ph.D. student ______ Yan Liu (signature) ______ Yan Liu

Head of the laboratory
Ph.D., Associate Professor ______ Jinfeng Yang (signature, seal) ______ Jinfeng Yang

食品与生物工程学院
4511020091352

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 8
from February 21, 2022

Results of different drying methods on quality attributes of frozen-thawed beetroots*

1. Results of moisture content and rehydration ratio of frozen-thawed beetroots affected by different drying methods

Indicators	Moisture content (%)	Method name and number	Drying time	Method name and number
MD	5.75±0.63	Moisture analyzer	41.5±2.6	Timing method
MVD	5.98±0.63	Moisture analyzer	70.3±2.5	Timing method
FD	6.05±0.41	Moisture analyzer	1340.0±34.6	Timing method
VD	5.62±1.00	Moisture analyzer	370.0±10.0	Timing method
HAD	5.64±0.83	Moisture analyzer	350.0±17.3	Timing method
SD	5.88±0.69	Moisture analyzer	570.0±30.0	Timing method

2. Results of shrinkage rate, rehydration ratio and hardness of frozen-thawed beetroots affected by different drying methods

Indicators	Shrinkage rate (%)	Method name and number	Rehydration ratio	Method name and number	Hardness (g)	Method name and number
MD	90.91±1.04	Volumetric method	4.68±0.12	Gravimetric method	546.1±95.3	Texture analyzer
MVD	81.60±1.80	Volumetric method	5.33±0.23	Gravimetric method	507.8±73.4	Texture analyzer
FD	74.32±1.72	Volumetric method	6.49±0.06	Gravimetric method	303.0±34.8	Texture analyzer
VD	92.27±1.04	Volumetric method	6.29±0.11	Gravimetric method	752.3±119.8	Texture analyzer
HAD	90.68±1.42	Volumetric method	5.72±0.25	Gravimetric method	1611.6±141.8	Texture analyzer
SD	91.37±0.39	Volumetric method	4.88±0.14	Gravimetric method	1805.4±126.7	Texture analyzer

3. Color results of frozen-thawed beetroots affected by different drying methods

Indicators	*L*	*a*	*b*	Δ*E*	Method name and number
MD	39.37±0.78	20.07±0.45	2.63±0.36	9.60±0.45	Color measurement
MVD	39.18±0.84	24.79±0.66	2.57±0.57	5.93±0.49	Color measurement
FD	40.47±0.93	26.93±0.75	2.66±0.19	5.61±0.48	Color measurement
VD	40.02±0.96	20.00±0.40	2.09±0.23	10.09±0.56	Color measurement
HAD	37.02±0.85	17.60±0.58	1.44 ± 0.27	11.95±0.57	Color measurement
SD	37.21±1.09	13.27±0.47	0.42 ±0.06	16.34±0.48	Color measurement
Fresh sample	36.62±0.50	28.48±0.77	6.23 ± 0.38	/	Color measurement

4. Results of betalains content in frozen-thawed beetroots affected by different drying methods

Indicators	Betacyanins, (mg/g)	Betaxanthins (mg/g)	Method name and number
MD	2.90±0.05	2.55±0.05	Colorimetric method
MVD	4.38±0.17	3.12±0.11	Colorimetric method
FD	3.93±0.07	2.95±0.04	Colorimetric method
VD	2.82±0.09	2.52±0.06	Colorimetric method
HAD	2.78±0.07	2.37±0.05	Colorimetric method
SD	3.12±0.02	2.38±0.01	Colorimetric method

5. Results of ascorbic acid content and total phenolic content of frozen-thawed beetroots at different drying methods

Indicators	Ascorbic acid (mg/100g)	Method name and number	Total phenolic (mg GAE/g)	Method name and number
MD	359.9±7.1	Ascorbic acid determination kit	8.33±0.09	Folin-Ciocalteu method
MVD	431.6±3.5	Ascorbic acid determination kit	8.58±0.04	Folin-Ciocalteu method

FD	419.7±2.4	Ascorbic acid determination kit	6.40±0.13	Folin-Ciocalteu method
VD	417.6±6.7	Ascorbic acid determination kit	6.97±0.10	Folin-Ciocalteu method
HAD	290.2±4.1	Ascorbic acid determination kit	6.00±0.10	Folin-Ciocalteu method
SD	322.8±5.4	Ascorbic acid determination kit	5.88±0.09	Folin-Ciocalteu method

6. Results of total flavonoids content, FRAP and ABTS values in frozen-thawed beetroots affected by different drying methods

Indicators	Total flavonoids (mg RE/g)	Method name and number	FRAP (mg TE/g)	ABTS (mg TE/g)	Method name and number
MD	11.85±0.26	Colorimetric method	15.95±0.05	11.68±0.04	Colorimetric method
MVD	14.53±0.44	Colorimetric method	16.65±0.03	13.64±0.26	Colorimetric method
FD	12.14±0.62	Colorimetric method	13.93±0.06	9.34±0.07	Colorimetric method
VD	12.06±0.40	Colorimetric method	11.32±0.05	11.01±0.20	Colorimetric method
HAD	10.73±0.36	Colorimetric method	13.05±0.06	10.59±0.14	Colorimetric method
SD	9.37±0.26	Colorimetric method	10.87±0.05	10.24±0.03	Colorimetric method

* Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor ______ (signature) Anna O. Helikh

Responsible executor
Ph.D. student ______ (signature) Yan Liu

Head of the laboratory
Ph.D., Associate Professor ______ (signature, seal) Jinfeng Yang

食品与生物工程学院 451102008135

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA № 9
from December 1, 2022

Research results of meat products enriched with dried beetroot, pretreated by freeze-thaw method*

1. Sensory analysis of meat products

Indicators	Color	Odor	Flavor	Texture	Overall acceptability	Method name and number
B0 (0%)	7.02±0.11*e*	8.01±0.14*a*	8.41±0.15*ab*	8.33±0.07*b*	7.96 ±0.16*b*	Organoleptic evaluation
B1 (0.5%)	7.74±0.11*d*	7.24±0.11*bc*	7.93±0.12*c*	8.02±0.08*c*	7.75±0.11*bc*	Organoleptic evaluation
B2 (1.0%)	8.30±0.16*c*	7.44±0.11*b*	8.19±0.09*b*	8.21±0.07*b*	8.00±0.10*b*	Organoleptic evaluation
B3 (1.5%)	9.75±0.11*a*	7.88±0.19*a*	8.33±0.12*ab*	8.64±0.11*a*	8.67±0.08*a*	Organoleptic evaluation
B4 (2.0%)	9.38±0.10*bc*	7.98±0.12*a*	8.52±0.10*a*	8.67±0.12*a*	8.72±0.13*a*	Organoleptic evaluation
B5 (2.5%)	9.51±0.08*b*	7.80±0.16*a*	8.40±0.16*ab*	8.62±0.13*a*	8.69±0.07*a*	Organoleptic evaluation

2. Color changes of meat products

Indicators	*L**	*a**	*b**	Method name and number
B0 (0%)	62.16±0.92	5.09±0.18	6.24±0.44	Color measurement
B1 (0.5%)	58.69±0.78	10.96±0.36	11.17±0.47	Color measurement
B2 (1.0%)	54.18±0.95	15.12±0.73	10.38±0.46	Color measurement
B3 (1.5%)	50.06±0.83	18.16±0.40	8.95±0.39	Color measurement
B4 (2.0%)	48.45±1.04	19.00±0.71	9.46±0.47	Color measurement
B5 (2.5%)	43.43±0.66	21.62±0.52	7.35±0.43	Color measurement

3. Texture profile analysis of meat products

Indicators	Hardness, g	Springiness, %	Cohesiveness, %	Gumminess	Chewiness	Resilience, %	Method name and number
B0 (0%)	3138.1±175.3	0.364±0.047	0.272±0.047	867.0±60.1	319.6±54.5	0.070±0.009	TPA texture analysis
B1 (0.5%)	2472.5±112.5	0.377±0.044	0.251±0.025	593.5±86.2	240.9±30.5	0.075±0.010	TPA texture analysis
B2 (1.0%)	3052.0±143.3	0.316±0.027	0.260±0.020	793.7±39.6	251.6±47.2	0.071±0.007	TPA texture analysis
B3 (1.5%)	3640.7±131.3	0.328±0.017	0.264±0.027	865.0±48.0	306.6±46.2	0.070±0.009	TPA texture analysis
B4 (2.0%)	2871.2±179.4	0.304±0.022	0.235±0.016	673.3±34.6	205.2±21.0	0.064±0.005	TPA texture analysis
B5 (2.5%)	4391.3±138.4	0.335±0.020	0.249±0.021	1032.1±79.8	347.6±36.4	0.067±0.007	TPA texture analysis

4. pH, TBARS and peroxide value of meat products

Indicators	pH	Method name and number	Peroxide value (g/100g)	Method name and number	TBARS (mg/100g)	Method name and number
B0 (0%)	6.04±0.01	pH meter	0.326±0.006	Titration method	0.973±0.036	Colorimetric method
B1 (0.5%)	5.94±0.01	pH meter	0.301±0.005	Titration method	0.781±0.014	Colorimetric method
B2 (1.0%)	5.84±0.01	pH meter	0.270±0.007	Titration method	0.720±0.022	Colorimetric method
B3 (1.5%)	5.81±0.03	pH meter	0.248±0.005	Titration method	0.667±0.038	Colorimetric method
B4 (2.0%)	5.86±0.03	pH meter	0.249±0.008	Titration method	0.671±0.030	Colorimetric method
B5 (2.5%)	5.91±0.03	pH meter	0.253±0.009	Titration method	0.673±0.027	Colorimetric method

5. Nutrient of meat products with different beetroot powder additions

Indicators	B0 (0%)	B1 (0.5%)	B2 (1.0%)	B3 (1.5%)	B4 (2.0%)	B5 (2.5%)	Method name and number
Water (g/100 g)	51.14±0.31	52.64±0.38	53.31±0.45	57.81±0.41	57.07±0.53	58.00±0.47	Infrared moisture analyzer
Ash (g/100 g)	3.09±0.01	3.36±0.02	3.35±0.03	3.36±0.01	3.37±0.02	3.39±0.02	Determination of total ash in food (GB 5009.4-2016)
Protein (g/100 g)	15.23±0.15	16.10±0.20	15.69±0.18	15.72±0.11	15.68±0.17	15.80±0.10	Kjeldahl determination (GB 5009.5-2016)
Fat (g/100 g)	3.55±0.05	3.45±0.05	3.43±0.09	3.40±0.06	3.38±0.06	3.39±0.09	Soxhlet extraction (GB 5009.6-2016)

*Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor ____________ (signature) Anna O. Helikh

Responsible executor
Ph.D. student Yan Liu (signature) Yan Liu

Head of the laboratory
Associate Professor Feifei Shang (signature, seal) Feifei Shang

食品与生物工程学院
4511020091352

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL OF EXPERIMENTAL DATA №10
from December 30, 2022

Research results of biscuits enriched with dried beetroot, pretreated by freeze-thaw method*

1. Sensory analysis of biscuits

Indicators	Moisture content (%)	Method name and number	Sensory score (points)	Method name and number
T0 (0%)	3.13±0.50	Infrared moisture analyzer	70.0±2.4	Organoleptic evaluation
T1 (5%)	2.79±0.63	Infrared moisture analyzer	79.6±2.0	Organoleptic evaluation
T2 (10%)	3.02±0.60	Infrared moisture analyzer	89.1±1.9	Organoleptic evaluation
T3 (15%)	3.30±0.32	Infrared moisture analyzer	84.6±2.0	Organoleptic evaluation
T4 (20%)	3.05±0.34	Infrared moisture analyzer	80.7±1.8	Organoleptic evaluation

2. Color parameters of biscuits

Indicators	*L*	*a*	*b*	Method name and number
T0 (0%)	65.66±2.47	11.34±0.43	22.32±0.72	Color measurement
T1 (5%)	48.76±0.78	23.16±0.24	13.08±0.46	Color measurement
T2 (10%)	42.79±0.66	25.06±0.39	11.52±0.51	Color measurement
T3 (15%)	40.46±0.67	23.35±0.58	9.61±0.25	Color measurement
T4 (20%)	38.92±0.77	22.56±0.29	7.67±0.43	Color measurement

3. Results of texture parameters in biscuits

Indicators	Hardness (g)	Fracturability (g)	Springiness	Cohesiveness	Gumminess	Chewiness	Method name and number
T0 (0%)	228.3±90.8	313.3±147.1	0.967±0.026	0.016±0.003	3.043±0.805	3.009±0.883	TPA texture analysis
T1 (5%)	215.8±54.2	259.3±83.8	0.924±0.056	0.018±0.005	3.539±0.829	3.443±0.774	TPA texture analysis
T2 (10%)	209.0±90.2	224.0±87.4	0.925±0.060	0.021±0.007	3.184±0.848	2.954±0.687	TPA texture analysis
T3 (15%)	182.1±49.7	224.5±61.1	0.967±0.036	0.020±0.007	3.422±1.005	3.285±1.042	TPA texture analysis
T4 (20%)	165.9±32.3	188.7±67.8	0.965±0.024	0.014±0.004	2.290±0.720	2.190±0.719	TPA texture analysis

4. Nutrient of biscuits with different beetroot powder additions

Indicators	T0 (0%)	T1 (5%)	T2 (10%)	T3 (15%)	T4 (20%)	Method name and number
Ash (g/100 g)	1.47±0.18	2.08±0.13	2.34±0.22	2.75±0.11	3.24±0.07	Determination of total ash in food (GB 5009.4-2016)
Protein (g/100 g)	9.85±0.07	10.10±0.08	10.30±0.11	10.52±0.09	10.80±0.14	Kjeldahl determination (GB 5009.5-2016)
Fat (g/100 g)	7.80±0.09	8.12±0.08	8.30±0.10	8.26±0.09	8.25±0.07	Soxhlet extraction (GB 5009.6-2016)

*Statistical processing of the experimental data given in the dissertation was carried out for three measurements of all studied properties. The final results in the tables were given in the form of mean±SD, where mean is the average value, SD is standard deviation. Statistical processing of experimental data was carried out using SPSS Statistics Version 20 and Excel with Microsoft Office 2010.

Scientific supervisor
Ph.D., Associate Professor _______ (signature) _______ Anna O. Helikh

Responsible executor
Ph.D. student _______ (signature) _______ Yan Liu

Head of the laboratory
Associate Professor _______ (signature, seal) _______ Yuhua Xie

食品与生物工程学院
4511020091352

Addition B

"Degustation certificates"

SCHOOL OF FOOD AND BIOENGINEERING, HEZHOU UNIVERSITY
Fruit and Vegetable Processing Laboratory

PROTOCOL № 11
from November 30, 2022

Meeting of the expert-tasting commission (METC)
School of Food and Bioengineering, Hezhou University

Chairman of the METC Commission – Ph.D., Professor, Zhenhua Duan
METC Secretary – Ph.D. student, Research Associate, Yan Liu

PRESENT: 19 members of the commission (attendance letter attached):

NAME ALL MEMBERS:
Dongjian Zhu, Qiao Zhang, Wen Cai, Nianfang Deng, Dingjin Li, Hui Nie, Mubo Song, Hanying Tan, Wei Xie, Feilong Yin, Yunfeng Liu, Yuhua Xie, Xiaomei Yang, Jinfeng Yang, Jiaya Yin, Xiaoxian Tang, Yuanli Liang, Xiaochun Li, Ni Yang.

PROTOCOL:

1. Tasting of samples of new products developed in the framework of the dissertation for the degree of Ph.D. student, Research Associate, Yan Liu:
- Biscuits enriched with dried beetroot, pretreated by freeze-thaw method
- Meat products enriched with dried beetroot, pretreated by freeze-thaw method

SPEAKERS:

Ph.D. student, Research Associate, Yan Liu: tasting of food products made according to the technologies developed as part of the dissertation "Technology of semi-finished product from dried beetroot, pretreated by freeze-thaw method and food products using it" is planned. The aim of the research was to improve the quality attributes of finished products.

We have proposed the technology to obtain dried beetroot using freeze-thaw pretreatment and heat pump drying followed by microwave vacuum drying method. This dried beetroot, pretreated by freeze-thaw method was used in the technology of the presented products. Dried beetroot, pretreated by freeze-thaw method has high bioactive compounds and strong antioxidant capacity. Products using it have good organoleptic properties and high nutritional and biological value.

The developed types of food products enriched with dried beetroot, pretreated by freeze-thaw method are intended for dietary, children's and mass consumption.

New technologies have passed production tests at food industry enterprises of Ukraine and China.

The results of tasting new products:

Members of the expert tasting commissions took part in the sensory evaluation of the presented products. The results of sensory analysis were noted by experts in tasting letters. Generalized data of expert evaluation of new products are given in Attachment A.

HAVE APPROVED:

1. Recognize the feasibility of implementation new food products using dried beetroot, pretreated by freeze-thaw method.
2. Note the relevance of presented developments, the presence of competitive advantages over traditional counterparts (use of available raw materials, high nutritional and biological value, available price, etc.).
3. Recognize that the new products that were presented for tasting are characterized by high organoleptic characteristics. Taking into account the wishes of the experts, the following products should be recommended for introduction in food industry:

- Biscuits enriched with dried beetroot, pretreated by freeze-thaw method;
- Meat products enriched with dried beetroot, pretreated by freeze-thaw method;

4. Introduce the results of scientific research into the educational process of Sumy National Agrarian University and Hezhou University of Food and Bioengineering.

Chairman of METC, Ph.D., Prof.	Zhenhua Duan (signature, seal) 食品与生物工程学院	Zhenhua Duan
METC Secretary, Ph.D. student	Yan Liu (signature)	Yan Liu

Attachment A

Expert sensory evaluation of biscuits and meat products

Characteristic	Coefficient of weight	GPA
Meat products enriched with dried beetroot, pretreated by freeze-thaw method		
Appearance	0.1	5.0
Consistence	0.3	4.7
Surface	0.1	4.9
Color	0.1	4.8
Scent	0.2	4.9
Taste	0.2	4.8
Total score		**4.9**
Biscuits enriched with dried beetroot, pretreated by freeze-thaw method		
Appearance	0.1	5.0
Consistence	0.3	4.6
Surface	0.1	4.8
Color	0.1	5.0
Scent	0.2	4.9
Taste	0.2	4.7
Total score		**4.8**

Addition C

TS 10.3-04718013-007:2022 "Dried beetroot"

ДКПП 10.39.13-90.00 УКНД 67.080

ПОГОДЖУЮ
Директор
ФОП «Філон А.М.»
__________ А.М. Філон
«27» 10 2022 р.

ЗАТВЕРДЖУЮ
Ректор Сумського національного
аграрного університету,
академік НААН України
__________ В.І. Ладика
«__» ______ 2022 р.

БУРЯК СУШЕНИЙ

Технічні умови

ТУ У 10.3-04718013-007:2022

Вперше
Дата надання чинності 10.12.2022
Чинні до 10.12.2027

РОЗРОБЛЕНО

К. т. н., доцент кафедри технологій та безпечності харчових продуктів СНАУ
__________ А.О. Геліх
«20» 10 2022 р.

Ст. викладач факультету харчових та біотехнологій університету Хечжоу, Китай
Liu Yan Лю Янь
«10» 10 2022 р.

МІНІСТЕРСТВО РОЗВИТКУ ЕКОНОМІКИ, ТОРГІВЛІ ТА СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ
ДЕРЖАВНЕ ПІДПРИЄМСТВО
"СУМСЬКИЙ РЕГІОНАЛЬНИЙ НАУКОВО-ВИРОБНИЧИЙ ЦЕНТР СТАНДАРТИЗАЦІЇ, МЕТРОЛОГІЇ ТА СЕРТИФІКАЦІЇ"
ДП "СУМИСТАНДАРТМЕТРОЛОГІЯ"
Ідентифікаційний код 02568064
ПЕРЕВІРЕНО
на відповідність законодавству України
«15» листопада 2022 р.
Внесено до книги обліку за № 02568064/002519

ЗМІСТ

МІНІСТЕРСТВО РОЗВИТКУ ЕКОНОМІКИ, ТОРГІВЛІ ТА СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ
ДП "СУМИСТАНДАРТМЕТРОЛОГІЯ"
ПЕРЕВІРЕНО

1 СФЕРА ЗАСТОСУВАННЯ

Ці технічні умови (ТУ) поширюються на буряк сушений, а саме буряк столовий сушений та буряк столовий сушений із некондиційної сировини, який виробляють комбінованим способом сушки, що включає попередню обробку тепловим насосом та безпосередньо основну мікрохвильову вакуумну сушку, названий далі за текстом – буряк сушений.

Буряк сушений використовують у харчовій промисловості, кондитерській галузі, ресторанному господарстві та реалізації через торгівельну мережу.

Обов'язкові вимоги до буряка сушеного, що забезпечують його безпеку для життя і здоров'я споживачів та охорони навколишнього природного середовища викладені в розділах (4 – 6) цих технічних умов.

Приклад позначення буряку сушеного при замовленні та в іншій документації:

Буряк сушений скибочками ТУ У 10.3-04718013-007:2022.

Буряк сушений порошок ТУ У 10.3-04718013-007:2022.

Ці ТУ придатні для цілей сертифікації.

Право власності на ТУ належить Сумському національному аграрному університету та кафедрі харчування та біоінженерії Університету Хечжоу, Китай (Food and Bioengineering department of Hezhou University, China).

Перевірка технічних умов здійснюється не рідше одного разу на п'ять років, після надання їм чинності чи останнього перевіряння, якщо не виникає потреби перевіряти їх раніше у разі прийняття нормативно-правових актів, відповідних національних (міждержавних) стандартів та інших нормативних документів, якими регламентовано інші вимоги ніж ті, що встановлені у цих ТУ.

2 НОРМАТИВНІ ПОСИЛАННЯ

В цих ТУ є посилання на наступні нормативні документи:

Закон України від 05.03.1998 р. № 187/98-ВР «Про відходи»

Закон України від 16.10.1992 р. №2707-XII «Про охорону атмосферного повітря»

Закон України від 14.01.2001р. №1393-XIV «Про вилучення з обігу, переробку, утилізацію, знищення або подальше використання неякісної та небезпечної продукції»

Закон України від 06.12.2018 р. № 2639-VIII «Про інформацію для споживачів щодо харчових продуктів»

ДСТУ 3147-95 Коди та кодування інформації. Штрихове кодування. Маркування об'єктів ідентифікації. Формат та розташування штрихкодових позначок EAN на тарі та пакуванні товарної продукції. Загальні вимоги

ДСТУ 3273-95 Безпечність промислових підприємств. Загальні положення та вимоги

ДСТУ 4912:2008 Фрукти, овочі та продукти перероблення. Методи визначання домішок рослинного походження

ДСТУ 4913:2008 Фрукти, овочі та продукти перероблення. Методи визначання мінеральних домішок

ДСТУ 4948:2008 Фрукти, овочі та продукти їх перероблення. Методи визначання вмісту нітратів

ДСТУ 7033:2009 Буряк столовий свіжий. Технічні умови

ДСТУ 7237:2011 Система стандартів безпеки праці. Електробезпека. Загальні вимоги та номенклатура видів захисту

ДСТУ 7239:2011 ССБП. Засоби індивідуального захисту. Загальні вимоги та класифікація

ДСТУ 7670:2014 Сировина і продукти харчові. Готування проб. Мінералізація для визначення вмісту токсичних елементів

ДСТУ 7804:2015 Продукти перероблняння фруктів та овочів. Методи визначання сухих речовин або вологи

ДСТУ 7963:2015 Продукти харчові. Готування проб для мікробіологічних аналізів

ДСТУ 8040:2015 Продукти харчові. Метод виявлення та визначення Bacillus cereus

ДСТУ 8051:2015 Продукти харчові. Методи відбирання проб для мікробіологічних аналізів

ДСТУ 8446:2015 Продукти харчові. Методи визначення кількості мезофільних аеробних та факультативно анаеробних мікроорганізмів

ДСТУ 8447:2015 Продукти харчові. Метод визначення дріжджів і пліснявих грибів

ДСТУ 8655:2016 Буряк сушений. Технічні умови

ДСТУ 8828:2019 Пожежна безпека. Загальні положення

ДСТУ 9027:2020 Системи управління якістю. Настанови щодо вхідного контролю продукції

ДСТУ prEN 1672-1-2001 Обладнання для харчової промисловості. Вимоги щодо безпеки і гігієни. Основні положення. Частина 1. Вимоги щодо безпеки

ДСТУ EN 765:2005 (EN 765:1994, IDT) Мішки для транспортування продовольства. Мішки з поліолефінового тканого матеріалу, крім поліпропіленового

ДСТУ EN 767:2005 (EN 767:1994, IDT) Мішки для транспортування продовольства. Мішки з джуто-поліолефінового тканого матеріалу

ДСТУ EN 769:2005 (EN 769:1994, IDT) Мішки для транспортування продовольства. Мішки з бавовняно-поліолефінового тканого матеріалу

ДСТУ EN 1672-2:2018 Устаткування для харчової промисловості. Основні принципи. Частина 2. Гігієнічні вимоги

ДСТУ EN 12824:2004 Мікробіологія харчових продуктів і кормів для тварин.

Горизонтальний метод виявлення *Salmonella*

ДСТУ ISO 2447:2004 Фрукти, овочі та продукти перероблянння. Визначення вмісту олова

ДСТУ ISO 6561:2001 Фрукти, овочі та продукти перероблянння. Визначення вмісту кадмію. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 6633-2001 Фрукти, овочі та продукти перероблення. Визначання вмісту свинцю. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 6634:2004 Фрукти, овочі та продукти перероблянння. Визначення вмісту миш´яку спектрометричним методом із застосуванням діетилдутіокарбамату срібла

ДСТУ ISO 6635:2005 Фрукти, овочі та продукти перероблянння. Визначення вмісту нітритів та нітратів спектрометричним методом молекулярної абсорбції

ДСТУ ISO 6636-2:2004 Фрукти, овочі та продукти перероблянння. Визначення вмісту цинку. Частина 2. Спектрометричний метод атомної абсорбції

ДСТУ ISO 6636-3-2001 Продукти перероблення фруктів і овочів. Визначання вмісту цинку. Частина 3. Спектрометричний метод із застосуванням діапазону

ДСТУ ISO 6637-2001 Фрукти, овочі та продукти перероблення. Визначання вмісту ртуті. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 7952:2004 Фрукти, овочі та продукти перероблення. Визначання вмісту міді спектрометричним методом полуменевої атомної абсорбції

ДСТУ OIML R 87:2017 Кількість фасованого товару в упаковках

ДСТУ Б А.3.2-12:2009 Система стандартів безпеки праці. Системи вентиляційні. Загальні вимоги

ГОСТ 30178-96 Сырье и продукты пищевые. Атомно- абсорбционный метод определения токсичных элементов (Сировина і продукти харчові. Атомно-абсорбційний метод визначення токсичних елементів)

ГОСТ 30518-97 Продукты пищевые. Методы выявления и определения количества бактерий группы кишечных палочек (колиформных бактерий) (Продукти харчові. Методи виявлення та визначення кількості бактерій групи кишкових паличок (коліформи, бактерії))

ГН 6.6.1.1-130-2006 Допустимі рівні вмісту радіонуклідів ^{137}Cs та ^{90}Sr у продуктах харчування та питній воді. Державні гігієнічні нормативи

ДСанПіН 8.8.1.2.3.4-000-2001 Допустимі дози, концентрації, кількості та рівні вмісту пестицидів у сільськогосподарській сировині, харчових продуктах, повітрі робочої зони, атмосферному повітрі, воді водоймищ, ґрунті

ДСанПіН 2.2.4-171-10 Гігієнічні вимоги до води питної, призначені для споживання людиною

НПАОП 0.00-7.14-17 Вимоги безпеки та захисту здоров'я під час використання виробничого обладнання працівниками

НПАОП 0.00-7.17-18 Мінімальні вимоги безпеки і охорони здоров'я при використанні працівниками засобів індивідуального захисту на робочому місці

ДБН В.2.5-28:2018 Природне і штучне освітлення

ДБН В.2.5-67:2013 Опалення, вентиляція та кондиціонування

ДСН 3.3.6.037-99 Державні санітарні норми виробничого шуму, ультразвуку та інфразвуку

ДСН 3.3.6.039-99 Державні санітарні норми виробничої загальної та локальної вібрації

ДСН 3.3.6.042-99 Державні санітарні норми мікроклімату виробничих приміщень

МР 4.4.4-108-2004 Методичні рекомендації. Періодичність контролю продовольчої сировини та харчових продуктів за показниками безпеки

Постанова КМУ від 25.03.1999 №465 Правила охорони поверхневих вод від забруднення зворотними водами

Наказ МОЗ України № 52 від 14.01.2020 Про затвердження гігієнічних регламентів допустимого вмісту хімічних і біологічних речовин в атмосферному повітрі населених місць

Наказ МОЗ України № 145 від 17.03.2011 Про затвердження Державних санітарних норм та правил утримання територій населених місць

Наказ МОЗ України № 150 від 21.02.2013 Про внесення змін до наказу Міністерства охорони здоров'я України від 23 липня 2002 року № 280

Наказ МОЗ України № 280 від 23.07.2002 Щодо організації проведення обов'язкових профілактичних медичних оглядів працівників окремих професій, виробництв і організацій, діяльність яких пов'язана з обслуговуванням населення і може призвести до поширення інфекційних хвороб

Наказ МОЗ України №368 від 13.05.2013 Про затвердження Державних гігієнічних правил і норм «Регламент максимальних рівнів окремих забруднюючих речовин у харчових продуктах»

Наказ МОЗ України № 548 від 19.07. 2012 Про затвердження мікробіологічних критеріїв для встановлення показників безпечності харчових продуктів

3 ТЕРМІНИ ТА ВИЗНАЧЕННЯ ПОНЯТЬ

3.1 В цих технічних умовах використано термін

Буряк сушений – напівфабрикат, що виготовлений із буряка столового або буряка столового некондиційного у формі скибочок або порошку комбінованим способом сушки, що включає попередню обробку тепловим насосом та безпосередньо основну мікрохвильову вакуумну сушку.

4 ТЕХНІЧНІ ВИМОГИ

4.1 Буряк сушений повинен відповідати вимогам цих технічних умов і вироблятися відповідно до вимог технологічної інструкції з дотриманням санітарних правил і норм, затверджених на підприємстві в установленому порядку.

4.2 Класифікація буряка сушеного:

а) за способом одержання:

- комбінованим способом сушки з попередньою обробкою тепловим насосом;
- без попередньої обробки за допомогою мікрохвильової вакуумної сушки;

б) за фізичною формою:

- у вигляді скибочок;
- у вигляді порошку.

4.3 Буряк сушений залежно від масової частки вологи виробляють:

- скибочки, з масовою часткою вологи від 4,5 % до 5,5 %;
- порошок, з масовою часткою вологи від 4,5 % до 5,5 %.

4.4 Основні показники і характеристики

4.4.1 За органолептичними показниками буряк сушений повинен відповідати вимогам, наведеним в таблиці 1.

Таблиця 1 – Органолептичні показники буряку сушеного

Назва показника	Характеристика і норми	Метод контролювання
Зовнішній вигляд	Шматочки сушеного буряку у вигляді порошку або скибочок	ГОСТ 13340.1[1]
Форма та розміри:		
- скибочок	Нарізані рівномірно завтовшки не більше ніж 4 мм, завширшки та завдовжки не більше ніж 12 мм	ГОСТ 13340.1[1]
- порошку	Часточки порошку розміром менше ніж 0,5 мм за найбільшим виміром	ГОСТ 13340.1[1]
Консистенція	Скибочки еластичні. Порошок без грудочок, розсипчастий	ГОСТ 13340.1[1]
Смак та залах	Натуральні, приємні, властиві сушеному буряку. Заборонено сторонні присмак та запах	ГОСТ 13340.1[1]
Колір	Бордовий різних відтінків	ГОСТ 13340.1[1]
Примітка1. Залах, смак та колір сушеного буряку визначають у відновленому вигляді. **Примітка 2**. Дозволено наявність стружки розміром менше ніж 5 мм за найбільшим виміром у сушеному буряку скибочками не більше ніж 5%.		

4.4.2 За фізико - хімічними показниками буряк сушений повинен відповідати вимогам, наведеним у таблиці 2.

Таблиця 2 – Фізико - хімічні показники буряку сушеного

Назва показника	Норма для сушеного буряку		Метод контролювання
	скибочками	порошок	
Масова частка стружки з чорними плямами і з рештою шкірочки %, не більше ніж	3	-	ГОСТ 13340.1[1]
Масова частка стружки з білими прожилками, %, не більше ніж	5	-	ГОСТ 13340.1[1]
Тривалість розварювання під час зберігання не більше між 12 місяців від дати виготовлення, хв, не більше ніж	25		ГОСТ 13340.1[1]
Масова частка металевих домішок (розмір частинок мас бути не більше ніж 0,3 мм за найбільшим виміром) %, не більше ніж	$3x10^{-4}$		ГОСТ 13340.2 [2]
Масова частка мінеральних домішок, %, не більше ніж	0,01		ДСТУ 4913
Сторонні домішки	Заборонено		8.4
Домішки рослинного походження	Заборонено		ДСТУ 4912
Ураженість шкідниками хлібних запасів	Заборонено		ГОСТ 13340.2 [2]
Наявність сушеного буряку, що загниває та плісняви	Заборонено		ГОСТ 13340.2 [2]

4.4.3 За вмістом токсичних елементів і мікотоксинів буряк сушений повинен відповідати вимогам, наведеним в таблиці 3.

Таблиця 3 – Показники безпечності буряку сушеного

Назва показника	Одинця вимірювання	Допустимим рівень, не більше ніж	Метод контролювання
Токсичні елементи:			
свинець	мг/кг	0,50	ГОСТ 26932 [6], ГОСТ 30178, ДСТУ ISO 6633
кадмій	мг/кг	0,03	ГОСТ 26933[7], ГОСТ 30178, ДСТУ ISO 6561
миш'як	мг/кг	0,20	ГОСТ 26930 [4], ДСТУ ISO 6634
ртуть	мг/кг	0,02	ГОСТ 26927 [3], ДСТУ ISO 6637
мідь	мг/кг	5,00	ГОСТ 26931[5], ДСТУ ISO 7952

Кінець таблиці 3

цинк	мг/кг	10.00	ГОСТ 26934[8], ДСТУ ISO 6636-2, ДСТУ ISO 6636-3
олово (для сушеного буряку в металевій складаній тарі)	мг/кг	200,0	ГОСТ 26935[9] , ДСТУ ISO 2447
Нітрати	мг/кг	1400,0	ДСТУ 4948, ДСТУ ISO 6635
Радіонукліди:			
цезій-137	Бк/кг	240,0	ГН 6.6.1.1-130
стронцій-90	Бк/кг	80,0	

4.4.4 За показниками безпеки (мікробіологічні показники) буряк сушений повинен відповідати вимогам, зазначеним у наказі МОЗ від 19.07.2017 №548 та таблиці 4.

Таблиця 4 – Мікробіологічні показники буряка сушеного

Назва показника	Норма	Метод контролювання
Кількість мезофільних аеробних та факультативно-анаеробних мікроорганізмів, КУО в 1 г, не більше ніж	$5.0x10^5$	ДСТУ 8446
Бактерії групи кишкових паличок (коліформи) в 0,01 г	Заборонено	ГОСТ 30518
Патогенні мікроорганізми, зокрема роду *Salmonella*, в 25 г	Заборонено	ДСТУ EN 12824
Bacillus cereus, КУО в 1 г, не більше ніж	10^3	ДСТУ 8040

4.4.5 Вміст пестицидів у буряку сушеному не повинен перевищувати допустимих рівнів, наведених у Наказі МОЗ України від 13.05. 2013 № 368, ДСанПіН 8.8.1.2.3.4-000.

4.5 Вимоги до сировини та матеріалів

4.5.1 Для виробництва буряка сушеного використовують наступну сировину:

- буряк столовий свіжий - згідно з ДСТУ 7033.
- буряк столовий некондиційний - згідно з ДСТУ 7033.

Під час виробництва буряку сушеного застосовують сировину, в якій вміст токсичних елементів, мікотоксинів та пестицидів не перевищує допустимі рівні, встановлені згідно з Наказом МОЗ України від 19.07.2017 № 548, Наказом МОЗ України від 13.05. 2013 № 368 та ДСанПіН 8.8.1.2.3.4-000.

Заборонено використовувати модифіковану сировину, яка не дозволена для використовування центральним органом виконавчої влади у сфері охорони здоров'я.

Вміст радіонуклідів ^{137}Cs і ^{90}Sr у буряку столовому свіжому не повинен перевищувати встановлені допустимі рівні згідно з ГН 6.6.1.1-130.

За мікробіологічними показниками сировина не повинна перевищувати допустимі рівні, які встановлено згідно Наказу МОЗ України від 19.07.2017 № 548.

4.5.2 Обладнання та матеріали, що застосовуються при виробництві буряку сушеного, повинні відповідати чинним нормативним документам та бути дозволені для використання центральним органом виконавчої влади, що забезпечує формування державної політики у сфері охорони здоров'я для даних цілей.

4.5.3 Вхідний контроль сировини, матеріалів проводять у відповідності з ДСТУ 9027 та порядком, встановленим виробником.

4.5.4 Кожна партія сировини та матеріалів повинна супроводжуватись документом про якість встановленої форми та повинна бути дозволена для використання центральним органом виконавчої влади України у сфері охорони здоров'я.

4.6 Пакування

4.6.1 Буряк сушений випускають фасованим.

Буряк сушений порошок та буряк сушений скибочками фасують масою нетто від 1 кг 30 кг у:

- мішки паперові марки ПМ згідно з ДСТУ EN 769;
- мішки паперові марки НМ згідно з ДСТУ EN 767, з поліетиленовими мішками-укладками згідно з ДСТУ EN 765.

Мішки з буряком сушеним зашивають машинним способом нитками лляними, бавовняними, синтетичними згідно з діючими НД, які забезпечують міцність зшивання.

Мішки для фасування буряка сушеного дозволено використовувати тільки чисті, сухі, вони не повинні мати сторонніх запахів, не бути зараженими шкідниками.

4.6.2 Дозволено використання інших видів тари і пакування, як вітчизняного, так і імпортного виробництва, дозволених до використання центральним органом виконавчої влади у сфері охорони здоров'я для контакту з харчовими продуктами і, які забезпечують збереженість і якість продукції під час транспортування і зберігання.

4.6.3 Фасування буряка сушеного здійснюється за масою.

4.6.4 Значення допустимих мінусових відхилень маси буряка сушеного в пакувальній одиниці згідно з ДСТУ OIML R 87 та повинні відповідати вимогам, наведеним в таблиці 5.

Таблиця 5 – Допустимі мінусові відхилення маси буряка сушеного в пакувальній одиниці

Маса продукту фасованого, г	Допустиме від'ємне відхилення маси продукту в пакувальній одиниці	
	%	г
Понад 500 г до 1000 г включно	-	15
Понад 1000 г до 10000 г включно	1,5	-
Понад 10000 г до 15000 г включно	-	150,0
Більше 15000 г	1,0	-

4.6.5 Додаткові вимоги до пакування, що не суперечать законодавству України, можуть бути передбачені договором або контрактом.

4.7 Маркування

4.7.1 Маркування повинно відповідати вимогам Закону України від 06.12.2018 №2639-VIII та цих ТУ.

4.7.2 На кожну одиницю споживчої тари з фасованим буряком сушеним наносять маркування, яке повинно містити наступну інформацію:

- назву продукту (власну назву - за наявності);
- вид буряку сушеного (у вигляді порошку, у вигляді скибочок);
- назву виробника, його юридичну адресу та адресу потужності виробництва;
- торгівельну марку виробника (за наявності);
- масу нетто одиниці пакування, кг та допустиме мінусове відхилення;
- харчову (поживну) цінність та енергетичну цінність (калорійність) (у кДж і/або ккал) на 100 г продукту (Додаток А);
- кінцеву дату споживання «Вжити до» або дату виробництва (число, місяць, рік) та строк придатності;
- умови зберігання;
- номер партії;
- позначення цих ТУ;
- штриховий код EAN згідно з ДСТУ 3147.

5 ВИМОГИ БЕЗПЕКИ

5.1 Під час виготовлення буряку сушеного необхідно дотримуватись вимог щодо безпеки, що встановлені технологічною інструкцією, розробленою та затвердженою у встановленому порядку.

5.2 Виробничі приміщення повинні відповідати діючим санітарним нормам.

5.3 Технологічне обладнання повинно відповідати вимогам ДСТУ 3273, ДСТУ EN 1672-2, ДСТУ prEN 1672-1.

Технологічне обладнання та устаткування повинні очищуватись та дезінфікуватись за допомогою мийних та дезінфекційних засобів, дозволених для використання центральним органом виконавчої влади, що забезпечує формування державної політики у сфері охорони здоров'я, та за наявності свідоцтва про реєстрацію згідно з інструкцією з використання та графіком, розробленими і затвердженими у встановленому порядку.

Після проведеної дезінфекції проводиться промивка обладнання питною водою до відсутності залишків дезінфікуючого розчину. Проби для аналізів відбирають з останніх промивних вод.

5.4 При виявленні бактеріального забруднення, проводять позачергову дезінфекцію. Для дезінфекції слід використовувати тільки свіжовиготовлені розчини згідно з інструкцією з використання.

5.5 Робочі місця повинні бути забезпечені інструкціями з техніки безпеки.

5.6 Працівники повинні бути забезпечені спецодягом згідно чинного законодавства та ДСТУ 7239, НПАОП 0.00-7.14, НПАОП 0.00-7.17.

5.7 Персонал, що працює на виробництві буряка сухого, повинен проходити періодичні медичні огляди згідно з Наказом МОЗ України від 23.07.2002 № 280 та Наказом МОЗ України від 21.02.2013 № 150.

5.8 Виробничі приміщення повинні бути обладнані припливно-витяжною вентиляцією та опалюванням згідно з ДСТУ Б А.3.2-12, ДБН В.2.5-67.

5.9 Повітря робочої зони та мікроклімат виробничих приміщень повинні відповідати вимогам ДСН 3.3.6.042.

5.10 Штучне та природнє освітлення виробничих приміщень повинно відповідати вимогам ДБН В.2.5-28.

5.11 В процесі виробництва необхідно дотримуватись вимог електробезпеки згідно ДСТУ 7237.

5.12 Пожежна безпека на підприємстві повинна відповідати вимогам ДСТУ 8828.

5.13 Виробничі приміщення повинні бути забезпечені питною водою згідно з ДСанПіН 2.2.4-171.

5.14 Рівень шуму та вібрації у виробничому приміщенні під час роботи виробничого обладнання не повинен перевищувати рівні, встановлені ДСН 3.3.6.037, ДСН 3.3.6.039.

6 ВИМОГИ ОХОРОНИ ДОВКІЛЛЯ, УТИЛІЗАЦІЯ

6.1 Охорона атмосферного повітря від забруднення повинна здійснюватися відповідно до вимог Закону України № 2707-XII від 16.10.1992 р., Наказу МОЗ України № 52 від 14.01.2020 р.

6.2 Переробку, утилізацію, знищення неякісної продукції здійснюють згідно з вимогами, що встановлені Законом України № 1393-XIV від 14.01.2000, Закону України №187/98-ВР від 05.03.1998.

6.3 Охорона ґрунту від забруднення побутовими та промисловими відходами повинна здійснюватися згідно з вимогами Наказу МОЗ України від 17.03.2011 № 145.

6.4 Охорона поверхневих вод від забруднення повинна здійснюватися відповідно до вимог Постанови КМУ № 465 від 25.03.1999 р.

7 ПРАВИЛА ПРИЙМАННЯ

7.1 Буряк сушений приймають партіями.

Партія – будь-яка кількість буряка сушеного з однією назвою, виготовлена з однакової сировини на одному і тому ж обладнанні протягом одного технологічного циклу та оформлена одним документом про якість.

Правила приймання, визначання партії, об'єм вибірки та відбирання проб - згідно з ДСТУ 8655, ДСТУ 8051, ДСТУ 7963, ДСТУ 7670.

7.2 Для визначання відповідності якості буряка сушеного вимогам цих ТУ підприємство-виробник проводить приймальне і періодичне контролювання.

7.3 Приймальне контролювання кожної партії проводять за органолептичними, фізико-хімічними показниками, масою нетто пакувальної одиниці, якістю пакування і маркування.

7.4 Періодичність контролю за показниками безпеки – згідно МР 4.4.4-108.

7.5 У разі отримання незадовільних результатів контролювання хоча б за одним із показників (органолептичних, фізико-хімічних, мікробіологічних і безпечності) проводять повторне аналізування подвійної кількості вибірки буряка сухого від тієї самої партії.

7.6 Незадовільні результати після повторного контролювання поширюють на всю партію і партію бракують.

8 МЕТОДИ КОНТРОЛЮВАННЯ

8.1 Зовнішній вигляд, правильність пакування і маркування на відповідність вимогам цих ТУ контролюють візуально.

8.2 Органолептичні показники визначають згідно з ДСТУ 8655 та методами, наведеними в таблиці 1.

8.3 Масову частку вологи визначають згідно з ДСТУ 7804 .

8.4 Визначання сторонніх домішок.

Відібрану пробу розкладають тонким шаром на дошці та прискіпливо переглядають на наявність сторонніх домішок.

У разі наявності сторонніх домішок продукцію бракують.

8.5 Методи контролю фізико-хімічних показників наведені в таблиці 2.

8.6 Вміст токсичних елементів визначають згідно з ДСТУ ISO 6633, ДСТУ ISO 6636-3, ДСТУ ISO 6637, ДСТУ ISO 7952, ДСТУ ISO 2447, ДСТУ ISO 6561, ДСТУ ISO 6634, ДСТУ ISO 6635, ДСТУ ISO 6636-2.

8.7 Вміст радіонуклідів визначають згідно з ГН 6.6.1.1-130 та іншими методиками, затвердженими у встановленому порядку.

8.8 Контролювання вмісту пестицидів здійснюється згідно з ДСанПіН 8.8.1.2.3.4-000.

8.9 Мікробіологічні показники визначають методами, вказаними у таблиці 4

8.10 Масу буряка у споживчій упаковці контролюють за допомогою ваг для статичного зважування згідно чинних НД.

9 ТРАНСПОРТУВАННЯ ТА ЗБЕРІГАННЯ

9.1 Буряк сушений транспортують усіма видами транспорту згідно з правилами перевезення вантажу, чинними на відповідному виді транспорту. Транспортні засоби повинні бути криті, чисті, сухі, без стороннього запаху.

9.2 Буряк сушений пакований у мішки, дозволено транспортувати транспортними пакетами із застосуванням піддонів згідно з діючою НД, або універсальним металевим контейнером - згідно з діючою НД.

9.3 Зберігають буряк сушений порошок та скибочки у чистих сухих приміщеннях, не заражених шкідниками рослинних запасів, добре вентильованих або обладнаних припливно-витяжною вентиляцією, захищених від дії прямого сонячного світла та джерел тепла, за температури (20-30) °С та відносної вологості повітря не більше ніж 75 %.

9.4 Термін зберігання - не більше 2-х років.

Якщо термін зберігання буряка перевищує 1 рік, то перед використанням у харчовому виробництві необхідно перевірити його на відповідність органолептичним та мікробіологічним нормам.

10 ГАРАНТІЇ ВИРОБНИКА

10.1 Виробник гарантує відповідність безпечності та якості буряка сушеного вимогам цих технічних умов при дотриманні умов зберігання і транспортування.

10.2 Гарантійний термін зберігання продуктів встановлено в 9.4 цих ТУ.

ДОДАТОК А
(довідковий)
ПОЖИВНА (ХАРЧОВА) ТА ЕНЕРГЕТИЧНА ЦІННІСТЬ (КАЛОРІЙНІСТЬ) БУРЯКУ СУШЕНОГО

Таблиця А.1

Назва продукту	Білки, г	Вуглеводи, г	Енергетична цінність (калорійність)	
			ккал	кДж
Буряк сушений	13,5	59,6	292	1224

ДОДАТОК Б
(довідковий)
БІБЛІОГРАФІЯ

1 ГОСТ 13340.1-77 Овощи сушеные. Методы определения массы нетто, формы и размера частиц, крупности помола, дефектов по внешнему виду, соотношения компонентов, органолептических показателей и развариваемости (Овочі сушені. Методи визначення маси нето, форми та розміру часток, крупності помелу, дефектів по зовнішньому вигляду, співвідношення компонентів, органолептичних показників та розварюваності)

2 ГОСТ 13340.2-77 Овощи сушеные. Методы определения металлических примесей и зараженности вредителями хлебных запасов (Овочі сушені. Методи визначення металевих домішок та ураженості шкідниками хлібних запасів)

3 ГОСТ 26927–86 Сырье и продукты пищевые. Метод определения ртути (Сировина і продукти харчові. Метод визначання ртуті)

4 ГОСТ 26930-86 Сырье и продукты пищевые. Метод определения мышьяка (Сировина і продукти харчові. Метод визначення миш'яку)

5 ГОСТ 26931-86 Сырье и продукты пищевые. Метод определения меди (Сировина і продукти харчові. Метод визначення міді)

6 ГОСТ 26932–86 Сырье и продукты пищевые. Методы определения свинца (Сировина і продукти харчові. Методи визначання свинцю)

7 ГОСТ 26933-86 Сырье и продукты пищевые. Метод определения кадмия (Сировина і продукти харчові. Метод визначення кадмію)

8 ГОСТ 26934-86 Сырье и продукты пищевые. Метод определения цинка (Сировина і продукти харчові. Метод визначення цинку)

9 ГОСТ 26935-86 Продукты пищевые консервированные. Метод определения олова (Продукти харчові консервовані. Метод визначення олова)

АРКУШ ОБЛІКУ ЗМІН ТЕХНІЧНИХ УМОВ

№ Зм.	Номера листів				Номер документа	Підпис	Дата	Термін введення змін
	Змінених	Нових	Скасованих	Замінених				

Addition D

TS 10.3-04718013-008:2022 "Concentrated and dried taro products"

ДКПП 10.3 УКНД 67.080.20

ПОГОДЖУЮ
Директор
ФОП «Філон А.М.»
_________А.М. Філон
«_____»___________2023 р.

ЗАТВЕРДЖУЮ
Ректор Сумського національного
аграрного університету,
академік НААН України
_________ В.І. Ладика
«_____»_________2023 р.

ЗМІНА №1

до **ТУ У 10.3-04718013-008:2022**

ПРОДУКТИ ІЗ ТАРО КОНЦЕНТРОВАНІ ТА СУШЕНІ

Технічні умови

Дата надання чинності 11.08.2023

Чинні до 11.08.2028

РОЗРОБЛЕНО
К.т.н, доцент кафедри технологій та
безпечності харчових продуктів СНАУ
_________А.О. Геліх
«19»__07__2023 р.

Ст. викладач факультету харчових та
біотехнологій університету Хечжоу,
Китай
Liu Yan Лю Янь
«20»__07__2023 р.

Ст. викладач факультету харчових та
біотехнологій університету Хечжоу,
Китай
Gao Dan Гао Дан
«21»__07__2023 р.

МІНІСТЕРСТВО РОЗВИТКУ ЕКОНОМІКИ, ТОРГІВЛІ ТА СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ
ДЕРЖАВНЕ ПІДПРИЄМСТВО
"СУМСЬКИЙ РЕГІОНАЛЬНИЙ НАУКОВО-ВИРОБНИЧИЙ ЦЕНТР СТАНДАРТИЗАЦІЇ, МЕТРОЛОГІЇ ТА СЕРТИФІКАЦІЇ"
ДП "СУМИСТАНДАРТМЕТРОЛОГІЯ"
Ідентифікаційний код 02568064
ПЕРЕВІРЕНО
на відповідність законодавству України
«11» серпня 2023 р.
Внесено до книги обліку за № 02568064/002522/01

ЗМІСТ

1 СФЕРА ЗАСТОСУВАННЯ

Ці технічні умови (ТУ) поширюються на концентровані та сушені продукти із таро (пюре, пасту, порошок), названі далі за текстом – продукти.

Продукти із таро концентровані (пюре, пасту) виготовляють з цілих або подрібнених, грубопротертих чи протертих коренеплодів таро або відновленням порошку таро; порошок - з попередньо підготовлених, висушених та подрібнених до заданого розміру частинок коренеплодів таро.

Продукти із таро концентровані та сушені використовують у харчовій промисловості, м'ясопереробній, хлібопекарській, кондитерській галузях, ресторанному господарстві тощо.

Обов'язкові вимоги до концентрованих та сушених продуктів із таро, що забезпечують їх безпеку для життя і здоров'я споживачів та охорони навколишнього природного середовища викладені в розділах (4 - 6) цих технічних умов.

Приклад позначення концентровані та сушені продукти із таро при замовленні та в іншій документації:

Пюре таро ТУ У10.8-04718013-007:2022.

Паста таро ТУ У 10.8-04718013-007:2022.

Порошок таро ТУ У 10.8-04718013-007:2022.

Ці ТУ придатні для цілей сертифікації.

Право власності на ТУ належить Сумському національному аграрному університету та кафедрі харчування та біоінженерії Університету Хечжоу, Китай (Food and Bioengineering department of Hezhou University, China).

Перевірка технічних умов здійснюється не рідше одного разу на п'ять років, після надання їм чинності чи останнього перевіряння, якщо не виникає потреби перевіряти їх раніше у разі прийняття нормативно-правових актів, відповідних національних (міждержавних) стандартів та інших нормативних документів, якими регламентовано інші вимоги ніж ті, що встановлені у цих ТУ.

2 НОРМАТИВНІ ПОСИЛАННЯ

В цих ТУ є посилання на наступні нормативні документи:

Закон України від 05.03.1998 р. № 187/98-ВР «Про відходи»

Закон України від 16.10.1992 р. №2707-XII «Про охорону атмосферного повітря»

Закон України від 14.01.2001р. №1393-XIV «Про вилучення з обігу, переробку, утилізацію, знищення або подальше використання неякісної та небезпечної продукції»

Закон України від 06.12.2018 р. № 2639-VIII «Про інформацію для споживачів щодо харчових продуктів»

ДСТУ ISO 6561:2004 Фрукти, овочі та продукти перероблення. Визначання вмісту кадмію. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 6633-2001 Фрукти, овочі та продукти перероблення. Визначання вмісту свинцю. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 6634:2004 Фрукти, овочі та продукти їх перероблення. Визначання вмісту миш'яку спектрометричним методом із застосуванням діетилдитіокарбомату

ДСТУ ISO 6637-2001 Фрукти, овочі та продукти перероблення. Визначання вмісту ртуті. Спектрометричний метод безполуменевої атомної абсорбції

ДСТУ ISO 7952:2004 Фрукти, овочі та продукти перероблення. Визначення вмісту міді спектрометричним методом атомної абсорбції

ДСТУ 3147-95 Коди та кодування інформації. Штрихове кодування. Маркування об'єктів ідентифікації. Формат та розташування штрихкодових позначок EAN на тарі та пакуванні товарної продукції. Загальні вимоги

ДСТУ 3273-95 Безпечність промислових підприємств. Загальні положення та вимоги

ДСТУ 4912:2008 Фрукти, овочі та продукти перероблення. Методи визначання домішок рослинного походження

ДСТУ 4913:2008 Фрукти, овочі та продукти перероблення. Методи визначання мінеральних домішок

ДСТУ 4947:2008 Фрукти, овочі та продукти перероблення. Метод визначення вмісту мікотоксину патуліну

ДСТУ 5093:2008 Консерви. Готування розчинів реактивів, фарб, індикаторів і поживних середовищ, які застосовують у мікробіологічному аналізі

ДСТУ 8449:2015 Продукти харчові консервовані. Методи визначення органолептичних показників, маси нетто або обсягу та масової частки складових частин

ДСТУ 7237:2011 Система стандартів безпеки праці. Електробезпека. Загальні вимоги та номенклатура видів захисту

ДСТУ 7239:2011 ССБП. Засоби індивідуального захисту. Загальні вимоги та класифікація

ДСТУ 7804:2015 Продукти переробляння фруктів та овочів. Метод визначення сухих речовин та вологи

ДСТУ 8004:2015 Концентрати харчові. Методи визначення вологи

МІНІСТЕРСТВО РОЗВИТКУ ЕКОНОМІКИ, ТОРГІВЛІ ТА СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ
ДП "СУМИСТАНДАРТМЕТРОЛОГІЯ"
ПЕРЕВІРЕНО

ДСТУ 7670:2014 Сировина і продукти харчові. Готування проб. Мінералізація для визначення вмісту токсичних елементів

ДСТУ ISO 1871:2003 Продукти харчові сільськогосподарські. Загальні настанови щодо визначення вмісту азоту методом К'єльдаля (ISO 1871:1975, IDT)

ДСТУ ISO 5498:2004 Продукти харчові сільськогосподарські. Загальний метод визначення вмісту сирої клітковини (ISO 5498:1981, IDT)

ДСТУ 4957:2008 Продукти перероблення фруктів та овочів. Методи визначення титрованої кислотності

ДСТУ 7963:2015 Продукти харчові. Готування проб для мікробіологічних аналізів

ДСТУ 8051:2015 Продукти харчові. Методи відбирання проб для мікробіологічних аналізів

ДСТУ 3583:2015 Сіль кухонна. Загальні технічні умови. З поправкою

ДСТУ 8446:2015 Продукти харчові. Методи визначення кількості мезофільних аеробних та факультативно анаеробних мікроорганізмів

ДСТУ 8447:2015 Продукти харчові. Метод визначення дріжджів і пліснявих грибів

ДСТУ 8828:2019 Пожежна безпека. Загальні положення

ДСТУ 9027:2020 Системи управління якістю. Настанови щодо вхідного контролю продукції

ДСТУ prEN 1672-1-2001 Обладнання для харчової промисловості. Вимоги щодо безпеки і гігієни. Основні положення. Частина 1. Вимоги щодо безпеки

ДСТУ EN 1672-2:2018 Устаткування для харчової промисловості. Основні принципи. Частина 2. Гігієнічні вимоги

ДСТУ EN 765:2005 (EN 765:1994, IDT) Мішки для транспортування продовольства. Мішки з поліолефінового тканого матеріалу, крім поліпропіленового

ДСТУ EN 767:2005 (EN 767:1994, IDT) Мішки для транспортування продовольства. Мішки з джуто-поліолефінового тканого матеріалу

ДСТУ EN 769:2005 (EN 769:1994, IDT) Мішки для транспортування продовольства. Мішки з бавовняно-поліолефінового тканого матеріалу

ДСТУ EN 12824:2004 Мікробіологія харчових продуктів і кормів тварин. Горизонтальний метод виявлення *Salmonella*

ДСТУ EN 12955-2001 Продукти харчові. Визначення афлатоксинів B1, B2,G1, G2 у зернових культурах, фруктах з твердою шкірою та похідних від них продуктах. Метод високоефективної рідинної хроматографії за допомогою постколонкової дериватизації

ДСТУ OIML R 87:2017 Кількість фасованого товару в упаковках

ДСТУ Б А.3.2-12:2009 Система стандартів безпеки праці. Системи вентиляційні. Загальні вимоги

ГОСТ 30178-96 Сырье и продукты пищевые. Атомно- абсорбционный метод определения токсичных элементов (Сировина і продукти харчові. Атомноабсобційний метод визначення токсичних елементів)

ГОСТ 30518-97 Продукты пищевые. Методы выявления и определения количества бактерий группы кишечных палочек (колиформы бактерий) (Ппродукти харчові. Методи виявлення і визначення кількості бактерій групи кишкових паличок (коліформи бактерій)

ГН 6.6.1.1-130-2006 Допустимі рівні вмісту радіонуклідів ^{137}Cs та ^{90}Sr у продуктах харчування та питній воді. Державні гігієнічні нормативи

ДСанПіН 8.8.1.2.3.4-000-2001 Допустимі дози, концентрації, кількості та рівні вмісту пестицидів у сільськогосподарській сировині, харчових продуктах, повітрі робочої зони, атмосферному повітрі, воді водоймищ, ґрунті

ДСанПіН 2.2.4-171-10 Гігієнічні вимоги до води питної, призначені для споживання людиною

НПАОП 0.00-7.14-17 Вимоги безпеки та захисту здоров'я під час використання виробничого обладнання працівниками

НПАОП 0.00-7.17-18 Мінімальні вимоги безпеки і охорони здоров'я при використанні працівниками засобів індивідуального захисту на робочому місці

ДБН В.2.5-28:2018 Природне і штучне освітлення

ДБН В.2.5-67:2013 Опалення, вентиляція та кондиціонування

ДСН 3.3.6.037-99 Державні санітарні норми виробничого шуму, ультразвуку та інфразвуку

ДСН 3.3.6.039-99 Державні санітарні норми виробничої загальної та локальної вібрації

ДСН 3.3.6.042-99 Державні санітарні норми мікроклімату виробничих приміщень

МР 4.4.4-108-2004 Методичні рекомендації. Періодичність контролю продовольчої сировини та харчових продуктів за показниками безпеки

Постанова КМУ від 25.03.1999 №465 Правила охорони поверхневих вод від забруднення зворотними водами

Наказ МОЗ України № 52 від 14.01.2020 Про затвердження гігієнічних регламентів допустимого вмісту хімічних і біологічних речовин в атмосферному повітрі населених місць

Наказ МОЗ України № 145 від 17.03.2011 Про затвердження Державних санітарних норм та правил утримання територій населених місць

Наказ МОЗ України № 150 від 21.02.2013 Про внесення змін до наказу Міністерства охорони здоров'я України від 23 липня 2002 року № 280

Наказ МОЗ України № 280 від 23.07.2002 Щодо організації проведення обов'язкових профілактичних медичних оглядів працівників окремих професій, виробництв і організацій, діяльність яких пов'язана з обслуговуванням населення і може призвести до поширення інфекційних хвороб

Наказ МОЗ України №368 від 13.05.2013 Про затвердження Державних гігієнічних правил і норм «Регламент максимальних рівнів окремих забруднюючих речовин у харчових продуктах»

Наказ МОЗ України № 548 від 19.07. 2012 Про затвердження мікробіологічних критеріїв для встановлення показників безпечності харчових продуктів

3 ТЕРМІНИ ТА ВИЗНАЧЕННЯ ПОНЯТЬ

3.1 В цих технічних умовах використано терміни:

3.1.1 Продукти із таро концентровані (пюре, паста) - це продукти, які виготовляють з цілих або подрібнених, грубопротертих чи протертих коренеплодів таро або відновленням порошку таро.

3.1.2. Продукти із таро сушені (порошок) - це продукт, який виготовляють з попередньо підготовлених, висушених та подрібнених до заданого розміру частинок коренеплодів таро.

4 ТЕХНІЧНІ ВИМОГИ

4.1 Продукти із таро концентровані та сушені повинні відповідати вимогам цих технічних умов і вироблятися відповідно до вимог технологічної інструкції з дотриманням санітарних правил і норм, затверджених на підприємстві в установленому порядку.

4.2 Класифікація концентрованих та сушених продуктів із таро:

- концентроване пюре таро;
- концентрована паста таро;
- порошок таро.

4.4 Основні показники і характеристики

4.4.1 За органолептичними показниками продукти із таро концентровані та сушені повинні відповідати вимогам, наведеним в таблиці 1.

Таблиця 1

Найменування показників	Характеристика	
	концентроване пюре, концентрована паста	порошок
1 Смак і запах	Чистий без сторонніх присмаків і запахів	
2 Колір	Від прозорого до світло-кремового кольору та від рожевого до світло червоного, у залежності від сорту допускається жовтий та помаранчевий відтінок	Від білого до світло-кремового та від рожевого до світло червоного, у залежності від сорту допускається жовтий та помаранчевий відтінок
3 Консистенція	Однорідний гель без осаду	Порошок без сторонніх домішок

4.4.2 За фізико - хімічними показниками продукти із таро концентровані та сушені повинні відповідати вимогам, наведеним у таблиці 2.

Таблиця 2 – Фізико - хімічні показники продуктів із таро концентрованих та сушених

Найменування показників	Нормовані значення		Методи контролювання
	порошок	пюре, паста	
Масова частка вологи, %, не більше ніж	15,0	65,0	ДСТУ 8004
Масова частка протеїну, %, не менше ніж	10,0	5,0	ДСТУ ISO 1871
Масова частка харчових волокон (клітковини), %, не менше ніж	40,0	15,0	ДСТУ ISO 5498
pH 10 % водної суспензії	10-11		ДСТУ 4957

4.4.3 За вмістом токсичних елементів і мікотоксинів продукти із таро концентровані та сушені повинні відповідати вимогам, наведеним у Наказі МОЗ України №368 від 13.05.2013 і зазначеним в таблиці 3.

Таблиця 3

Назва токсичних елементів	Допустимі рівні	Методи випробовування
Токсичні елементи, мг/кг, не більше ніж:		
ртуть	0,02	Згідно з ГОСТ 26927 [1], ДСТУ ISO 6637
миш’як	1,0	Згідно з ГОСТ 26930[2], ДСТУ ISO 6634
мідь	5,0	Згідно з ГОСТ 26931[3], ДСТУ ISO7952,ГОСТ 30178
свинець	0,5	Згідно з ГОСТ 26932[4], ДСТУ ISO 6633, ГОСТ 30178
кадмій	0,03	Згідно з ГОСТ 26933[5], ДСТУ ISO 6561, ГОСТ 30178
Мікотоксини, мг/кг, не більше ніж:		
афлатоксин В1	0,005	Згідно з МУ 4082 [8], МР 2273 [6], ДСТУ EN 12955
мікотоксин патулін	0,05	ДСТУ 4947
зеараленон	1,0	Згідно з МР 2964 [7]

4.4.4 За показниками безпеки (мікробіологічні показники) продукти із таро концентровані та сушені повинні відповідати вимогам, наведеним у Наказі МОЗ України № 548 від 19.07.2012 і зазначеним у таблиці 4.

Таблиця 4

Назва показників	Допустимі рівні	Методи випробовування
Кількість мезофільних аеробних і факультативно-анаеробних мікроорганізмів, КУО в 1 г, не більше ніж	$5\text{-}10^4$	Згідно з ДСТУ 8446
Бактерії групи кишкових паличок (коліформи) в 0,1 г	Не дозволено	Згідно з ГОСТ 30518
Патогенні мікроорганізми, зокрема бактерії роду Salmonella, в 25 г	Не дозволено	Згідно з ДСТУ EN 12824
Плісняві гриби, КУО в 1 г, не більше ніж	1-102	Згідно з ДСТУ 8447
Дріжджі, КУО в 1 г, не більше ніж	1-102	Згідно з ДСТУ 8447

4.5 Вимоги до сировини та матеріалів

Для виробництва продуктів із таро концентрованих та сушених використовують наступну сировину:

- коренеплоди таро (Colocásia esculénta) — багаторічна рослина, вид роду колоказія (Colocasia) родини кліщинцеві (Araceae) згідно з чинною НД;

- масу таро подрібнену або грубопротерту або протерту, прогріту та охолоджену, яку застосовують для виробництва пюре та пасти із таро, згідно з чинним нормативним документом;

- сіль кухонну харчову згідно з ДСТУ 3583 виварену, запаковану, не нижче вищого ґатунку, без добавок;

- воду питну згідно з ДСанПіН 2.2.4-171, яка не містить спор мезофільних облігатних анаеробних мікроорганізмів у 100 $см^3$.

Під час виробництва продуктів із таро концентрованих та сушених застосовують сировину, в якій вміст токсичних елементів, мікотоксинів та пестицидів не перевищує допустимі рівні, встановлені згідно з Наказом МОЗ України від 19.07.2017 № 548, Наказом МОЗ України від 13.05. 2013 № 368 та ДСанПіН 8.8.1.2.3.4-000.

Заборонено використовувати модифіковану сировину, яка не дозволена для використовування центральним органом виконавчої влади у сфері охорони здоров'я.

Вміст радіонуклідів ^{137}Cs і ^{90}Sr у сировині не повинен перевищувати встановлені допустимі рівні згідно з ГН 6.6.1.1-130.

За мікробіологічними показниками сировина не повинна перевищувати допустимі рівні, які встановлено згідно Наказу МОЗ України від 19.07.2017 № 548.

4.5.2 Обладнання та матеріали, що застосовуються при виробництві продуктів, повинні відповідати чинним нормативним документам та бути дозволені для використання центральним органом виконавчої влади, що забезпечує формування державної політики у сфері охорони здоров'я для даних цілей.

4.5.3 Вхідний контроль сировини, матеріалів проводять у відповідності з ДСТУ 9027 та порядком, встановленим виробником.

4.5.4 Кожна партія сировини та матеріалів, що надходять на підприємство, повинна супроводжуватись документом про якість встановленої форми та повинна бути дозволена для використання центральним органом виконавчої влади України у сфері охорони здоров'я.

4.6 Пакування

4.6.1 Продукти із таро концентровані та сушені випускають фасованим.

4.6.1.1 Продукти сушені (порошок) фасують масою нетто від 1 кг 30 кг у:

- мішки паперові марки ПМ згідно з ДСТУ EN 769;

- мішки паперові марки НМ згідно з ДСТУ EN 767, з поліетиленовими мішками-укладками згідно з ДСТУ EN 765.

Мішки з порошком таро зашивають машинним способом нитками лляними, бавовняними, синтетичними згідно з діючими НД, які забезпечують міцність зшивання.

Мішки для фасування порошку таро дозволено використовувати тільки чисті, сухі, вони не повинні мати сторонніх запахів, не бути зараженими шкідниками хлібних запасів.

4.6.1.2 Продукти із таро концентровані (пасти та пюре) фасують масою нетто від 5 кг до 200 кг в:

- паперові пакети з комбінованого матеріалу типу «Pure-Pak» згідно діючої НД;

- пакети з поліетиленової плівки з внутрішнім чорним покриттям згідно діючої НД;

- бочки харчові пластикові «Euro Plast» згідно діючої НД.

4.6.2 Дозволено використання інших видів тари і пакування, як вітчизняного, так і імпортного виробництва, дозволених до використання центральним органом виконавчої влади у сфері охорони здоров'я для контакту з харчовими продуктами і, які забезпечують збереженість і якість продукції під час транспортування і зберігання.

4.6.3 Фасування продуктів із таро концентрованих та сушених здійснюється за масою.

4.6.4 Значення допустимих мінусових відхилень маси продуктів із таро концентрованих та сушених в пакувальній одиниці згідно з ДСТУ OIML R 87 та повинні відповідати вимогам, наведеним в таблиці 5.

Таблиця 5

Маса продукту фасованого, г, см^3	Допустиме від'ємне відхилення маси продукту в пакувальній одиниці	
	%	г
Понад 500 г до 1000 г включно	-	15
Понад 1000 г до 10000 г включно	1,5	-
Понад 10000 г до 15000 г включно	-	150,0
Більше 15000 г	1,0	-

4.6.5 Додаткові вимоги до пакування, що не суперечать законодавству України, можуть бути передбачені договором або контрактом.

4.7 Маркування

4.7.1 Маркування повинно відповідати вимогам Закону України від 06.12.2018 №2639-VIII та цих ТУ.

4.7.2 На кожну одиницю споживчої таро з фасованими продуктами із таро концентрованими та сушеними наносять маркування, яке повинно містити наступну інформацію:

- назву продукту (власну назву - за наявності);
- вид продукту (пюре, паста, порошок).
- назву виробника, його юридичну адресу та адресу потужності виробництва;
- торгівельну марку виробника (за наявності);
- масу нетто одиниці пакування, кг або об'єм, дм^3 та допустиме мінусове відхилення;
- харчову (поживну) цінність та енергетичну цінність (калорійність) (у кДж і/або ккал) на 100 г продукту (розраховує виробник відповідно до рецептури за формулою, наведеною в додатку А);
- кінцеву дату споживання «Вжити до» або дату виробництва (число, місяць, рік) та строк придатності;
- умови зберігання;
- номер партії;
- позначення цих ТУ;
- штриховий код EAN згідно з ДСТУ 3147.

5 ВИМОГИ БЕЗПЕКИ

5.1 Під час виготовлення продуктів із таро концентрованих та сушених необхідно дотримуватись вимог щодо безпеки, що встановлені технологічною інструкцією, розробленою та затвердженою у встановленому порядку.

5.2 Виробничі приміщення повинні відповідати діючим санітарним нормам.

5.3 Технологічне обладнання повинно відповідати вимогам ДСТУ 3273, ДСТУ EN 1672-2, ДСТУ prEN 1672-1.

Технологічне обладнання та устаткування повинні очищуватись та дезінфікуватись за допомогою мийних та дезінфекційних засобів, дозволених для використання центральним органом виконавчої влади, що забезпечує формування державної політики у сфері охорони здоров'я, та за наявності свідоцтва про реєстрацію згідно з інструкцією з використання та графіком, розробленими і затвердженими у встановленому порядку.

Після проведеної дезінфекції проводиться промивка обладнання питною водою до відсутності залишків дезінфікуючого розчину. Проби для аналізів відбирають з останніх промивних вод.

5.4 При виявленні бактеріального забруднення, проводять позачергову дезінфекцію. Для дезінфекції слід використовувати тільки свіжовиготовлені розчини згідно з інструкцією з використання.

5.5 Робочі місця повинні бути забезпечені інструкціями з техніки безпеки.

5.6 Працівники повинні бути забезпечені спецодягом згідно чинного законодавства та ДСТУ 7239, НПАОП 0.00-7.14, НПАОП 0.00-7.17.

5.7 Персонал, що працює на виробництві продуктів із таро концентрованих та сушених, повинен проходити періодичні медичні огляди згідно з Наказом МОЗ України від 23.07.2002 № 280 та Наказом МОЗ України від 21.02.2013 № 150.

5.8 Виробничі приміщення повинні бути обладнані припливно-витяжною вентиляцією та опалюванням згідно з ДСТУ Б А.3.2-12, ДБН В.2.5-67.

5.9 Повітря робочої зони та мікроклімат виробничих приміщень повинні відповідати вимогам ДСН 3.3.6.042.

5.10 Штучне та природнє освітлення виробничих приміщень повинно відповідати вимогам ДБН В.2.5-28.

5.11 В процесі виробництва необхідно дотримуватись вимог електробезпеки згідно ДСТУ 7237.

5.12 Пожежна безпека на підприємстві повинна відповідати вимогам ДСТУ 8828.

5.13 Виробничі приміщення повинні бути забезпечені питною водою згідно з ДСанПіН 2.2.4-171.

5.14 Рівень шуму та вібрації у виробничому приміщенні під час роботи виробничого обладнання не повинен перевищувати рівні, встановлені ДСН 3.3.6.037, ДСН 3.3.6.039.

6 ВИМОГИ ОХОРОНИ ДОВКІЛЛЯ, УТИЛІЗАЦІЯ

6.1 Охорона атмосферного повітря від забруднення повинна здійснюватися відповідно до вимог Закону України № 2707-XII від 16.10.1992 р., Наказу МОЗ України № 52 від 14.01.2020 р.

6.2 Переробку, утилізацію, знищення неякісної продукції здійснюють згідно з вимогами, що встановлені Законом України № 1393-XIV від 14.01.2000, Закону

України №187/98-ВР від 05.03.1998.

6.3 Охорона ґрунту від забруднення побутовими та промисловими відходами повинна здійснюватися згідно з вимогами Наказу МОЗ України від 17.03.2011 № 145.

6.4 Охорона поверхневих вод від забруднення повинна здійснюватися відповідно до вимог Постанови КМУ № 465 від 25.03.1999 р.

7 ПРАВИЛА ПРИЙМАННЯ

7.1 Продукти із таро концентровані та сушені приймають партіями.

Партія – будь-яка кількість продуктів із таро концентрованих та сушених (пюре, паста, порошок) з однією назвою, виготовлена з однакової сировини на одному і тому ж обладнанні протягом одного технологічного циклу та оформлена одним документом про якість.

Правила приймання, визначання партії, об'єм вибірки та відбирання проб - згідно з ДСТУ 8051, ДСТУ 7963, ДСТУ 4595, ДСТУ 7670, ДСТУ 5093.

7.2 Для визначання відповідності якості продуктів вимогам цих ТУ підприємство-виробник проводить приймальне і періодичне контролювання.

7.3 Приймальне контролювання кожної партії проводять за органолептичними, фізико-хімічними показниками, масою нетто або об'ємом пакувальної одиниці, якістю пакування і маркування.

7.4 Періодичність контролю за показниками безпеки – згідно МР 4.4.4-108.

7.5 У разі отримання незадовільних результатів контролювання хоча б за одним із показників (органолептичних, фізико-хімічних, мікробіологічних і безпечності) проводять повторне аналізування подвійної кількості вибірки продуктів концентрованих та сушених із таро (пюре, паста, порошок) від тієї самої партії.

7.6 Незадовільні результати після повторного контролювання поширюють на всю партію і партію бракують.

8 МЕТОДИ КОНТРОЛЮВАННЯ

8.1 Зовнішній вигляд, правильність пакування і маркування на відповідність вимогам цих ТУ контролюють візуально.

8.2 Визначають органолептичні показники (запах, колір) згідно з ДСТУ 8449.

8.2.1 Визначання смаку

8.2.1.1 Засоби вимірювання, матеріали

Ваги лабораторні - згідно з діючою НД, 3-го класу точності з найбільшою межею зважування до 1 кг.

Вода дистильована - згідно з діючою НД.

8.2.1.2 Правила проведення випробовування

Наважку продуктів із таро концентрованих та сушених (пюре, паста, порошок) (10 ± 1) г, злегка зволожують дистильованою водою. Смак визначають шляхом органолептичного оцінювання.

8.3 Визначають масову частку вологи згідно з ДСТУ 8004.

8.4 Визначають масову частку протеїну згідно з ДСТУ ISO 1871.

8.5 Визначають рН 10 % водної суспензії згідно з ДСТУ 4957.

8.6 Визначання сторонніх домішок (для порошку)

Визначення домішок – згідно ДСТУ 4912, ДСТУ 4913.

Відібрану пробу розкладають тонким шаром на дошці та прискіпливо переглядають на наявність сторонніх домішок.

У разі наявності сторонніх домішок продукцію бракують.

8.7 Визначають вміст токсичних елементів згідно з ДСТУ ISO 6637, ДСТУ ISO 6634, ДСТУ ISO 6633, ДСТУ ISO 6561, ДСТУ ISO 7952, ГОСТ 26927 [1], ГОСТ 26930[2] , ГОСТ 26931[3], ГОСТ 26932[4], ГОСТ 26933[5], ГОСТ 30178.

8.8 Вміст мікотоксинів визначають згідно з МУ 4082 [6], МР 2273 [6], ДСТУ EN 12955, МР 2964 [7], ДСТУ 4947.

8.9 Вміст радіонуклідів визначають згідно з ГН 6.6.1.1-130 МУ 5778 [9] та МУ 5779 [10] та іншими методиками, затвердженими у встановленому порядку.

8.10 Контролювання вмісту пестицидів здійснюється згідно з ДСанПіН 8.8.1.2.3.4-000.

8.11 Визначають плісняві гриби та дріжджі згідно з ДСТУ 8447.

8.12 Масу продуктів концентрованих та сушених із таро (пюре, паста, порошок) у споживчій упаковці контролюють за допомогою ваг для статичного зважування згідно чинних НД.

9 ТРАНСПОРТУВАННЯ ТА ЗБЕРІГАННЯ

9.1 Продукти концентровані та сушені із таро (пюре, паста, порошок) транспортують усіма видами транспорту згідно з правилами перевезення вантажу, чинними на відповідному виді транспорту. Транспортні засоби повинні бути криті, чисті, сухі, без стороннього запаху.

9.2 Продукти сушені із таро (порошок), пакований у мішки, дозволено транспортувати транспортними пакетами із застосуванням піддонів згідно з діючою НД, або універсальним металевим контейнером - згідно з діючою НД.

9.3 Продукти концентровані із таро (пюре, паста), пакований у паперові пакети з комбінованого матеріалу типу «Pure-Pak», пакети з поліетиленової плівки з внутрішнім чорним покриттям дозволено транспортувати транспортними пакетами із застосуванням піддонів згідно діючої НД, або універсальним металевим контейнером згідно з діючою НД.

9.4 Зберігають продукти сушені із таро (порошок) у чистих сухих приміщеннях, не заражених шкідниками хлібних запасів, добре вентильованих або обладнаних припливно-витяжною вентиляцією, захищених від дії прямого сонячного світла та джерел тепла, за температури (20-30) °С та відносної вологості повітря не більше ніж 75 %. Термін зберігання - не більше 3 роки. Якщо термін зберігання порошку перевищує 1 рік, то перед використанням у харчовому виробництві необхідно перевірити його на відповідність органолептичним та мікробіологічним нормам.

9.5 Продукти концентровані (пюре, паста) зберігають у чистих сухих приміщеннях, добре вентильованих або обладнаних припливно-витяжною вентиляцією, захищених від дії прямого сонячного світла та джерел тепла за температури (0-8) °С та відносній вологості повітря не більше 80 %. Термін зберігання не більше 1 року. Якщо термін зберігання перевищує 180 діб, то перед використанням у харчовому виробництві необхідно перевірити його на відповідність органолептичним та мікробіологічним нормам.

9.6 Строки придатності продуктів концентрованих та сушених із таро (пюре, паста, порошок) може встановлювати виробник (залежно від якості сировини, рівня технології виробництва, характеристик обладнання, умов фасування та властивостей пакувальних матеріалів) за умов відповідності продуктів вимогам цих ТУ та погодження цих строків з центральним органом виконавчої влади з питань охорони здоров'я.

10 ГАРАНТІЇ ВИРОБНИКА

10.1 Виробник гарантує відповідність безпечності та якості продуктів вимогам цих технічних умов при дотриманні умов зберігання і транспортування.

10.2 Гарантійний термін зберігання продуктів встановлено в 9.4, 9.5 цих ТУ.

ДОДАТОК А

(довідковий)

МЕТОД РОЗРАХУНКУ ПОЖИВНОЇ (ХАРЧОВОЇ) ЦІННОСТІ ТА ЕНЕРГЕТИЧНОЇ ЦІННОСТІ (КАЛОРІЙНОСТІ) У 100 Г ПРОДУКТІВ КОНЦЕНТРОВАНИХ ТА СУШЕНИХ ІЗ ТАРО (ПЮРЕ, ПАСТА, ПОРОШОК)

Для розрахунку енергетичної цінності продуктів концентрованих та сушених із таро (пюре, паста, порошок) застосовують наступну формулу:

$$E = k_б \times (M_б + M_в) + k_б \times M_ж, \qquad (1)$$

де E - енергетична цінність, ккал;

$M_б$ - масова частка білка, г/100 г продукту;

$M_в$ - масова частка вуглеводів, г/100 г продукту;

$M_ж$ - масова частка жиру, г/100 г продукту;

$k_б = 4$ – коефіцієнт енергетичної цінності 1 г білка чи 1 г вуглеводів у продукті, ккал/г;

$k_ж = 9$ - коефіцієнт енергетичної цінності 1 г жиру в продукті, ккал/г.

Якщо потрібно подати енергетичну цінність (калорійність) у вигляді поживної (харчової) цінності, у кілоджоулях, використовують наступний перерахунок:

1 ккал = 4,184 кДж

ДОДАТОК Б

(довідковий)

БІБЛІОГРАФІЯ

1 ГОСТ 26927-86 Сырье и продукты пищевые. Метод определения ртути (Сировина і продукти харчові. Метод визначання ртуті)

2 ГОСТ 26930-86 Сырье и продукты пищевые. Метод определения мышьяка (Сировина і продукти харчові. Метод визначення миш'яку)

3 ГОСТ 26931-86 Сырье и продукты пищевые. Метод определения меди (Сировина і продукти харчові. Метод визначання міді)

4 ГОСТ 26932-86 Сырье и продукты пищевые. Методы определения свинца (Сировина і продукти харчові. Методи визначання свинцю)

5 ГОСТ 26933-86 Сырье и продукты пищевые. Метод определения кадмия (Сировина і продукти харчові. Метод визначання кадмію)

6 МР 2273-80 Методические рекомендации по обнаружению, идентификации и определению содержания афлатоксинов в пищевых продуктах (Методичні рекомендації щодо виявлення, ідентифікації і визначання вмісту афлатоксинів у харчових продуктах), затверджені МОЗ СРСР 10.12.1980 р.

7 МР 2964-84 Методические рекомендации по обнаружению, идентификации и определению содержания зеараленона в пищевых продуктах (Методичні рекомендації щодо виявлення, ідентифікації і визначання вмісту зеароленону в харчових продуктах), затверджені МОЗ СРСР 23.01.1984 р. 5

8 МУ 4082-86 Методические указания по обнаружению, идентификации и определению содержания афлатоксинов в продовольственном сырье и пищевых продуктах с помощью высокоэффективной жидкостной хроматографии (Методичні вказівки щодо виявлення, ідентифікації і визначання вмісту афлатоксинів у продовольчій сировині і харчових продуктах за допомогою високо-ефективної рідинної хроматографії), затверджені МОЗ СРСР 20.03.86 р.

9 МУ 5778-91 Стронций-90. Определение в пищевых продуктах (Стронцій-90. Визначанняв харчових продуктах)

10 МУ 5779-91 Цезий-137. Определение в пищевых продуктах (Цезій-137. Визначання в харчових продуктах), затверджені МОЗ СРСР 04.01.1991 р.

АРКУШ ОБЛІКУ ЗМІН ТЕХНІЧНИХ УМОВ

№ Зм.	Номера листів				Номер документа	Підпис	Дата	Термін введення змін
	Змінених	Нових	Скасованих	Замінених				

Addition E

Q/YTBG-0004S-2023 "Tough biscuits fortified with beetroot powder"

Q/YTBG

深圳市易通报关有限公司企业标准

Q/YTBG-0004S-2023

富含甜菜粉的韧性饼干

2023-01-07 发布　　　　2023-01-08 实施

深圳市易通报关有限公司　发布

前　言

本标准根据 GB/T 1. 1—2020《标准化工作导则第 1 部分:标准化文件的结构和起草规则》的规定编写。

本标准的感官指标、水分、碱度根据产品的特性和 GB/T 20980《饼干质量通则》制定;酸价、过氧化值、菌落总数、大肠菌群、霉菌限量根据 GB 7100《食品安全国家标准 饼干》制定;其他项目根据有关规定编写。

本标准由贺州学院、苏梅国立农业大学、深圳市易通报关有限公司提出。

本标准起草人: 刘艳、Anna 0. Helikh 提出。

本标准首次发布日期: 2023 年 1 月 7 日。

企业标准信息公共服务平台
公开 2023年01月07日 10点33分

富含甜菜粉的韧性饼干

1 适用范围

本标准规定了富含甜菜粉的韧性饼干的技术要求、生产加工过程卫生要求、试验方法、检验规则和标志、包装、运输、贮存等要求。

本标准适用于以低筋小麦粉、甜菜粉、鲜鸡蛋、黄油、白砂糖、水为主要原料，以全脂奶粉、玉米淀粉、碳酸氢钠、食用盐为辅料，经配料、搅拌、碾压、成型、烘烤、冷却、包装等工序制成的富含甜菜粉的韧性饼干。

2 规范性引用文件

下列文件对于本文件的应用是必不可少的。凡是注日期的引用文件，仅注日期的版本适用于本件。凡是不注日期的引用文件，其最新版本（包括所有的修改单）适用于本文件。

GB/T 191 包装储运图示标志

GB 1886.2 食品安全国家标准 食品添加剂 碳酸氢钠

GB 2749 食品安全国家标准 蛋与蛋制品

GB/T 317 白砂糖

GB 19644 食品安全国家标准 乳粉

GB/T 8885 食用玉米淀粉

GB 2721 食品安全国家标准 食用盐

NY/T 1884 绿色食品 果蔬粉

GB 2760 食品安全国家标准 食品添加剂使用标准

GB 2762 食品安全国家标准 食品中污染物限量

GB 2763 食品安全国家标准 食品中农药最大残留限量

GB 4789.1 食品安全国家标准 食品微生物学检验 总则

GB 4789.2 食品安全国家标准 食品微生物学检验 菌落总数测定

GB 4789.3 食品安全国家标准 食品微生物学检验 大肠菌群计数

GB 4789.15 食品安全国家标准 食品微生物学检验 霉菌和酵母计数

GB 5009.3 食品安全国家标准 食品中水分的测定

企业标准信息公共服务平台 公开 2023年01月07日 10点33分

GB 4806.7 食品安全国家标准 食品接触用塑料材料及制品

GB 5009.227 食品安全国家标准 食品中过氧化值的测定

GB 5009. 229 食品安全国家标准 食品中酸价的测定

GB 5749 生活饮用水卫生标准

GB 7100 食品安全国家标准 饼干

GB/T 20980 饼干质量通则

GB/T 8608 食品安全国家标准 低筋小麦粉

GB 7718 食品安全国家标准 预包装食品标签通则

GB 9683 复合食品包装袋卫生标准

GB 14881 食品安全国家标准 食品生产通用卫生规范

GB28050 食品安全国家标准 预包装食品营养标签通则

LS/T 3217 人造奶油（人造黄油）

JJF 1070 定量包装商品净含量计量检验规则

国家质量监督检验检疫总局第 75 号令《定量包装商品计量监督管理办法》

3 技术要求

3.1 原辅料

3.1.1 低筋小麦粉: 应符合 GB/T 8608 的要求。

3.1.2 甜菜粉：应符合 NY/T 1884 的要求。

3.1.3 鲜鸡蛋: 应符合 GB 2749 的要求。

3.1.4 生产用水: 应符合 GB 5749 的要求。

3.1.5 白砂糖：应符合 GB/T 317 的要求。

3.1.6 全脂乳粉：应符合 GB 19644 的要求。

3.1.7 玉米淀粉：应符合 GB/T 8885 的要求。

3.1.8 食用盐：应符合 GB 2721 的要求。

3.1.9 碳酸氢钠：应符合 GB 1886.2 的要求。

3.2 感官指标

感官指标应符合表 1 的要求。

企业标准信息公共服务平台 公开 2023年01月07日 10点33分

表 1 感官要求

项　目	要　求	检验方法
颜色	具有该产品应有的正常色泽	取适量试样置于白瓷盘中，在自然光下用目测法进行色泽、组织形态、杂质等项目检验；取适量试样，先闻气味，然后温开水漱口，再品尝试验的滋味。
滋味、气味	不粘牙，口感松脆，有产品应有的自然香味，无异味	
组织状态	外形完整，花纹清晰，厚薄基本均匀，不变形，无裂纹，有均匀泡点，无较大或较多凹底部，断面有层次或多孔状	
杂质	无肉眼可见的外来杂质	

3.3 理化指标

理化指标应符合表 2 的要求。

表 2 理化指标

项　目		指　标
水分含量/（g/100 g）	≤	4.0
碱度（以碳酸钠计）（g/100 g）	≤	0.4
酸价（以脂肪计）（KOH）/（mg/g）	≤	5
过氧化值（以脂肪计）/（g/100 g）	≤	0.25

3.4 致病菌限量

致病菌限量应符合表 3 的要求。

表 3 致病菌限量

项　目	采样方式[a]及限量			
	n	c	m	M
菌落总数/（CFU/g）	5	2	10^4	10^5
大肠菌群/（CFU/g）	5	2	10	10^2
霉菌/（CFU/g）　≤	50			
[a] 样品的采集及处理 GB 4789.1。				

3.5 净含量

应符合国家质量监督检验检疫总局第 75 号令，《定量包装商品计量监督管理办法》的规定。

3.6 食品添加剂

3.6.1 食品添加剂的质量应符合相应标准和有关规定。

3.6.2 食品添加剂的品种和使用量应符合 GB 2760 规定。碳酸氢钠根据生产需要适量添加。

4　生产加工过程卫生要求

生产加工过程应符合 GB 14881 的规定。

5　试验方法

5.1 感官指标

在正常条件下，将样品置于洁净白搪瓷盘中，观察其色泽、组织形态及杂质，闻其气味，尝其滋味。

5.2 理化指标

5.2.1 水分：按 GB 5009.3 规定的方法检验。

5.2.2 碱度：按 GB/T 20980 规定的方法检验。

5.2.3 酸价：按 GB 5009. 229 规定的方法检验。

5.2.4 过氧化值：按 GB 5009. 227 规定的方法检验。

5.3 微生物

5.3.1 菌落总数：按 GB 4789. 2 规定的方法检验。

5.3.2 大肠菌群：按 GB 4789. 3 平板计数法规定的方法检验。

5.3.3 霉菌：按 GB 4789. 15 规定的方法检验。

5.4 净含量

按 JJF 1070 规定的方法检验。

6　检验规则

6.1 组批

以同一投料同一班次生产的同一规格产品为一货批。

6.2 抽样

从同货批产品中按不少于 200 个独立包装的抽样基数随机抽取样品，样品数量不少于 6 个最小独立包装，样品质量不少于 1kg。样品分成二份，一份用于检验；另一份留置备查。

6.3 检验

6.3.1 出厂检验

产品须经生产企业质量检验部检验合格后方可出厂。出厂检验项目包括感官、水分、净含量、菌落总数、大肠菌群和标签。

6.3.2 型式检验

型式检验项目为本标准规定的全部项目每半年进行+次有下列情形之一时也应进行型式检验。

企业标准信息公共服务平台
公开
2023年01月07日 10点33分

a)新产品投产时；

b)连续停产三个月以上，恢复生产时；

c)主要原材料来源、关键工艺或设备发生改变时；

d)出厂检验结果与上次型式检验有较大差异时；

e)国家食品安全监管部门提出要求时。

6.4 判定规则

检验结果如有不合格项，可对原批次产品双倍取样或对留置备查样品复检，复检结果如仍有不合格项，则判该批产品为不合格品:微生物指标不合格不得复检。

7 标志、包装、运输、贮存及保质期

7.1 标志

标签应符合 GB 7718 和 GB 28050 的规定。包装贮运图示标志应符合 GB/T 191 的规定。

7.2 包装

产品采用塑料制品或复合食品包装袋包装，包装材料应分别符合 GB 4806. 7 或 GB 9683 的要求。外包装瓦楞纸箱应符合 GB/T 6543 的要求。

7.3 运输

7.3.1 运输工具应保持干燥、清洁、平整、无异味；应防止污染。不能影响包装及质量。

7.3.2 运输时要防止受热、受潮。

7.3.3 运输时应轻装轻卸，平面堆放，防止倾倒、重压，防止包装破碎和产品变形。若有破损时，应及时加封。

7.3.4 在周转堆放时，应防止日晒雨淋，不得在露天长期堆放，或直接放在地上，以免受潮。

7.4 贮存

产品应存放于通风阴凉、干燥、清洁、无异味的库房中，避免阳光直射。应有防火、防虫、防鼠设施，并应防止农药和其他化学物品污染成品。产品不得与有毒、有腐蚀性、易挥发或恶臭的物品同库储存，贮存时货物离地面≥20 cm，离墙面≥20 cm。

7.5 保质期

在符合上述文件规定的包装、运输和贮存条件下，且包装完好，产品的保质期不少于 12 个月，具体按产品包装标注执行。

Addition F

Q/YTBG-0005S-2023 "Chicken sausages fortified with beetroot powder"

Q/YTBG

深圳市易通报关有限公司企业标准

Q/YTBG-0005S-2023

添加甜菜粉的鸡肉香肠

2023-01-07 发布　　　　2023-01-08 实施

深圳市易通报关有限公司 发布

前 言

本标准根据 GB/T 1. 1—2020《标准化工作导则第 1 部分：标准化文件的结构和起草规则》的规定起草。

本标准由贺州学院、苏梅国立农业大学、深圳市易通报关有限公司提出。

本标准起草人：刘艳、Anna 0. Helikh。

本标准首次发布日期：2023 年 1 月 7 日。

企业标准信息公共服务平台
公开 2023年01月07日 10点40分

添加甜菜粉的鸡肉香肠

1 适用范围

本标准规定了一种添加甜菜粉的鸡肉香肠的技术要求、生产加工过程卫生要求、试验方法、检验规则和标志、包装、运输、贮存等要求。

本标准适用于以鸡胸肉、猪皮为主要原料，以甜菜粉、木薯淀粉、水、料酒、食盐、五香粉、白胡椒粉、异抗坏血酸钠为辅料，经绞肉、配料、腌制、灌制、干燥、冷却、包装、冷藏等工序制成的富含甜菜粉的鸡肉香肠。

2 规范性引用文件

下列文件对于本文件的应用是必不可少的。凡是注日期的引用文件，仅注日期的版本适用于本件。凡是不注日期的引用文件，其最新版本（包括所有的修改单）适用于本文件。

GB/T 191 包装储运图示标志

GB/T 23493 中式香肠

NY/T 1884 绿色食品 果蔬粉

NY/T 875 食用木薯淀粉

GB/T 29343 木薯淀粉

SB/T 10279 熏煮香肠

SB/T 10416 调味料酒

GB/T 7740 天然肠衣

GB/T 5461 食用盐

GB 2760 食品安全国家标准 食品添加剂使用标准

GB 1886.28 食品安全国家标准 食品添加剂 D-异抗坏血酸钠

GB 2707 食品安全国家标准 鲜（冻）畜、禽产品

GB/T 19676 畜禽肉质量分级 鸡肉

GB 2726 食品安全国家标准 熟肉制品

GB 2733 食品安全国家标准 鲜、冻动物性水产品

GB 5009.3 食品安全国家标准 食品中水分的测定

GB 5009.5 食品安全国家标准 食品中蛋白质的测定

GB 5009.6 食品安全国家标准 食品中脂肪的测定

企业标准信息公共服务平台 公开 2023年01月07日 10点40分

GB 5009.9 食品安全国家标准 食品中淀粉的测定

GB 5009.44 食品安全国家标准 食品中氯化物的测定

GB 5009.227 食品安全国家标准 食品中过氧化值的测定

GB 5009.33 食品安全国家标准 食品中亚硝酸盐与硝酸盐的测定

GB 19303 熟肉制品企业生产卫生规范

GB/T 21735 肉与肉制品物流规范

GB/T 29342 肉制品生产管理规范

SB/T 10826 加工食品销售服务要求 肉制品

GB 14880 食品安全国家标准 食品营养强化剂使用标准

GB 5749 生活饮用水卫生标准

GB 7718 食品安全国家标准 预包装食品标签通则

GB 14881 食品安全国家标准 食品生产通用卫生规范

GB 28050 食品安全国家标准 预包装食品营养标签通则

JJF 1070 定量包装商品净含量计量检验规则

国家质量监督检验检疫总局第 75 号令《定量包装商品计量监督管理办法》

3 技术要求

3.1 原料

3.1.1 原料肉：应符合 GB 2707，GB/T 19676、GB 2733 等的规定

3.1.2 原料肉应保持肉质新鲜、不沾污、不混有其他杂质。

3.2 辅料

3.2.1 木薯淀粉: 应符合 GB/T 29343 的要求。

3.2.2 甜菜粉：应符合 NY/T 1884 的要求。

3.2.3 异抗坏血酸钠: 应符合 GB 1886.28 的要求。

3.2.4 生产用水: 应符合 GB 5749 的要求。

3.2.5 食用盐：应符合 GB 2721 的要求。

3.2.6 料酒：应符合 SB/T 10416 的要求。

3.2.7 肠衣：应符合 GB 14967 和 GB/T 7740 的要求。

3.3 感官指标

感官指标应符合表 1 的要求。

企业标准信息公共服务平台 公开 2023年01月07日 10点40分

表 1 感官要求

项　目	要　求
外观	肠体均匀，无破损
色泽	产品呈红色、枣红色，有光泽
组织状态	组织致密，切片性能好，有弹性，无密集气孔
风味	滋味鲜美，香味纯正浓郁，具有鸡肉香肠固有的风味，无异味，无酸败味
杂质	无正常视力可见杂质

3.4　理化指标

理化指标应符合表 2 的要求。

表 2 理化指标

项　目		指　标		
		特级	优级	普通级
蛋白质/(g/100 g)	≥	16	14	10
脂肪/(g/100 g)	≤	15	25	35
淀粉/(g/100 g)	≤	3	4	10
水分含量/(g/100 g)	≤	60		
氯化物（以 NaCl 计）/（g/100 g）	≤	8		
过氧化值（以脂肪计）/(g/100 g)	≤	0.5		
亚硝酸盐（以 $NaNO_2$ 计）/（mg/kg）	≤	30		

3.5　食品安全指标

3.5.1　污染物限量

应符合 GB 2762 的规定。

3.5.2　微生物限量

应符合 GB 2726 的规定。

3.5.3　食品添加剂

应符合 GB 2760 的规定。

3.5.4　食品营养强化剂

应符合 GB 14880 的规定。

3.6　净含量

应符合《定量包装商品计量监督管理办法》的要求。

3.7　生产管理

应符合 GB 14881，GB 19303，GB/T 29342 等标准的规定。

4 检验方法

4.1 感官

取样品置于白色器皿内，在自然光下肉眼观察其外观、色泽、组织状态、杂质，品尝其风味。

4.2 蛋白质

按 GB 5009. 5 规定的方法测定。

4.3 淀粉

按 GB 5009. 9 规定的方法测定。

4.4 脂肪

按 GB 5009. 6 规定的方法测定。

4.5 水分

按 GB 5009. 3 规定的方法测定。

4.6 氯化物

按 GB 5009.44 规定的方法测定。

4.7 过氧化值

样品处理按 GB/T5009.44 规定的方法操作，按 GB/T5009.37 规定的方法测定。

4.8 亚硝酸盐

按 GB/T 5009. 33 规定的方法测定。

4.9 食品安全指标

按相关食品安全国家标准规定的方法检验。

4.10 净含量偏差

按 JJF 1070 规定的方法测定。

5 检验规则

5.1 组批

以同一投料同一班次生产的同一规格产品为一批。

5.2 抽样

5.2.1 样本数量：从同一批产品中随机按表 3 抽取样本，并将 1/3 样品进行封存，保留备查。

表 3　抽样表

批量范围/箱	样本数量/箱	合格判定数（Ac）	不合格判定数（Re）
≤1000	6	0	1
1001～3000	7～12	1	2
≥3001	13～21	2	3

5.2.2　样品数量：从样本中随机抽足 2 kg 作为检验样品。

5.3　检验

5.3.1　出厂检验

产品出厂前，需经质量检验部门按本标准规定逐批进行检验，检验合格后签发质量证明书方可出厂。

出厂检验项目：感官、包装。净含量、菌落总数、大肠菌群和标签为每批必检项目，其他为不定期抽检项目。

5.3.2　型式检验

型式检验项目为本标准规定的全部项目每半年进行+次有下列情形之一时也应进行型式检验。

a)新产品投产时；

b)连续停产三个月以上，恢复生产时；

c)主要原材料来源、关键工艺或设备发生改变时；

d)出厂检验结果与上次型式检验有较大差异时；

e)国家食品安全监管部门提出要求时。

5.3.3　型式检验项目

本标准中 3.3、3.4、3.5、3.6 和 8.1.1 规定的项目。

5.4　判定规则

5.4.1　出厂检验判定与复验

5.4.1.1　全部符合 5.3.1 规定的项目，判该批产品为合格产品。

5.4.1.2　出厂 检验项目有一项不符合本标准，可以从同批产品中加倍抽样复验，复验后仍不符合本标准的规定，判该批产品为不合格品。

5.4.2　型式检验判定与复验

5.4.2.1　型式检验项目全部符合本标准的规定，判为合格品。

5.4.2.2　型式检验项目不超过两项不符合本标准，可以从同批产品中加倍抽样复验，复验后仍有一项不符合本标准的规定，判该批产品为不合格品。

6 标志、包装、运输、贮存及保质期

6.1 标志

标签应符合 GB 7718 和 GB 28050 的规定，并注明等级。包装贮运图示标志应符合 GB/T 191 的规定。

6.2 包装

包装材料应符合国家标准、行业标准的相关规定。

6.3 贮存

6.3.1 应在 0°C~4°C 或-18°C 以下贮存。

6.3.2 贮存时应包装完整、不破不漏，避免有毒物质的污染。

6.3.3 仓库应卫生、干燥，具有冷藏/冷冻功能，不应同库贮存有毒、有害、有异味、易挥发、易腐蚀性的物品。

6.3.4 产品堆放应垫板，与地面距离应不小于 10 cm，距墙面距离应不小于 15 cm。

6.3.5 按不同批次堆码，堆码应整齐。

6.4 运输

6.4.1 运输工具应保持干燥、清洁、平整、无异味；应防止污染。不能影响包装及质量。

6.4.2 运输时要防止受热、受潮。

6.4.3 运输时应轻装轻卸，平面堆放，防止倾倒、重压，防止包装破碎和产品变形。若有破损时，应及时加封。

6.4.4 在周转堆放时，应防止日晒雨淋，不得在露天长期堆放，或直接放在地上，以免受潮。

6.5 保质期

在符合上述文件规定的包装、运输和贮存条件下，且包装完好，产品的保质期不少于 6 个月，具体按产品包装标注执行。

Addition G

Certificate of implementation "Sausage technology using dried beetroot, pretreated by freeze-thaw method"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО	ЗАТВЕРДЖУЮ
Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	Директор ФОП «Філон А.М.»
Ю.І. Данько	А.М. Філон
(підпис) (ініціали, прізвище)	(підпис) (ініціали, прізвище)
«06» 02 (дата) 2023 рік	«16» січня (дата) 2023 рік

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Філон А. М.»
(найменування організації)

директор Філон Андрій Михайлович
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення (найменування теми)
	Номер державної реєстрації:	0122U201635
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Філон А.М.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасок із використанням буряку заморожено-розмороженого сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, використана нова сировина, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Філон А.М.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	48 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбаски рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

(підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Завідувач кафедрою

(підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Філон А.М.»

(підпис) А.М. Філон (ініціали, прізвище)

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбаски із використанням буряку заморожено-розмороженого сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 48 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасок.

Ковбаски із використанням буряку заморожено-розмороженого сушеного є високоякісними, безпечними, з високими органолептичними показниками та рекомендуються для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_________ (підпис) А.М. Філон (ініціали, прізвище)

«16» січня (дата) 2023 рік

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбаски із використанням буряку заморожено-розмороженого сушеного є економічно доступними для широких верств населення з різним рівнем доходу, можуть бути використані у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_______________ (підпис) А.М. Філон (ініціали, прізвище)

«__» січня (дата) 2023 рік

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Addition H

Certificate of implementation "Biscuit technology using dried beetroot, pretreated by freeze-thaw method"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор Ю.І. Данько (підпис) (ініціали, прізвище) «06» 02 2023 рік (дата)	ЗАТВЕРДЖУЮ Директор ФОП «Філон А.М.» А.М. Філон (підпис) (ініціали, прізвище) «16» січня 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Філон А. М.»
(найменування організації)

директор Філон Андрій Михайлович
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення (найменування теми)
	Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Філон А.М.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія печива із використанням буряку заморожено-розмороженого сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, використана нова сировина, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Філон А.М.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	41 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблене печиво рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, кондитерські вироби), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

(підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Завідувач кафедрою

(підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Філон А.М.»

(підпис) А.М. Філон (ініціали, прізвище)

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології печива, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Печиво із використанням буряку заморожено-розмороженого сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 41 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура печива.

Печиво із використанням буряку заморожено-розмороженого сушеного є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дитячому та дієтичному харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_______ (підпис) А.М. Філон (ініціали, прізвище)

«16» січня (дата) 2023 рік

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0122U201635

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології печива, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Печиво із використанням буряку заморожено-розмороженого сушеного є економічно доступним для широких верств населення з різним рівнем доходу, може бути використане у дитячому та дієтичному харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_________ (підпис) А.М. Філон (ініціали, прізвище)

«16» січня (дата) 2023 рік

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Addition I

Certificate of implementation "Technology of sausage products using dried beetroot"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО	ЗАТВЕРДЖУЮ
Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	Директор ФОП «Філон А.М.»
________ Ю.І. Данько (підпис) (ініціали, прізвище)	________ А.М. Філон (підпис) (ініціали, прізвище)
«06» ________ 2023 рік (дата)	«16» січня 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Філон А. М.»
(найменування організації)

директор Філон Андрій Михайлович
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення (найменування теми)
	Номер державної реєстрації:	0122U201635
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Філон А.М.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасних виробів із використанням буряку сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)
6	**Впроваджені в промислове виробництво**	ФОП «Філон А.М.» (назва підприємства)

7	**Рентабельність продукції (Додаток 1)**	27 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбасні вироби рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

(підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Завідувач кафедрою

(підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Філон А.М.»

(підпис) А.М. Філон (ініціали, прізвище)

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасних виробів, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбасні вироби із використанням буряку сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 27 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасних виробів.

Ковбасні вироби із використанням буряку сушеного є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

(підпис) А.М. Філон (ініціали, прізвище)

«16» січня 2023 рік
(дата)

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасних виробів, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбасні вироби із використанням буряку сушеного є економічно доступним для широких верств населення з різним рівнем доходу, може бути використаний у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_________ (підпис) А.М. Філон (ініціали, прізвище)

«16» січня (дата) 2023 рік

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Addition J

Certificate of implementation "Technology of chicken sausages using concentrated taro products"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	ЗАТВЕРДЖУЮ Директор ФОП «Філон А.М.»
Ю.І. Данько (підпис) (ініціали, прізвище)	А.М. Філон (підпис) (ініціали, прізвище)
«06» 02 2023 рік (дата)	«30» січня 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Філон А. М.»
(найменування організації)

директор Філон Андрій Михайлович
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення (найменування теми)
	Номер державної реєстрації:	0122U202024
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Філон А.М.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасок курячих із використанням продуктів із таро концентрованих (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	використана нова сировина, розроблено нову технологію, нові досліджені результати, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-008:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Філон А.М.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	45 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбаски курячі рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами та рослинним білком і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

________ А.О. Геліх
(підпис) (ініціали, прізвище)

Аспірант

Liu Yan Лю Янь
(підпис) (ініціали, прізвище)

Аспірант

Shang fei fei Шань Фейфей
(підпис) (ініціали, прізвище)

Завідувач кафедрою

________ М.М. Самілик
(підпис) (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Філон А.М.»

________ А.М. Філон
(підпис) (ініціали, прізвище)

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії

за темою:

Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 2 0 2 4

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення» полягає у розробці технології продуктів із таро концентрованих для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок курячих, що розширить асортимент готової продукції із зниженою калорійністю та підвищеною біологічною цінністю.

Ковбаски курячі із використанням продуктів із таро концентрованих виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 45 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасок курячих.

Ковбаски курячі із використанням продуктів із таро концентрованих є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_______________ (підпис) А.М. Філон (ініціали, прізвище)

«30» січня (дата) 2023 рік

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай
Номер державної реєстрації:	0 1 2 2 U 2 0 2 0 2 4

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення» полягає у розробці технології продуктів із таро концентрованих для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок курячих, що розширить асортимент готової продукції із зниженою калорійністю та підвищеною біологічною цінністю.

Ковбаски курячі із використанням продуктів із таро концентрованих є економічно доступним для широких верств населення з різним рівнем доходу, може бути використане у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Філон А.М.»

_______ (підпис) А.М. Філон (ініціали, прізвище)

«30» січня (дата) 2023 рік

ФІЗИЧНА ОСОБА-ПІДПРИЄМЕЦЬ ФІЛОН Андрій Михайлович 3316908299 УКРАЇНА

Addition K

Certificate of implementation "Tough Biscuits Fortified With Beetroot Powder"

Application testify

Product name	Tough Biscuits Fortified With Beetroot Powder
Standard number	Q/YTBG-0004S-2023
Invention Institution	Hezhou University Sumy National Agrarian University
Product inventor	Yan Liu, Anna O. Helikh
Application Enterprise	Shenzhen Huataixing Food Co., Ltd.
Postal address	No.43 Seafood Commercial Street, Shuitou Industrial Zone, Longgang District, Shenzhen, Guangdong Province, China

Since January 10, 2023, our company has adopted the product formula and processing technology of "Tough Biscuits Fortified With Beetroot Powder" provided by Yan Liu. The tough biscuits fortified with beetroot powder are crunchy and delicious, with the unique flavor and taste of beetroot powder. They are tempting, protein-rich, with good nutritional value and economic value, and they are in line with our company's product needs. The application of this technology has significantly improved the economic benefits of the company.

SHENZHEN WAH TAI XING FOODS CO. LTD.
深圳华泰兴食品有限公司

Enterprise (official seal): Shenzhen Huataixing Food Co., Ltd.

Head of enterprise: 杨强双 Yang Qiangshan

Date: 2023. 3. 25

Addition L

Certificate of implementation "Chicken Sausages Fortified With Beetroot Powder"

Application testify

Product name	Chicken Sausages Fortified With Beetroot Powder
Standard number	Q/YTBG-0005S-2023
Invention Institution	Hezhou University Sumy National Agrarian University
Product inventor	Yan Liu, Anna O. Helikh
Application Enterprise	Shenzhen Huataixing Food Co., Ltd.
Postal address	No.43 Seafood Commercial Street, Shuitou Industrial Zone, Longgang District, Shenzhen, Guangdong Province, China

Since January 15, 2023, our company has adopted the product formula and processing technology of "Chicken Sausages Fortified With Beetroot Powder" provided by Yan Liu. The chicken sausages fortified with beetroot powder are tempting and delicious, with the unique flavor and taste of beetroot powder. The addition of beetroot powder improves the nutritional values of chicken sausages and prolongs the shelf-life. They are protein-rich, with good nutritional value and economic value, and they are in line with our company's product needs.

SHENZHEN WAH TAI XING FOODS CO. LTD. 深圳华泰兴食品有限公司

Enterprise (official seal): Shenzhen Huataixing Food Co., Ltd.

Head of enterprise: 杨强双 Yang Qiangshan

Date: 2023. 3. 31

Addition M

Certificate of implementation "Sausage technology using dried beetroot, pretreated by freeze-thaw method"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор Ю.І. Данько (підпис) (ініціали, прізвище) «08» лютого 2023 рік (дата)	ЗАТВЕРДЖУЮ Директор ФОП «Клименко Л.О.» Л.О. Клименко (підпис) (ініціали, прізвище) «23» 01 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Клименко Л.О.»
(найменування організації)

директор Людмила Олександрівна Клименко
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення (найменування теми)
	Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Клименко Л.О.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасок із використанням буряку заморожено-розмороженого сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, використана нова сировина, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Клименко Л.О.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	43 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбаски рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

_______ (підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Завідувач кафедрою

_______ (підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Клименко Л.О.»

_______ (підпис) Л.О. Клименко (ініціали, прізвище)

ПІДПРИЄМЕЦЬ Клименко Людмила Олександрівна Ідентифікаційний 2185611609 номер Україна м. Суми

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**1**	**6**	**3**	**5**

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбаски із використанням буряку заморожено-розмороженого сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 43 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасок.

Ковбаски із використанням буряку заморожено-розмороженого сушеного є висококякісними, безпечними, з високими органолептичними показниками та рекомендуються для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»

_________ Л.О. Клименко
(підпис) (ініціали, прізвище)

«23» 01 2023 рік
(дата)

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**1**	**6**	**3**	**5**

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбаски із використанням буряку заморожено-розмороженого сушеного є економічно доступними для широких верств населення з різним рівнем доходу, можуть бути використані у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»
________ Л.О. Клименко
(підпис) (ініціали, прізвище)
«23» 01 2023 рік
(дата)

Підприємець Клименко Людмила Олександрівна, Ідентифікаційний номер 2185611819, Україна м. Суми

Addition N

Certificate of implementation "Biscuit technology using dried beetroot, pretreated by freeze-thaw method"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО	ЗАТВЕРДЖУЮ
Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	Директор ФОП «Клименко Л.О.»
______ Ю.І. Данько	______ Л.О. Клименко
(підпис) (ініціали, прізвище)	(підпис) (ініціали, прізвище)
«08» лютого 2023 рік (дата)	«23» 01 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Клименко Л.О.»
(найменування організації)

директор Людмила Олександрівна Клименко
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

наукової держбюджетної тематики: Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення
(найменування теми)

Номер державної реєстрації:

0	1	2	2	U	2	0	1	6	3	5

	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Клименко Л.О.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія печива із використанням буряку заморожено-розмороженого сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, використана нова сировина, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Клименко Л.О.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	34 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблене печиво рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, кондитерські вироби), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

(підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Завідувач кафедрою

(підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Клименко Л.О.»

(підпис) Л.О. Клименко (ініціали, прізвище)

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету									
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай									
Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**1**	**6**	**3**	**5**

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології печива, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Печиво із використанням буряку заморожено-розмороженого сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 34 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об’єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура печива.

Печиво із використанням буряку заморожено-розмороженого сушеного є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дитячому та дієтичному харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»

_________ Л.О. Клименко
(підпис) (ініціали, прізвище)

«23» 01 2023 рік
(дата)

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	0	1	2	2	U	2	0	1	6	3	5

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку заморожено-розмороженого сушеного для використання у складі харчової та кулінарної продукції, а саме, технології печива, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Печиво із використанням буряку заморожено-розмороженого сушеного є економічно доступним для широких верств населення з різним рівнем доходу, може бути використане у дитячому та дієтичному харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»
_________ Л.О. Клименко
(підпис) (ініціали, прізвище)
«23» 01 2023рік
(дата)

ПІДПРИЄМЕЦЬ Клименко Людмила Олександрівна Ідентифікаційний номер 2185611003 Україна м.Суми

Addition O

Certificate of implementation "Technology of sausage products using dried beetroot"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	ЗАТВЕРДЖУЮ Директор ФОП «Клименко Л.О.»
(підпис) Ю.І. Данько (ініціали, прізвище)	(підпис) Л.О. Клименко (ініціали, прізвище)
«08» лютого 2023 рік (дата)	«23» 01 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Клименко Л.О.»
(найменування організації)

директор Людмила Олександрівна Клименко
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

	наукової держбюджетної тематики:	Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення (найменування теми)
	Номер державної реєстрації:	0 1 2 2 U 2 0 1 6 3 5
	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Клименко Л.О.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасних виробів із використанням буряку сушеного (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	розроблено нову технологію, нові досліджені результати, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-007:2022 (вказати номер і назву нормативно-технічної документації)
6	**Впроваджені в промислове виробництво**	ФОП «Клименко Л.О.» (назва підприємства)

7	**Рентабельність продукції (Додаток 1)**	25 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбасні вироби рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами, натуральними харчовими барвниками та мінеральними речовинами і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

_______________ А.О. Геліх
(підпис) (ініціали, прізвище)

Аспірант

Liu Yan Лю Янь
(підпис) (ініціали, прізвище)

Завідувач кафедрою

_______________ М.М. Самілик
(підпис) (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор
ФОП «Клименко Л.О.»

_______________ Л.О. Клименко
(підпис) (ініціали, прізвище)

ПІДПРИЄМЕЦЬ * Клименко Людмила Олександрівна * Ідентифікаційний 2185611009 номер * Україна м. Суми

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**1**	**6**	**3**	**5**

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасних виробів, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбасні вироби із використанням буряку сушеного виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 25 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасних виробів.

Ковбасні вироби із використанням буряку сушеного є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»

_________ Л.О. Клименко
(підпис) (ініціали, прізвище)

«23» 01 2023 рік
(дата)

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи

за темою:

Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету									
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай									
Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**1**	**6**	**3**	**5**

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикати з рослинної сировини підвищеної біологічної цінності подвійного призначення» полягає у розробці технології буряку сушеного для використання у складі харчової та кулінарної продукції, а саме, технології ковбасних виробів, що розширить асортимент готової продукції із підвищеною біологічною цінністю.

Ковбасні вироби із використанням буряку сушеного є економічно доступним для широких верств населення з різним рівнем доходу, може бути використаний у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»
_____________ Л.О. Клименко
(підпис) (ініціали, прізвище)
«23» 01 2023 рік
(дата)

Клименко Людмила Олександрівна Ідентифікаційний номер 2185611603 ПІДПРИЄМЕЦЬ Україна м.Суми

Addition P

Certificate of implementation "Technology of chicken sausages using concentrated taro products"

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
СУМСЬКИЙ НАЦІОНАЛЬНИЙ АГРАРНИЙ УНІВЕРСИТЕТ

УЗГОДЖЕНО	ЗАТВЕРДЖУЮ
Проректор з наукової та міжнародної діяльності, доктор економічних наук, професор	Директор ФОП «Клименко Л.О.»
(підпис) Ю.І. Данько (ініціали, прізвище)	(підпис) Л.О. Клименко (ініціали, прізвище)
«08» лютого 2023 рік (дата)	«06» 02 2023 рік (дата)

АКТ
ВПРОВАДЖЕННЯ НАУКОВО-ДОСЛІДНОЇ РОБОТИ

Замовник: ФОП «Клименко Л.О.»
(найменування організації)

директор Людмила Олександрівна Клименко
(посада, ПІБ керівника організації)

Цим актом підтверджується, впровадження результатів роботи виконаних у межах

наукової держбюджетної тематики: Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення
(найменування теми)

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**2**	**0**	**2**	**4**

	Держбюджетна тематика виконується на кафедрі:	Технологій та безпечності харчових продуктів
	Дата виконання держбюджетної тематики:	2022–2023 р.
	Результати роботи впроваджені на підприємстві:	ФОП «Клименко Л.О.» (найменування підприємства, де здійснювалось впровадження)
1	**Вид впроваджених результатів**	технологія ковбасок курячих із використанням продуктів із таро концентрованих (експлуатація виробу, роботи, технології; виробництво виробу, роботи, технології, функціонування систем)
2	**Характеристика масштабу впровадження**	дослідно-промислова партія (унікальне, одиночне, партія, масове, серійне)
3	**Форма впровадження**	виробничий випуск
4	**Новизна результатів науково-дослідних робіт**	використана нова сировина, розроблено нову технологію, нові досліджені результати, продукція випускається вперше (піонерські, принципово нові, якісно нові, модифікація, модернізація старих розробок)
5	**Впроваджені на основі нормативно-технічної документації**	ТУ У 10.3-04718013-008:2022 (вказати номер і назву нормативно-технічної документації)

6	**Впроваджені в промислове виробництво**	ФОП «Клименко Л.О.» (назва підприємства)
7	**Рентабельність продукції (Додаток 1)**	38 % (характеристика прибутковості господарської діяльності підприємства від реалізації дослідно-промислової партії)
8	**Соціальний і науково-технічний ефект (Додаток 2)**	розроблені ковбаски курячі рекомендовано використовувати як самостійний харчовий продукт, так і у складі кулінарної продукції в закладах ресторанного господарства та підприємствах харчової промисловості (холодні та гарячі закуски, салати, виробів із борошна), які значно розширять асортимент готової продукції збагаченої харчовими волокнами та рослинним білком і можуть бути реалізовані в оптовій та роздрібній торгівлі. (використання в харчовій промисловості та реалізація населенню)
9	Удосконалено виробництво та доведено економічний ефект від випуску та реалізації дослідно-промислової партія розміром 30 кг. До акту додається розрахунок економічного ефекту (Додаток 1)	
10	До акту додається довідка про соціальний ефект від впровадження результатів науково-дослідної роботи (Додаток 2)	
11	Співвласниками акту впровадження науково-дослідної роботи є Сумський національний аграрний університет та Університет Хечжоу, Китай (School of Food and Biological Engineering, Hezhou University, Hezhou, China)	

ВІД ЗАКЛАДУ ОСВІТИ

Керівник роботи

(підпис) А.О. Геліх (ініціали, прізвище)

Аспірант

Liu Yan (підпис) Лю Янь (ініціали, прізвище)

Аспірант

shang feifei (підпис) Шань Фейфей (ініціали, прізвище)

Завідувач кафедрою

(підпис) М.М. Самілик (ініціали, прізвище)

ВІД ПІДПРИЄМСТВА

Директор

ФОП «Клименко Л.О.»

(підпис) Л.О. Клименко (ініціали, прізвище)

ПІДПРИЄМЕЦЬ Клименко Людмила Олександрівна Ідентифікаційний номер 2185611609 Україна м. Суми

Додаток 1

Довідка

щодо економічного ефекту від випуску та реалізації дослідно-промислової партії
за темою:
Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**2**	**0**	**2**	**4**

Економічний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення» полягає у розробці технології продуктів із таро концентрованих для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок курячих, що розширить асортимент готової продукції із зниженою калорійністю та підвищеною біологічною цінністю.

Ковбаски курячі із використанням продуктів із таро концентрованих виробили у кількості 30 кг, як дослідно-промислову партію.

Економічний ефект від випуску та реалізації дослідно-промислової партії визначали за показником рентабельності продукції, що склав 38 %. Рентабельність продукції визначали як відношення чистого прибутку від реалізації до собівартості продукції враховуючи об'єм дослідно-промислової партії.

Під час виробництва та реалізації населенню була апробована та оптимізована нова рецептура ковбасок курячих.

Ковбаски курячі із використанням продуктів із таро концентрованих є високоякісним, безпечним, з високими органолептичними показниками та рекомендується для використання у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»

_____________ Л.О. Клименко
(підпис) (ініціали, прізвище)

«06» 02 2023 рік
(дата)

Додаток 2

Довідка

щодо соціального ефекту від впровадження результатів науково-дослідної роботи
за темою:
Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення

Керівник роботи:	Геліх А.О., к. т. н., доцент кафедри технологій та безпечності харчових продуктів Сумського національного аграрного університету
Аспірант:	Лю Янь, ст. викладач школи харчової та біологічної інженерії Університету Хечжоу, Китай

Номер державної реєстрації:	**0**	**1**	**2**	**2**	**U**	**2**	**0**	**2**	**0**	**2**	**4**

Соціальний ефект від виконання науково-дослідної роботи «Розробка технічної документації на напівфабрикат з рослинної сировини для м'ясних фаршевих виробів подвійного призначення» полягає у розробці технології продуктів із таро концентрованих для використання у складі харчової та кулінарної продукції, а саме, технології ковбасок курячих, що розширить асортимент готової продукції із зниженою калорійністю та підвищеною біологічною цінністю.

Ковбаски курячі із використанням продуктів із таро концентрованих є економічно доступним для широких верств населення з різним рівнем доходу, може бути використане у дієтичному та дитячому харчуванні.

ЗАТВЕРДЖУЮ
Директор
ФОП «Клименко Л.О.»
_____________ Л.О. Клименко
(підпис) (ініціали, прізвище)
«08» 02 2023 рік
(дата)

ПІДПРИЄМЕЦЬ Клименко Людмила Олександрівна Ідентифікаційний номер 2185011603 Україна м. Суми