

The objective of this study was to investigate the effects of different microwave-assisted drying methods on the physical properties, bioactive compounds and antioxidant activity of beetroots. Beetroots were subjected to 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). The drying time, moisture content, hardness, color, microstructure, betalains, ascorbic acid, total flavonoids, 2,2'-azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging activity and ferric reducing antioxidant power (FRAP) of beetroots were analyzed. The shortest drying time (67.0 min) was observed in HMD, while VD+LMD required the longest drying time of 308.0 min. There was no significant difference in the moisture content of dried beetroots prepared by different microwave-assisted drying methods. Beetroots dried by HMD+HAD showed the highest hardness of 1332.0 g, VD+LMD led to the most desirable color with the lowest total color change. Porous structures were found in beetroots produced by HMD+LMD, HMD and LMD. Beetroots prepared by VD+LMD displayed the highest content of betacyanin, betaxanthin and total flavonoids. While beetroots dried by HMD illustrated the highest ascorbic acid content of 272.3 mg/100 g dry weight (DW). In terms of antioxidant activity, the highest FRAP value of beetroots obtained using VD+LMD was 14.95 mg trolox equivalent (TE)/g DW. Meanwhile, beetroots dried by VD+LMD exhibited the largest ABTS radical scavenging activity (16.92 mg TE/g DW). Compared to other microwave-assisted drying methods, VD+LMD is a more promising method for drying beetroots

**Keywords:** beetroot, bioactive compounds, antioxidant activity, color, betalains, microstructure, microwave-assisted drying

# INFLUENCE OF DIFFERENT MICROWAVE-ASSISTED DRYING METHODS ON THE PHYSICAL PROPERTIES, BIOACTIVE COMPOUNDS AND ANTIOXIDANT ACTIVITY OF BEETROOTS

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## 1. Introduction

Beetroot (*Beta vulgaris* L.) belongs to the *Chenopodiaceae* family and is a root vegetable originated from Southern Europe, Eastern Europe and Northern Africa [1]. World production of beetroot was estimated to be 275.49 million metric tons in 2018 [2]. Beetroots are valuable vegetables that are distributed worldwide and play a vital role in the diet of humans, provide the diet with color, phytochemicals, and nutrients. According to the data of the United States Department of Agriculture, 100 g of raw beetroots contain the following nutrients: average energy (43 kcal), water (88 g), total sugars (6.76 g), proteins (1.61 g), total dietary fiber (2.8 g), and total lipids (0.17 g) [3]. Beetroots also contain a considerable amount of essential and non-es-

sential amino acids. Beetroot is considered as a health-promoting food because it contains bioactive compounds for health promotion, such as betalains, phenolics, vitamins, minerals, carotenoids, nitrate, flavonoids, saponins, ascorbic acids, glycine, betaine and folate [4]. Beetroot is rich in betalain pigment, which has been approved as a natural colorant E-162 by European Union [5]. Betalains are commonly used for coloring a variety of foods, such as sauces, jam, jellies, ice cream, desserts, yogurt, candies and breakfast cereals.

In recent decades, there has been an increase in the research of beetroots in disease prevention and health promotion. It has been reported that bioactive compounds in beetroots exhibit anticancer, blood pressure and lipid lowering, anti-inflammatory, anti-anemic, antipyretic, antibacterial, anti-diabetic, antioxidative, anti-hypertensive, anti-obesity, detoxicant, antitumor,

hepato-protective and immunomodulatory properties [6, 7]. Beetroot can not only be consumed as a fresh vegetable, but also can be processed into canned, pickled, frozen and dehydrated products [8, 9].

Fresh beetroots are prone to spoilage due to high moisture content, and microbial and biochemical sensitivity to storage. Besides, the transportation cost of fresh beetroots is high, and it is easy to cause mechanical damage during transportation. Therefore, fresh beetroots are not suitable for long-distance transportation. So, it is necessary to process beetroots to reduce transportation costs and extend the storage period. Drying is one of the most commonly used processing methods. Drying can extend the shelf life of beetroots, reduce transportation and storage costs, and provide opportunities for the development of new products. Therefore, it is important to choose a suitable drying method to obtain high quality of dehydrated beetroots.

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## 2. Literature review and problem statement

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Drying is one of the most effective methods for food preservation. The removal of water will reduce the volume of the final product and decrease the availability of water for chemical, enzymatic and microbial reactions, thereby improving product stability, reducing transportation costs and facilitating storage [10]. It is well known that the drying process will lead to nutrient losses and change the raw material's chemical and physical properties. Thus, the selection of the most appropriate drying method mainly depends on the quality of the final products.

Although the most widely used method for drying agricultural products, hot air drying (HAD) has the disadvantages of long drying time, high energy consumption, browning effect, quality deterioration in color and texture, and possible nutrient loss [11]. Hot air drying equipment is relatively cheap and easy to operate, so it is widely used. Microwave drying (MD) is generally recognized for fast drying rate, short drying time, rapid process control, and fast switching [12]. However, microwave drying also has several shortcomings, such as uneven heating, textural damage, nutrient loss and limited penetration depth [13]. Vacuum drying (VD) is widely used in the drying of fruits and vegetables, which operates at lower pressure and lower boiling point of water. Therefore, the evaporation of water can be carried out at a lower temperature. This helps preserve the heat-sensitive components of food; meanwhile, the oxygen-deficient environment during vacuum drying prevents oxidative reactions [14]. The vacuum created by vacuum drying can make rapid and uniform removal of water from the material [15]. The study in [16] showed that pulsed vacuum drying enhanced the drying efficiency and quality of dried blueberries. The successive changes between atmospheric pressure and vacuum resulted in the enlargement and interconnection of pores that are beneficial to the moisture transfer in the initial stage of drying. Compared to hot air drying, pulsed vacuum drying can shorten drying time, better maintain total phenolics and total monomeric anthocyanins.

Any single drying method has its advantages and disadvantages, so it is necessary to consider combined drying methods. Combined drying refers to a composite drying technology in which two or more drying methods complement each other according to the characteristics of the materials [17]. A large number of studies on the combined drying of fruits and vegetables have been carried out. Previous literature has shown that the combination of microwave and hot

air drying is more suitable for the processing of agricultural products. In the study [18], two-stage intermittent microwave coupled with hot air (60 °C) drying (IM&AD) was used to dry carrot slices, and the results showed that the IM&AD displayed the lowest drying time with relatively low energy consumption and provided the best quality of final products with the best color appearance, highest rehydration ratio and highest  $\alpha$ - and  $\beta$ -carotene contents as compared to other four drying methods. The authors of [19] studied the drying characteristics and processing optimization of combined microwave and hot air drying of *Termitomyces albuminosus* mushroom. The optimal conditions of combined microwave and hot air drying were microwave density 2.0 W/g, moisture content 52 % at conversion point, and hot air temperature 57 °C, respectively. The obtained process parameters were helpful, effective, and suitable for the application of combined microwave and hot air drying technology to preserve good quality, especially for *Termitomyces albuminosus* mushroom. However, this combined microwave and hot air drying method has not been compared with other combined drying methods. In [20], *Rhodomyrtus tomentosa* berries were dried by the combined microwave-hot air drying (CD), hot air drying (HD) and microwave drying (MD). It was found that the hydration properties and oil holding capacity of CD berry powder were better than those of HD and MD ones. Furthermore, CD was beneficial to maintain the color, nutrition, and active ingredients of *Rhodomyrtus tomentosa* berry powder. The experimental design of this study was relatively simple, and there was no comparison between the CD and the combined microwave-hot air drying. Moreover, a combination of microwave vacuum drying (MVD) and air jet impingement drying (AJID) was proposed for drying apple slices. The result showed that combined AJID-MVD maintains the quality of apple slices better than MVD [21]. In the study [22], microwave vacuum drying (MVD) was combined with freeze drying (FD) to study the effect of drying processing on Huyou quality. MVD was used as pre-drying (MVD-FD), post-drying (FD-MVD) or pre-drying as well as post drying (MVD-FD-MVD) of FD to process Huyou fruit. The results showed that the combined drying in all cases significantly shortened the drying time of FD. FD-MVD gave significant advantages in increasing the contents of total phenol and flavonoid of Huyou extracts. MVD-FD samples had the same good color as FD samples. MVD-FD was the best in terms of the overall effect of maintaining product quality and reducing hygroscopicity in comparison with FD and MVD. The authors of [23] have developed combinations of hot air drying+explosive puffing drying (HAD+EPD) and freeze drying+explosive puffing drying (FD+EPD) to obtain pumpkin chips. The pumpkin chips obtained from FD+EPD showed the best texture properties, the highest rehydration ratio, the highest volumetric expansion and the lowest bulk density. Furthermore, FD+EPD products displayed the highest crispness as compared with HAD+EPD. In the paper [24], hot air drying (HAD), low-power intermittent microwave vacuum drying (LPIMVD), and high-power intermittent microwave vacuum drying (HPIMVD) were combined to dry taro slices. The result showed that taro slices dried by HAD+HPIMVD+LPIMVD showed high  $L^*$  value, ascorbic acid content, and suitable texture. Besides, the drying time was reduced by 62.5 % in comparison with IMVD+HAD. In the study [25], broccoli pieces were subjected to freeze drying (FD), hot air drying (HAD), microwave vacuum drying (MVD), vacuum drying (VD),

MVD combined with HAD (MVD+HAD), and MVD combined with VD (MVD+VD). The results demonstrated that MVD+HAD and MVD+VD led to higher retention of nutritional compositions, better antioxidant activity, and lower energy consumption than those of HAD.

According to literature reports, the drying methods of beetroots mainly include hot air drying [26], microwave convection drying [27], vacuum microwave drying [28], vacuum drying [29], freeze drying [30], vacuum belt drying [31], and appropriate combination of different drying methods. The paper [32] presented the combination of convective pre-drying and vacuum-microwave finish drying for drying beetroot cubes. This method significantly reduced the total drying time, decreased drying shrinkage compared with the convective method. Moreover, it provided a product of high antioxidant activity comparable to that obtained by FD. The authors of [33] proposed a two-stage combination of free convection, forced convection and microwave for drying red beetroot. The results showed that convection at 60 °C followed by microwave wattage 315 W/9 min leads to better preservation of betalains in comparison with convection drying at 50, 60 and 70 °C. This research required a special microwave oven with hot air convection and microwave functions. In the study [34], it was found that convective-ultrasound drying with pulse microwaves contributed to better color, higher betanin retention and attractive appearance compared with convective method without ultrasound and microwave drying. In addition, convective drying of red beetroots with intermittent microwaves and ultrasound was found to be a good alternative drying method. However, a special hybrid dryer was needed in this drying method. The paper [35] proposed microwave and ohmic heating pre-treatment and subsequent microwave-convection drying of red beetroot. The microstructure results showed that ohmic heating pretreatment coupled with microwave-convection drying was a mild hybrid heating treatment. The application of ohmic heating in beetroot drying is creative. New technologies such as drying by refractance window [36] and foam mat [37] were used to dry beetroots. However, the proper combination of traditional drying methods can achieve unexpected results. In the literature, there are rare studies on the effects of different microwave-assisted drying, especially different combinations of microwave drying and vacuum drying, combinations of microwave drying and hot air drying, on the quality properties of dried beetroots. So, we conducted different hybrid microwave-assisted drying to dry beetroots, exploring the effect of different combinations of microwave-assisted drying methods on the quality of beetroots, and looking forward to obtaining high-quality dried beetroots in this study.

### 3. The aim and objectives of the study

The aim of this study was to investigate the effects of different microwave-assisted drying methods on the quality characteristics of beetroots, and obtain high-quality dried beetroots with high bioactive compounds, antioxidant activity.

To achieve the aim, the following objectives were accomplished:

- to explore the physical properties (drying time, moisture content, hardness, color, and microstructure) of dehydrated beetroots prepared by different microwave-assisted drying methods;
- to determine the content of bioactive compounds (betalains, ascorbic acid and total flavonoids) in beet-

roots obtained using different microwave-assisted drying methods;

- to evaluate the antioxidant activity of beetroots dried by different microwave-assisted drying methods.

## 4. Materials and methods

### 4.1. Raw materials

Fresh beetroots (*Beta vulgaris* L.) used in this study were purchased from a local market in Xuzhou, Jiangsu, China. Before drying experiments, fresh beetroots were stored in a refrigerator at 4 °C. At the beginning of each experiment, fresh beetroots were rinsed with running water, peeled, and then cut transversely with a stainless steel slicer, and chopped into slices 65 mm in diameter and 4 mm in thickness.

### 4.2. Drying experiments

In this study, three drying devices were used to dry fresh beetroots, namely a microwave drying system (SAM-255, CEM Corporation, USA), a hot air drying oven (DHG-9245A, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China), and a vacuum drying oven (BPZ-6033B, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China).

In this study, seven different microwave-assisted drying techniques were designed and analyzed. Fresh beetroot slices (300 g) were spread evenly on the tray as a thin layer and dried by different microwave-assisted drying methods as below:

1. High-power microwave drying followed by low-power microwave drying (HMD+LMD): Fresh beetroot slices were dried at 650 W and then dried at 325 W in the above microwave drying system; the transition point of moisture content was 28.0 % on a wet basis (w.b.).

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

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

4. High-power microwave drying followed by hot air drying (HMD+HAD): Fresh beetroot slices were dried at 650 W the same as mentioned above, and then dried at 60 °C in the above hot air drying oven; the transition point of moisture content was 28.0 % on a wet basis (w.b.).

5. 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 same as mentioned above; the transition point of moisture content was 28.0 % (w.b.).

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

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

The moisture content transition point of beetroots was determined according to the results of the pre-experiment. The drying process was stopped when the moisture content of beetroot slices was less than 7.0 % (w. b.). All drying experiments were conducted in triplicate.

### 4.3. Methods of research of physical properties of beetroots

The moisture content (wet basis) of beetroots was determined by a moisture analyzer (HX204, Mettler Toledo Co. Ltd., Switzerland) at 105 °C until it reached the constant weight.

A texture analyzer (TA.XT PLUS, Stable Micro Systems Ltd., London, UK) fitted with a cylindrical probe (P/2) was used to determine the hardness of dried beetroots, using a TPA model. The parameters were as follows: test force using compression mode; pre-speed and test speed of 2 mm/s; post-speed of 10 mm/s and test distance of 10 mm; trigger force of 5.0 g. Eight measurements were performed for each sample and the average value was calculated.

Color parameters of beetroots were measured by a colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan). In order to ensure the uniformity of the sample color, fresh beetroots were mashed into pulp, and dried beetroots were grounded into powder to determine the color. Color parameters were expressed as  $L^*$ ,  $a^*$ , and  $b^*$  values, where  $L^*$  (brightness), ranging from 0 (black) to 100 (white),  $a^*$  (ranging between  $-a^*$ =greenness and  $+a^*$ =redness), and  $b^*$  (ranging between  $-b^*$ =blueness and  $+b^*$ =yellowness) [38]. Total color change ( $\Delta E$ ) indicates the magnitude of color change after drying and was calculated from formula (1) [38]:

$$\Delta E = \sqrt{(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2}, \quad (1)$$

where  $L^*$ ,  $a^*$ , and  $b^*$  are the values of dried beetroots;  $L_0^*$ ,  $a_0^*$ , and  $b_0^*$  are the values of fresh beetroots.

The micromorphology of dried beetroots was observed using a scanning electron microscope (SEM) (Quanta 450 FEG, FEI Nano Ports, USA). The SEM analysis was used to determine the damage degree of beetroot cells generated by different microwave-assisted drying methods. Dried beetroots were cut into thin slices and fixed on a copper tube with the cross-section upward, and then plated by gold through ion sputtering apparatus. The scanning was conducted at an accelerating voltage of 20 kV. The magnification was set at 500×

### 4.4. Extraction process of bioactive compounds in dried beetroots

Dried beetroots obtained by different microwave-assisted drying methods were grounded into powders (passed through a 60-mesh sieve). Beetroot powder (2.0 g) was placed in a 50-mL centrifuge tube, 20 mL of 50 % ethanol (v/v) was added, and then mixed for 5 min. The mixture was centrifuged at 5,000 rpm for 10 min using a centrifuge (L550, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China). After centrifugation, the supernatant was collected and the insoluble residue was extracted twice with 20 mL of 50 % ethanol (v/v). The combined supernatants were adjusted to 100 mL with 50 % ethanol (v/v). The extracts were stored at 4 °C until further analysis.

### 4.5. Determination of bioactive compounds in dried beetroots

A spectrophotometer (722, Shanghai Youke Instrument Co., Ltd, Shanghai, China) was used to determine the absorbance of the reaction solution by colorimetric methods.

Betalains are subdivided into betacyanins (red-violet color) and betaxanthins (yellow-orange color). The betalains

content of beetroot was determined colorimetrically according to the method given in [39]. The betalains content was expressed as milligrams per gram of dry weight (mg/g DW).

The content of ascorbic acid was determined by the colorimetric method using a detection kit (Nanjing Ji-an Cheng Institute of Bioengineering, Nanjing, China). The results were expressed as milligrams per 100 grams of dry weight (mg/100 g DW).

The determination of the total flavonoids content was carried out using the aluminum chloride colorimetric method [40] with slight modifications. A calibration curve was obtained using different concentrations (0–500 mg/L) of rutin. The results were expressed as milligrams of rutin equivalent per gram of dry weight (mg RE/g DW).

### 4.6. Methods for evaluating the antioxidant activity of beetroots

The ferric reducing antioxidant power (FRAP) assay was conducted by the method proposed in [41]. A calibration curve with trolox at concentrations of 0–600  $\mu$ mol/L was used. The results were expressed as milligrams of trolox equivalent per gram of dry weight (mg TE/g DW).

The 2,2'-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS) assay was modified from the method reported in [42]. Trolox with concentrations of 0–140  $\mu$ mol/L was used as the standard curve. The results were expressed as mg TE/g DW.

### 4.7. Statistical analysis

All experiments were conducted at least in triplicate and the results were expressed as mean  $\pm$  standard deviation (SD). SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA) was used to determine significant differences by one-way analysis of variance (ANOVA) followed by the Tukey's multiple range test. Values with different letters are significantly different at a 95 % confidence level ( $p < 0.05$ ). Figures were drawn using Origin 9.0 (Origin Lab, MA, USA).

## 5. Results of physical properties, bioactive compounds and antioxidant activity of beetroots

### 5.1. Effect of different microwave-assisted drying methods on the physical properties of dried beetroots

The drying time, moisture content, hardness of beetroots dried by different microwave-assisted drying methods are presented in Table 1.

In this study, the average initial moisture content of fresh beetroots was 89.5 % (w.b.), and the end point of the drying experiment was the moisture content of beetroots below 7 % (w. b.). The drying time refers to the time it takes to dry fresh beetroots to the final moisture content less than 7 % (w. b.). As it can be seen from Table 1, the drying time ranged from 67.0 to 308.0 min, which were significant differences in drying time under seven different microwave-assisted drying methods ( $p < 0.05$ ). It took only 67.0 min to dry fresh beetroot slices to the final moisture content for HMD, reduced by 24.7 % and 47.2 % as compared with the drying time for HMD+LMD (89.0 min) and LMD (127.0 min).

The drying time of HAD+LMD was 185.0 min, which was lower than that of HMD+HAD. The drying time of HMD+VD was higher than that of HMD+HAD, but lower than that of VD+LMD. Furthermore, the drying time of the three microwave drying methods (HMD+LMD, HMD and LMD) was less than that of four

combined drying methods (HMD+HAD, HAD+LMD, HMD+ VD and VD+LMD). VD+LMD exhibited the longest drying time (308.0 min) in comparison with other microwave-assisted drying methods. Short drying time can greatly save production costs and improve production efficiency.

The moisture content of dried product plays a vital role in safe storage and maintaining product quality. The moisture content of dried beetroots prepared by different microwave-assisted drying methods ranged from 6.17 to 6.48 % (w. b.). There was no significant difference in the moisture content of beetroots dried by different microwave-assisted drying methods ( $p>0.05$ ).

Texture is a very important quality property that affects food acceptance and is evaluated by hardness. As seen in Table 1, the hardness of dried beetroots obtained by different microwave-assisted drying methods ranged from 803.9 to 1332.0 g. Beetroots dried by HMD+HAD showed the maximum hardness value of 1332.0 g, whereas beetroots dried by HMD presented the lowest hardness value of 803.9 g, indicating that the texture of HMD beetroots was soft. HMD+LMD, HMD, LMD, HAD+LMD and VD+LMD had no significant effect on the hardness of dried beetroots ( $p>0.05$ ). In comparison with that of HMD beetroots, the hardness of the beetroots obtained by HMD+HAD and HMD+VD reached higher levels, indicating that the hot air drying and vacuum drying process significantly changed the texture profiles of the HMD beetroots ( $p<0.05$ ). The results showed that the hardness of dried beetroots obtained by HMD+HAD, HMD+VD was significantly higher than that of beetroots dried by HMD+LMD, HMD, LMD, HAD+LMD and VD+LMD.

Table 1

Drying time, moisture content, hardness of beetroots obtained by different microwave-assisted drying methods

Drying method	Drying time, min	Moisture content, % (w. b.)	Hardness, g
HMD+LMD	89.0±3.5 <sup>f</sup>	6.23±0.63 <sup>a</sup>	868.4 ±105.2 <sup>b</sup>
HMD	67.0±3.5 <sup>g</sup>	6.17±0.74 <sup>a</sup>	803.9±103.2 <sup>b</sup>
LMD	127.0±3.5 <sup>e</sup>	6.19±0.59 <sup>a</sup>	840.0±105.9 <sup>b</sup>
HMD+HAD	230.0±8.7 <sup>c</sup>	6.20±0.75 <sup>a</sup>	1332.0±109.2 <sup>a</sup>
HAD+LMD	185.0±6.2 <sup>d</sup>	6.29±0.76 <sup>a</sup>	932.6±118.2 <sup>b</sup>
HMD+VD	265.0±10.0 <sup>b</sup>	6.40±0.27 <sup>a</sup>	1237.7±81.2 <sup>a</sup>
VD+LMD	308.0±6.2 <sup>a</sup>	6.48±0.40 <sup>a</sup>	910.9±100.2 <sup>b</sup>

Note: Data are the mean±SD. Different superscripts in the same column indicate significant differences at  $p<0.05$  according to Tukey's test

Color is one of the important quality parameters of dried products. Color parameters of beetroots before and after drying are provided in Table 2.  $L^*$  value indicates the brightness of beetroots, which varied from 36.83 to 43.55. Fresh beetroots showed the lowest  $L^*$  value of 36.83, while beetroots dried by HMD+LMD showed the highest  $L^*$  value. The lower  $L^*$  value was obtained from the beetroots dried by HMD, which had a darker color than after other microwave-assisted drying methods. The color of beetroots after drying became significantly brighter ( $p<0.05$ ), meanwhile the beetroots after drying had significantly lower  $a^*$  and  $b^*$  values than those of fresh beetroots ( $p<0.05$ ). The decrease in  $a^*$  and  $b^*$  was due

to the degradation of pigments, such as betacyanin and betaxanthin. The  $a^*$  values of beetroots dried by different microwave-assisted drying methods ranged from 21.48 to 23.80. Compared with other microwave-assisted drying methods, the  $a^*$  value of beetroots obtained by VD+LMD was higher, which was closer to that of fresh beetroots. The  $b^*$  values of dried beetroots ranged between 2.09 and 3.82. Dried beetroots obtained by HMD+LMD showed a higher  $b^*$  value, which was close to that of fresh beetroots. Beetroots dried by HMD+HAD and HMD+VD had lower values of  $b^*$  than those of other microwave-assisted drying methods.

Table 2

Color parameters of beetroots affected by different microwave-assisted drying methods

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

Note: Data are the mean±SD (N=5). Different superscripts in the same column indicate significant differences at  $p<0.05$  according to Tukey's test

Beetroots dried by HMD+HAD had the lowest values of  $a^*$  and  $b^*$ . Beetroots dried by VD+LMD showed the lowest  $\Delta E$  value, while beetroots dried by HMD+HAD had the highest  $\Delta E$  value of 10.36. Moreover, beetroots dried by VD+LMD had the most desirable color among the beetroots dried by seven different microwave-assisted drying methods, with the lowest  $\Delta E$  and values of  $L^*$ ,  $a^*$  and  $b^*$  close to those of fresh beetroots. In addition, the worst color of beetroots was obtained by HMD+HAD, indicating that the different combinations of hot air drying and microwave drying had a great impact on the color of final dried products.

For a complete study of the effect of different microwave-assisted drying methods on the dried beetroots, the microstructure of dried beetroots was analyzed by scanning electron microscope (SEM). The microstructures of dried beetroots obtained by different microwave-assisted drying methods are exhibited in Fig. 1.

Different microwave-assisted drying methods had a great impact on the internal structure of dried beetroots. As shown in Fig. 1, beetroots dried by HMD+LMD, HMD and LMD had porous structures (Fig. 1, a–c), 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 [23]. However, beetroots dried by HMD+HAD and HAD+LMD demonstrated denser structures and collapse of the cell wall structure (Fig. 1, d, e), 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 (Fig. 1, f, g), resulting in negative effects on the texture of products.

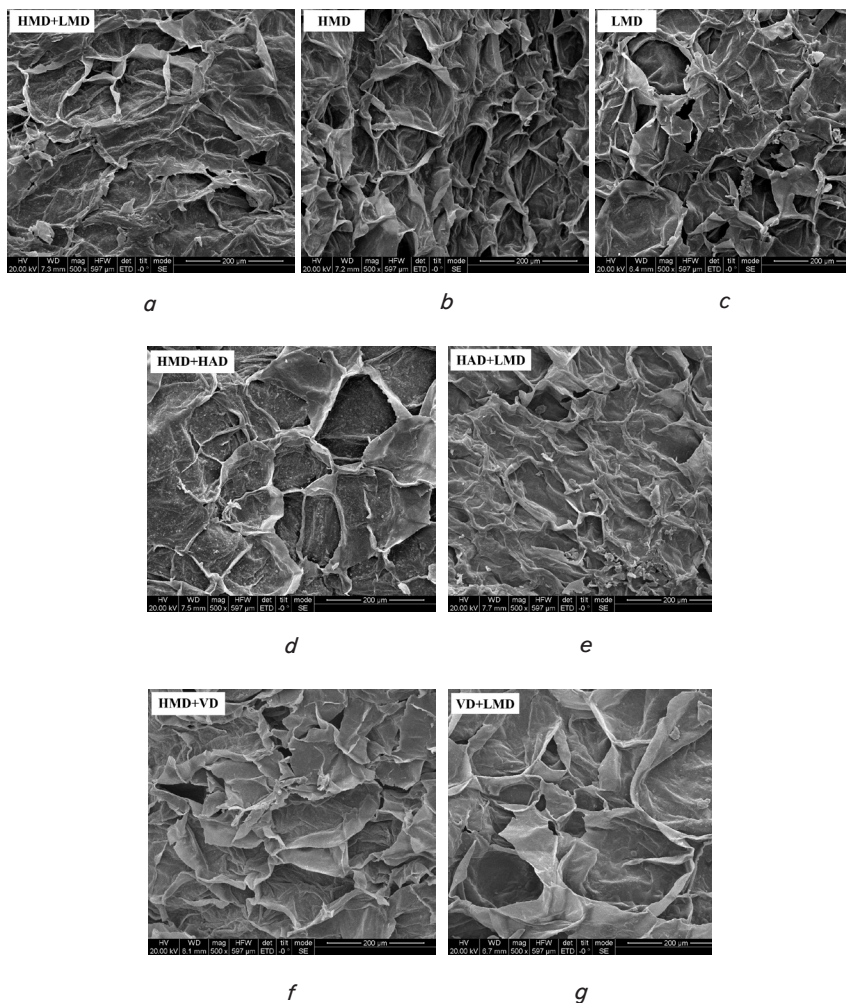


Fig. 1. SEM micrographs (500× magnification) of dried beetroots obtained by different microwave-assisted drying methods: a – HMD+LMD; b – HMD; c – LMD; d – HMD+HAD; e – HAD+LMD; f – HMD+VD; g – VD+LMD

**5. 2. Effect of different microwave-assisted drying methods on the bioactive compounds of dried beetroots**

The contents of betalains, ascorbic acid and total flavonoids of dehydrated beetroots are presented in Table 3. Beetroots contain a large number of betalains, which can be used as food colorants and food additives [43]. Betalains are water-soluble pigments including betacyanin and betaxanthin. The results showed that the betacyanin

content of beetroots obtained using VD+LMD was the highest (4.09 mg/g DW), while the minimum betacyanin content of 2.81 mg/g DW was observed in beetroots dried by LMD. The content of betaxanthin ranged from 2.43 to 3.45 mg/g DW. The betaxanthin content of beetroots obtained by VD+LMD was significantly higher than that of beetroots obtained by other microwave-assisted drying methods ( $p<0.05$ ). The lowest betaxanthin content of beetroots was 2.43 mg/g DW, which was obtained using LMD.

Ascorbic acid, as an important antioxidant, plays a variety of roles in the human diet. As observed in Table 3, the ascorbic acid content in the beetroots obtained by HMD was the highest (272.3 mg/100 g DW), followed by that of VD+LMD (265.4 mg/100 g DW) and HMD+LMD (262.1 mg/100 g DW). The lowest ascorbic acid content of beetroots obtained by HMD+VD was 222.1 mg/100 g DW. Compared with HMD+LMD and LDM, the beetroots dried by HMD had the highest ascorbic acid contents increased with the increase of microwave powers. A similar finding was reported in [44].

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 that the total flavonoids content of dried beetroots ranged from 12.76 to 16.74 mg RE/g DW. Beetroots dried by LMD (12.86 mg RE/g DW), HMD+HAD (12.91 mg RE/g DW) and HMD+VD (12.76 mg RE/g) exhibited lower total flavonoids content. Higher total flavonoids contents were observed in the beetroots dried by HMD+LMD (14.94 mg RE/g DW) and HAD+LMD (15.64 mg RE/g DW). Meanwhile, the beetroots prepared by VD+LMD showed the largest total flavonoids content of 16.74 mg RE/g DW.

Table 3

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

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

Note: Data are the mean±SD (N=3). Different superscripts in the same column indicate significant differences at  $p<0.05$  according to Tukey's test.

### 5.3. Effect of different microwave-assisted drying methods on the antioxidant activity of dried beetroots

Beetroots contain a wide variety of phytochemicals with antioxidant activity. The antioxidant activity of dried beetroots was evaluated by FRAP value and ABTS radical scavenging activity. Fig.2 shows the FRAP of dried beetroots affected by different microwave-assisted drying methods.

The FRAP in beetroots obtained by VD+LMD was the highest (14.95 mg TE/g), followed by that of HMD (14.70 mg TE/g DW) and HMD+LMD (14.38 mg TE/g DW), which were significantly higher than those of beetroots obtained by other microwave-assisted drying methods ( $p < 0.05$ ). HMD+VD beetroots gave the lowest FRAP value of 13.79 mg TE/g DW. It can be seen that the FRAP values of beetroots obtained by HMD and LMD were significantly different, while there was no significant difference in FRAP between LMD and HMD+HAD beetroots ( $p > 0.05$ ). There were significant differences ( $p < 0.05$ ) in the FRAP values of beetroots dried by different combinations of drying methods (HMD+HAD, HAD+LMD, HMD+VD and VD+LMD).

The results of the effect of different microwave-assisted drying methods on the ABTS radical scavenging activity of beetroots are provided in Fig. 3.

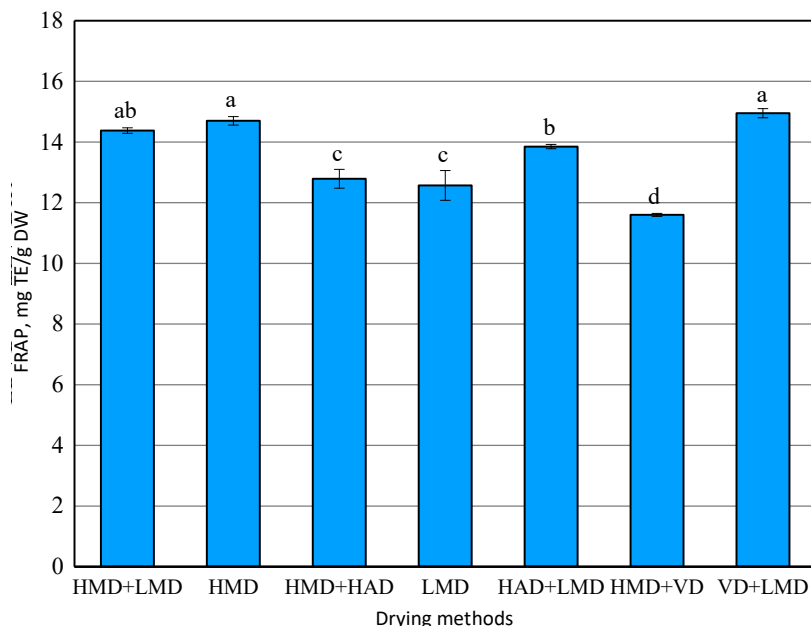


Fig. 2. Effect of different microwave-assisted drying methods on FRAP of beetroots. Different letters indicate that the mean values are significantly different at  $p < 0.05$

Beetroots dried by VD+LMD showed the highest ABTS radical scavenging activity equivalent to 16.92 mg TE/g DW, whereas the lowest ABTS radical scavenging activity value corresponding to 13.27 mg TE/g DW was obtained with HMD+HAD. As can be seen from Fig. 3, HMD+VD and HMD+HAD had no significant effect on ABTS radical scavenging activity of beetroots, and ABTS radical scav-

enging activities were significantly lower than those of other microwave-assisted drying methods ( $p < 0.05$ ). As a result, VD+LMD and HMD can well maintain the ABTS radical scavenging activity of dried beetroots.

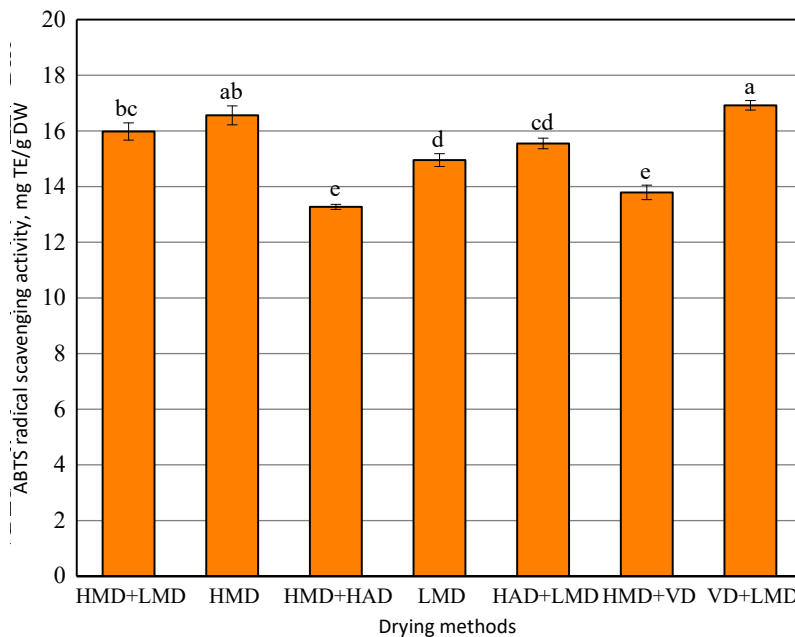


Fig. 3. Effect of different microwave-assisted drying methods on ABTS radical scavenging activity of beetroots. Different letters indicate that the mean values are significantly different at  $p < 0.05$

### 6. Discussion of the results of studying the influence of different microwave-assisted drying methods on the physical properties, bioactive compounds and antioxidant activity of beetroots

The results showed that single microwave drying methods (HMD+LMD, HMD and LMD) can better save drying time compared to four combined drying methods (HMD+HAD, HAD+LMD, HMD+VD and VD+LMD). Microwave drying can improve drying rates and reduce drying times. Importantly, time savings can be associated with significant savings in energy requirements. In the following work, it will be necessary to consider the energy consumption of different microwave-assisted drying methods. There was no significant difference in moisture content of beetroots obtained by different microwave-assisted drying methods, indicating that the effect of moisture content on the physicochemical properties and antioxidant activity of dried beetroots can be ignored.

It can be found from Table 1 that HMD+HAD and HMD+VD resulted in higher hardness than other microwave-assisted drying methods, indicating the firm texture of dried beetroots. The results of SEM showed that the beetroots dried by HMD+LMD, HMD and LMD had porous structures, without obvious cell damage. The porous structure in the dried product is conducive to decreasing

the hardness [24], so beetroots dried by HMD+LMD, HMD and LMD demonstrated lower hardness compared to that of beetroots prepared by other microwave-assisted drying methods (HMD+HAD, HAD+LMD, HMD+VD and VD+LMD). The formation of porous structures in microwave drying, which is due to the rapid surface drying effects, resulted in the formation of capillaries with less surface shrinkage [45]. It has been reported that heating and moisture loss exert pressure in the cell structure of the food, leading to changes and shrinkage of the microstructure. Meanwhile, the microstructure and porosity of dried products are related to the water migration mechanism and external pressure changes [46, 47].

The physical or chemical effects of many processes can damage or cause the loss of food color. Therefore, the color parameters of food are substantial attributes that determine the quality losses and the physical reflection of some chemical changes during processing [48]. Color is significant in the case of beetroots, which is valued particularly for the presence of betalains [45]. It can be seen from Table 2 that the  $L^*$  values of beetroots after drying were significantly higher than those of fresh beetroots, demonstrating that the color of dried beetroots became brighter over the drying process. Similar results were also found in [35, 37]. The  $a^*$  and  $b^*$  values of beetroots after different microwave-assisted drying methods decreased significantly compared to those of fresh beetroots (Table 2), which is consistent with the research reported in [7]. Beetroots dried by VD+LMD showed the lowest  $\Delta E$  value, while the beetroots dried by HMD+HAD had the highest  $\Delta E$  value, indicating that VD+LMD can better preserve the color of beetroots.

Drying processing will change the content of betalains and consequently the color of the product. The analysis of betalains showed that the beetroots obtained by VD+LMD exhibited the highest content of betacyanin and betaxanthin. Meanwhile, dried beetroots obtained using LMD showed the lowest content of betacyanin and betaxanthin, demonstrating a great degradation of betalains during LMD. It is well known that ascorbic acid is very susceptible to oxidation under certain conditions, such as heat, presence of oxygen, heavy metal ions and alkaline pH [7]. The result showed that HMD, HMD+LMD and VD+LMD had higher retention of ascorbic acid. This is possible thanks to the short drying time of HMD and HMD+LMD, and VD+LMD was kept away from oxygen at the first stage, thereby reducing the loss of ascorbic acid.

There were significant differences in total flavonoids content among different microwave-assisted drying methods ( $p < 0.05$ ). Beetroots prepared by VD+LMD and HAD+LMD showed relatively high total flavonoids content, which can be explained by the fact that the thermal treatment of beetroots resulted in the acceleration of the release of bound flavonoids, due to the breaking down of the cellular constituents, as well as the inactivation of endogenous oxidative enzymes, increased the total flavonoids content in beetroots [5]. There are many kinds of bioactive compounds in dried beetroots. We only considered several bioactive compounds (betalains, ascorbic acid and total flavonoids), however, other bioactive compounds, such as total polyphenols, carotenoids, saponins and nitrate, are also worthy of further study.

There are several evaluation methods for antioxidant activity. Antioxidants have different mechanisms, such as reducing capacity, decomposition of peroxides, free radical scavenging, and binding of transition metal ion catalysts [49, 50]. Choosing different methods can be expected to obtain differ-

ent antioxidant activity results, so as to better understand the wide variety and range of action of antioxidant compounds present in beetroots [51]. In this research, FRAP value and ABTS radical scavenging activity were used to evaluate the antioxidant activity of beetroots and similar results were observed from Fig. 2, 3. Beetroots dried by VD+LMD exhibited the highest FRAP value and ABTS radical scavenging activity. This meant that VD+LMD led to the strongest antioxidant activity of dried beetroots, which may be related to the presence of bioactive compounds, including total flavonoids, ascorbic acid and other non-nutrient phytochemicals in beetroots. In this study, we only used two methods to evaluate the antioxidant activity of beetroots. More comprehensive evaluation methods can be used in the future. In addition, the relationship between antioxidant activity and bioactive compounds, and how the bioactive compounds affect the antioxidant activity of beetroots need to be further investigated. The application of dried beetroots in food processing also needs further research.

Based on the physical properties, bioactive compounds and antioxidant activity of dried beetroots, it is proved that VD+LMD is a promising method for drying beetroots. The beetroots dried by VD+LMD can be used as functional food, as well as a natural coloring in the food processing industry. However, there are still some tasks that require further investigation in the future, such as which bioactive compounds are associated with the antioxidant activity of beetroots, and how these bioactive compounds affect the antioxidant activity of beetroots, etc. The disadvantage of this study is that we did not take into account the energy consumption and production costs of different microwave-assisted drying methods. This study could provide a theoretical basis for fresh beetroots processing, represent an important step for the transfer of the experiments from the laboratory scale to industrialization, and facilitate further development and application of dried beetroots.

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## 7. Conclusions

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1. In terms of physical properties, VD+LMD led to the longest drying time in comparison with other microwave-assisted drying methods. There was no significant difference in the moisture content of dried beetroots prepared by different microwave-assisted drying methods ( $p > 0.05$ ). The hardness of dried beetroots obtained by HMD+HAD and HMD+VD was significantly higher than that of other microwave-assisted drying methods ( $p < 0.05$ ). Dried beetroots showed significantly higher  $L^*$ , and lower  $a^*$  and  $b^*$  values than those of fresh beetroots. Beetroots dried by VD+LMD showed a desirable color with the lowest  $\Delta E$ . Dried beetroots prepared by HMD+LMD, HMD and LMD showed porous structures in dried beetroots. However, beetroots dried by HMD+HAD and HAD+LMD demonstrated denser structures and collapse of the cell wall structure. Besides, beetroots dried by HMD+VD and VD+LMD were found to have thin porous walls and a few large microscopic holes.

2. Different microwave-assisted drying methods can significantly affect the bioactive compounds of beetroots. Beetroots dried by VD+LMD displayed the highest content of betacyanin, betaxanthin, and total flavonoids, which were 4.09 mg/g DW, 3.45 mg/g DW, and 16.74 mg RE/g DW, respectively. Moreover, beetroots dried by LMD showed the lowest betacyanin content and betaxanthin content. In addi-



tion, beetroots dried by HMD exhibited the highest ascorbic acid content of 272.3 mg/100 g DW.

3. According to the antioxidant activity results, beetroots dried by VD+LMD showed the largest FRAP value and ABTS radical scavenging activity. In other words, VD+LMD led to the higher antioxidant activity of beetroots in comparison with other microwave-assisted drying methods. The dehydrated beetroots obtained by VD+LMD display strong antioxidant capacity, which can be used as an antioxidant in the food industry.

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