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RESEARCH OF PHYSICOCHEMICAL PROPERTIES AND ANTIOXIDANT ACTIVITY OF BEETROOTS AS AFFECTED BY VACUUM MICROWAVE DRYING CONDITIONS

The object of research is the beetroots, dried by vacuum microwave drying at different conditions. Physicochemical properties and antioxidant activity of beetroots were studied using vacuum microwave drying at different microwave power (500, 1000, and 1500 W), vacuum degree (-0.05 , -0.07 , and -0.09 MPa) and sample thickness (2, 4, and 6 mm). A colorimeter was used to evaluate the color quality of beetroots. Colorimetric methods were used to determinate contents of betalain, ascorbic acid and total flavonoid, and antioxidant activity (ferric reducing antioxidant power assay) of beetroots.

Results showed that the drying time decreased with increasing microwave power and vacuum degree, while increased significantly with the increase of sample thickness. The lightness (L^*) of dried beetroots was higher than that of fresh beetroots. The values of redness (a^*) increased with the increase of vacuum degree. The values of yellowness (b^*) increased with the growth of vacuum degree and microwave power, while reduced as the sample thickness added. The total color difference (ΔE) of dried beetroots reduced with increasing vacuum degree, and displayed the lowest value (5.95) at a vacuum degree of -0.09 MPa as compared to fresh beetroots. The content of betacyanin, betaxanthin and ascorbic acid displayed a declining tendency with the growth of microwave power, while increased with the increase of vacuum degree. And the total flavonoid content of beetroots illustrated a decreasing tendency with the increase of vacuum degree, microwave power and sample thickness. The ferric reducing antioxidant power (FRAP) of dried beetroots decreased significantly with the increase of microwave power, and showed the highest value (14.70 mg trolox equivalents/g) at a microwave power of 500 W.

The most favorable conditions for vacuum microwave drying of beetroots were microwave power of 500 W, vacuum degree of -0.09 MPa and sample thickness of 2 mm. It leads to better physicochemical properties and higher antioxidant activity of dried beetroots. The dried beetroots can be used as functional foods and value-added food products.

Keywords: dried beetroots, vacuum microwave drying, betalain, total flavonoid, colorimetric methods, antioxidant activity.

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1. Introduction

Beetroot (*Beta vulgaris L.*) is one of important root vegetables and rich in carbohydrates, protein, fat, betalains, ascorbic acid, carotenoids, polyphenols, flavonoids, saponins, nitrate, vitamins, minerals, and essential and non-essential amino acids [1]. Beetroot as a food source for humans is consumed fresh (salad, juice) as well as cooked, pickled, or canned all over the world [2]. Beetroot soup is a popular meal in Eastern Europe, and pickled beetroot is a traditional food of the South America. Nowadays a large proportion of beetroot is used for commercially pickles production [1]. Beetroot can also be used

as natural colorant, to coloring a variety of foods like candies, cheese, yogurts, ice cream, noodles, sausages, and pasta [3]. Beetroot contains a lot of bioactive compounds, which have many health benefits including antioxidant, antianemic, anti-hypertensive, antipyretic, antibacterial, anti-inflammatory, anti-diabetic, detoxicant, anticarcinogenic and hepato-protective activities, detoxicant, diuretic and wound healing benefits [4–6].

Vacuum microwave drying is one of novel technologies, an efficiently and gentle drying method. The intensive heating of microwave and low boiling point, generated by the vacuum, make the material to be dried at relatively low temperature over a short time, helping to maintain a high

level of healthy nutrition and sensory quality [7]. There are so many researches on vacuum microwave drying of vegetables and fruits, confirming to preserve color, total phenolic, total flavonoid, and ascorbic acid [8–10]. Fresh beetroots are exposed to spoilage due to its high moisture content. The drying of fresh beetroots can reduce moisture content and water activity, reducing microbial growth, chemical reactions, and enzymatic activity, as well as storage and transport costs [11].

The drying method and drying condition influence the physicochemical properties and antioxidant activity of the final product. Although vacuum microwave drying have been evaluated for drying application of foods, there are no researcher noticed in literature concerning to drying conditions on the physicochemical properties and antioxidant activity of beetroots. Therefore, *the aim of this study* was to investigate the influence of vacuum microwave drying conditions on the quality of beetroots in terms of drying time, color, total flavonoid content, betalain content, ascorbic acid content, and antioxidant capacity. Thus, *the object of research* is the beetroots, dried by vacuum microwave drying at different conditions.

2. Methods of research

Fresh beetroots were obtained from a local market in Xuzhou city, Jiangsu province, China. Ascorbic acid assay kit (Nanjing Jiancheng Institute of Bioengineering, Nanjing, China); Trolox, rutin, and tri-2-pyridyl-s-triazine (Shanghai yuanye Bio-Technology Co., Ltd, Shanghai, China); Ethanol (Tianjin Zhiyuan Chemical Reagent Co., Ltd, Tianjin, China).

The one-factor-at-a-time method was applied in this study to design experiments with three replications. Investigated factors include microwave power, vacuum degree and thickness. At the beginning of each experiment, fresh beetroots were washed and peeled, and then cut into slices with a diameter of 60 mm. Fresh beetroot slices (800.0 ± 5.0 g) were carefully placed on a tray ($610 \times 430 \times 50$ mm). The tray was put into a vacuum microwave dryer (WBZ-10, Guiyang Xinqi Microwave Industry Co., Ltd, Guiyang, China) for continuous dehydration at different microwave powers (500, 1000, and 1500 W), vacuum degrees (−0.05, −0.07, and −0.09 MPa) and sample thicknesses (2, 4, and 6 mm). Eight different microwave drying conditions are shown in Table 1. The average initial moisture content of beetroots was 90.1 %, and the drying process was stopped when the final moisture content of beetroots was below 7.0 % (wet basis), which was considered the final moisture ensuring safe storage.

Table 1

Vacuum microwave drying conditions for drying fresh beetroots

Treatment	Microwave power, W	Vacuum degree, MPa	Sample thickness, mm
T1	1500	−0.05	2
T2	1500	−0.07	2
T3	1500	−0.09	2
T4	500	0.08	2
T5	1000	0.08	2
T6	1500	0.08	2
T7	1500	0.08	4
T8	1500	0.08	6

In this study, the color parameters of beetroots were determined using a colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan). The CIE Lab color parameters were used to describe the color characteristics of beetroots. Value of L^* represents lightness, varies from 0 (black) to 100 (white); a^* refers to the region ranging from green ($-a^*$) to red ($+a^*$), and b^* ranges from blue ($-b^*$) to yellow ($+b^*$). The measurements were done 8 times for each sample. Total color difference (ΔE) indicates the magnitude of color change after drying and was calculated by Equation (1) [12].

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

where ΔE is the difference between the color of fresh beetroots and dried beetroots; L^* , a^* , and b^* are the color parameters of dried beetroots; L_0^* , a_0^* , and b_0^* are the color parameters of fresh beetroots.

Extraction of bioactive compounds. Dried beetroots were grounded, and then passed through a 60-mesh sieve to obtain sample powder. One gram of sample powder was mixed with 15 mL of 50 % ethanol (v/v) by a vortex mixer (VORTEX-5, Kylan-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China) for 2 min, and then the mixture was centrifuged at 5000 rpm for 10 min using a centrifuge (L550, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China). The supernatant was collected, and the residue was extracted twice with 15 mL of 50 % ethanol (v/v). Supernatants from the three extractions were mixed and diluted to 50 mL with 50 % ethanol (v/v), and then stored at 4 °C for further analysis.

The betalain content of beetroots was determined using the modified colorimetric method, reported in [13].

The ascorbic acid content was determined by the colorimetric method using a detection kit (Nanjing Jiancheng Institute of Bioengineering, Nanjing, China). The results were expressed as milligram per gram of dry weight.

The total flavonoid content was carried out using the aluminum chloride colorimetric method [14]. A calibration curve was obtained using different concentrations (0–1.0 mg/mL) of rutin. The results were expressed as milligram of rutin equivalent (RE) per gram of dry weight.

The antioxidant activity of dried beetroots was evaluated by the ferric reducing antioxidant power (FRAP) method. The FRAP assay was conducted by the method as described in [15]. Briefly, a FRAP reagent was prepared by mixing 0.01 M TPTZ solution (prepared in 0.04 M HCl), 0.02 M FeCl_3 solution and 0.3 M acetate buffer (pH 3.6) at the volumetric ratio of 1:1:10. The diluted extract (0.2 mL) was fully reacted with 6 mL FRAP reagent. After incubating at 37 °C for 10 min, the absorbance was measured at 593 nm using a visible spectrophotometer (722, Precision Scientific Instruments Co., Ltd, Shanghai, China). A standard curve was built by using a trolox solution as stand and the results were expressed as milligram of trolox equivalent (TE) per gram of dry weight (mg TE/g).

All experiments were conducted at least in triplicate and the results were expressed as mean \pm standard deviation. The analysis of variance (ANOVA) and Tukey's test were performed using SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA) to determine significant differences at 95 % level ($p < 0.05$). Figures were drawn using Origin 9.0 (Origin Lab, MA, USA).

3. Research results and discussion

3.1. The drying time of beetroots affected by vacuum microwave drying conditions. The drying time of beetroots at different vacuum microwave drying conditions are exhibited in Fig. 1. The drying time of vacuum microwave drying for beetroots ranged from 33.0 to 87.3 min. The beetroots, dried at a vacuum degree of -0.09 MPa (T3), showed the lowest drying time (33.0 min). Meanwhile, the dried beetroots, obtained at a microwave power of 500 W (T4), required the longest drying time (87.3 min). The drying time increased with sample thickness of beetroots, but decreased with the increase of microwave power and vacuum degree at the designed levels. As the vacuum degree increased from -0.05 to -0.09 MPa, the drying time of beetroots decreased from 40.3 to 33.0 min. The time to dry fresh beetroots reduced 43.0 % when microwave power increased double (from 500 to 1000 W), and when the microwave power was 1500 W, the drying time of beetroots was only 38.9 % of that at a microwave power of 500 W. The drying time of beetroots increased with increasing sample thickness of beetroots. When the sample thickness increases, the distance of internal moisture migration to the surface increases, and the drying time increases accordingly. The drying time was 34.0 min when the sample thickness of beetroots was 2 mm (T6), which was only 50.5 % of that of beetroots with a sample thickness of 6 mm (T8). In other words, as the sample thickness of beetroots increased from 2 to 6 mm, the drying time increased by 97.9 %.

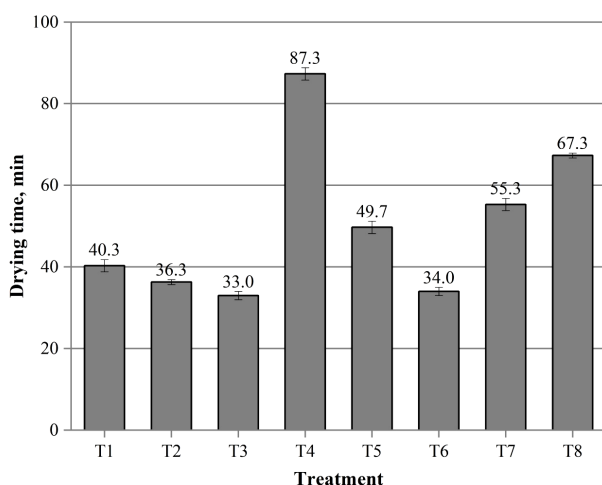


Fig. 1. Drying time of beetroots at different vacuum microwave drying conditions

In this study, higher microwave power and vacuum degree, and smaller sample thickness resulted in less drying time at the designed levels. Similar result has been reported on microwave-vacuum drying of kiwifruit slices [16].

3.2. Color parameters of beetroots. Color is one of important quality factors that affects consumers' acceptability for dried products. The color parameters of beetroots are shown in Table 2. The L^* values of dried beetroots were significantly higher than that of fresh beetroots ($p < 0.05$), demonstrating that dried beetroots are brighter than fresh beetroots. Similar results were also found for obtaining beetroot powder [17, 18]. The L^* values of dried beet-

roots differed among eight different drying conditions, with the L^* value of T5 samples (the beetroots, dried at a microwave power of 1000 W) being the highest (43.51), and that of T2 samples (the beetroots, dried at a vacuum degree of -0.07 MPa) being the lowest (39.86). The a^* and b^* values of all beetroots after vacuum microwave drying were significantly lower than that of fresh beetroots ($p < 0.05$). The value of a^* was found to increase with the increase of vacuum degree from -0.05 to -0.09 MPa. The beetroots, dried at -0.09 MPa (T3), showed the largest a^* value (23.97) among eight vacuum microwave drying conditions, while the beetroots with a sample thickness of 4 mm (T7) showed the lowest a^* value (21.05). There was a significant increase in b^* with the increase of vacuum degree ($p < 0.05$). The b^* value also increased with the increase of microwave power. The beetroots with a sample thickness of 4 mm (T7) displayed the lowest b^* value (2.48), while the beetroots, dried at a vacuum degree of -0.09 MPa (T3), showed the highest b^* value (3.72) among all the vacuum microwave drying conditions. The total color differences (ΔE) of dried beetroots was between 5.95 and 9.74 in comparison with fresh beetroots. It has been reported, that the ΔE parameters were between 5.06 and 13.39 for microwave vacuum drying of red beetroot samples [19]. The beetroots, dried at a vacuum degree of -0.09 MPa (T3), showed the lowest ΔE (5.95), while the beetroots with a sample thickness of 4 mm (T7) displayed the biggest ΔE . It has been reported, that the enzymatic reaction and Maillard reaction during the drying process were the main reasons for discoloration of materials [20]. During the vacuum microwave drying process, it can significantly prevent the enzymatic reaction and Maillard reaction, result in a good color characteristics.

Table 2

Color changes of dried beetroots affected by different vacuum microwave drying conditions

Treatment	L^*	a^*	b^*	ΔE
Fresh	37.52 ± 0.66^e	28.47 ± 0.63^a	6.02 ± 0.17^a	–
T1	41.26 ± 0.82^{bc}	22.77 ± 0.42^{cd}	2.70 ± 0.12^{de}	7.62 ± 0.57^c
T2	39.86 ± 0.89^d	23.23 ± 0.53^{bc}	3.00 ± 0.07^c	6.53 ± 0.63^{de}
T3	40.57 ± 0.76^{cd}	23.97 ± 0.41^b	3.72 ± 0.10^b	5.95 ± 0.42^e
T4	40.86 ± 0.90^{bcd}	22.87 ± 0.33^c	2.82 ± 0.09^{cd}	7.31 ± 0.29^{cd}
T5	43.51 ± 0.59^a	23.80 ± 0.38^b	3.51 ± 0.19^b	8.01 ± 0.51^{bc}
T6	40.59 ± 0.63^{cd}	23.37 ± 0.48^{bc}	3.56 ± 0.17^b	6.46 ± 0.58^{de}
T7	42.73 ± 0.53^a	21.05 ± 0.21^d	2.48 ± 0.12^e	9.74 ± 0.37^a
T8	42.15 ± 0.67^{ab}	21.97 ± 0.26^c	2.67 ± 0.10^{de}	8.67 ± 0.49^b

Note: in the same column, there are significant differences among those with different superscript letters ($p < 0.05$), and those with the same letters are not significantly different ($p > 0.05$)

As a result, beetroots, dried at a vacuum degree of -0.09 MPa (T3), had the most desirable color among the beetroots, dried at eight different vacuum microwave drying conditions, with the lowest ΔE and the values of L^* , a^* and b^* close to the fresh one, owing to the highest vacuum degree and the shortest drying time.

3.3. Bioactive compounds of dried beetroots. Contents of bioactive compounds in dehydrated beetroots, dried by different vacuum microwave drying conditions, are displayed

in Table 3. As we know, vacuum treatment can remove available oxygen or at low oxygen levels reduce pigment degradation better than under air atmosphere [19].

As shown in Table 3, betacyanin contents of dried beetroots increased significantly with increasing vacuum degree from -0.05 to -0.09 MPa ($p < 0.05$). It was also observed, that an increase in vacuum degree resulted in a significant increase in betaxanthin content ($p < 0.05$). It is well known, that betalain is sensitive to oxidation. Available oxygen removal under vacuum or under low oxygen levels results in decreased pigment degradation more than under air atmosphere. With an increase in microwave power from 500 to 1500 W, there was a significant decrease in betacyanin content ($p < 0.05$). There was also a decrease in betaxanthin content with the increase of microwave power. However, when the sample thickness of beetroots were 2 mm and 6 mm, there was no significant difference in contents of betacyanin and betaxanthin ($p > 0.05$). In conclusion, the highest contents of betacyanin (4.65 mg/g) and betaxanthin (3.34 mg/g) were found in the dried beetroots, obtained at a microwave power of 500 W (T4). The results showed that the content of betacyanin was the lowest (3.38 mg/g) in the beetroots, dried at a vacuum degree of -0.05 MPa (T1), while the lowest content (2.52 mg/g) of betaxanthin was observed in the beetroots with a sample thickness of 4 mm (T7).

Table 3

Bioactive compounds of beetroots dried by vacuum microwave drying conditions

Treatment	Betacyanin, mg/g	Betaxanthin, mg/g	Ascorbic acid, mg/g	Total flavonoid, mg RE/g
T1	3.38 ± 0.02 ^f	2.57 ± 0.01 ^d	7.30 ± 0.02 ^e	25.49 ± 0.57 ^b
T2	3.65 ± 0.02 ^e	2.79 ± 0.01 ^c	8.35 ± 0.09 ^c	22.37 ± 0.57 ^c
T3	4.09 ± 0.03 ^c	2.91 ± 0.01 ^b	8.70 ± 0.12 ^b	20.09 ± 0.91 ^d
T4	4.65 ± 0.03 ^a	3.34 ± 0.06 ^a	10.96 ± 0.04 ^a	28.34 ± 0.44 ^a
T5	4.29 ± 0.07 ^b	2.85 ± 0.04 ^{bc}	7.94 ± 0.12 ^d	26.04 ± 0.49 ^b
T6	4.02 ± 0.04 ^{cd}	2.82 ± 0.01 ^c	7.89 ± 0.06 ^d	25.92 ± 0.49 ^b
T7	3.44 ± 0.02 ^f	2.52 ± 0.01 ^d	6.77 ± 0.07 ^f	22.81 ± 0.98 ^c
T8	3.97 ± 0.00 ^d	2.83 ± 0.00 ^{bc}	8.69 ± 0.04 ^b	21.53 ± 0.24 ^c

Note: different superscript letters in the same column indicate significant differences ($p < 0.05$), and those with the same letters are not significantly different ($p > 0.05$)

Ascorbic acid has a low stability during the heat treatment, so it is an important indicator of food processing quality. It has been reported, that the drying process can cause significant loss of ascorbic acid content [20]. The ascorbic acid content of dried beetroots was clearly influenced by vacuum degree and sample thickness ($p < 0.05$). The ascorbic acid content of dried beetroots increased with a rise in vacuum degree from -0.07 to -0.09 MPa. There was no significant difference on the ascorbic acid content of beetroots, dried at a microwave power of 1000 W (T5) and 1500 W (T6) ($p > 0.05$). The highest ascorbic acid content (10.96 mg/g) was noted in dried beetroots, obtained at a microwave power of 500 W (T4), whereas the lowest ascorbic acid content (6.77 mg/g) was observed in beetroots with a sample thickness of 4 mm (T7).

A clear dependency between vacuum degree and total flavonoid loss was observed in beetroots, subjected to va-

cuum microwave drying. With an increase in vacuum degree from -0.05 to -0.09 MPa, there was a significant decrease in total flavonoid content ($p < 0.05$). It may be explained, that the degradation of betacyanin and betaxanthin lead to other flavonoid compounds. The beetroots, obtained at a vacuum degree of -0.09 MPa (T3), showed the lowest total flavonoid content, which was only 20.09 mg RE/g. The total flavonoid content of dried beetroots decreased with the increase of microwave power and sample thickness. The highest total flavonoid content (28.34 mg RE/g) of dried beetroots was appeared at a microwave power of 500 W (T4). An increase in microwave power led to a decrease in total flavonoid content. A similar result has been reported for microwave-vacuum drying of cranberries [21].

In this study, the beetroots, dried at a microwave power of 500 W (T4), showed the highest content of betacyanin, betaxanthin, ascorbic acid and total flavonoid.

3.4. Antioxidant activity of dried beetroots. Ferric reducing antioxidant power (FRAP) assay was selected to evaluate the antioxidant activity of dried beetroots, obtained at different vacuum microwave drying conditions, and the results are exhibited in Fig. 2.

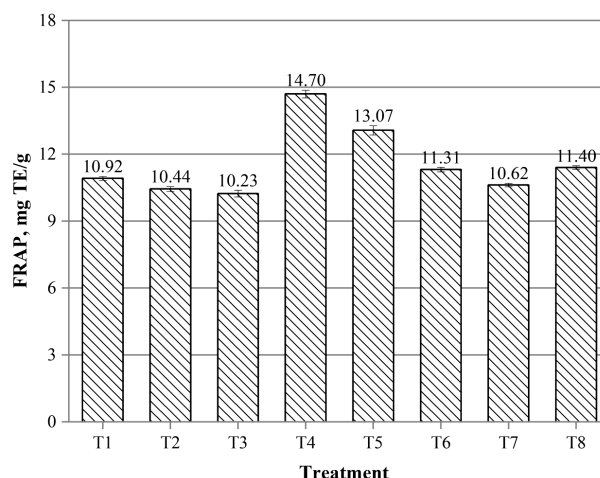


Fig. 2. FRAP values of dried beetroots affected by vacuum microwave drying conditions

The FRAP values of dried beetroots, obtained at different vacuum microwave drying conditions, were ranged from 10.23 to 14.70 mg TE/g. It can be seen, that FRAP decreased slightly with the increase of vacuum degree. The lowest FRAP of beetroots was obtained at a vacuum degree of -0.09 MPa (T3), which was only 10.23 mg RE/g. Meanwhile, FRAP values decreased significantly with the increase of microwave power ($p < 0.05$). It was clearly shown, that the dried beetroots, obtained at a microwave power of 500 W (T4), revealed the highest FRAP value (14.70 mg TE/g). The highest FRAP value, as well as contents of betalain, ascorbic acid and total flavonoid were found in the beetroots, dried at a microwave power of 500 W, indicating that ferric reducing ability was direct correlation to betalain, ascorbic acid and total flavonoid. The results are in agreement with the result of paper [21], who found that the increase in antioxidant activities of samples depends not only on the presence of betalains but also other polyphenols, which could have been increased during the treatments. Similar correlations were also reported in

other studies about drying cranberries and bitter melon [22–24]. As shown in Fig. 2, no significant difference was found in FRAP values of dried beetroots with different sample thickness.

The iron reduction antioxidant capacity (FRAP) of dried beets decreased significantly with increasing microwave power and showed the highest value (14.70 mg TE/g) at 500 W microwave power.

The most favorable conditions for vacuum microwave drying of beets were microwave power of 500 W, vacuum degree of -0.09 MPa, and sample thickness of 2 mm. This leads to better physicochemical properties of biologically active compounds and a higher antioxidant activity of dried beets. Dried beetroots can be used as a functional food in food technology.

In this study, only one method (FRAP assay) was used to evaluate the antioxidant activity of dried beetroots. More methods should be employed to evaluate the total antioxidant capacity due to the different mechanisms of antioxidants. Moreover, it is necessary to avoid high temperature and long time treatment in the processing of beetroots. Dried beetroots prepared by vacuum microwave drying have a strong antioxidant capability, which can be used as antioxidants in foods.

4. Conclusions

This study analyzes the influence of microwave power, vacuum degree and sample thickness on the physicochemical properties and antioxidant activity of beetroots. The drying time, color, contents of betalain, ascorbic acid and total flavonoid, and FRAP values of beetroots were analyzed.

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 decreased with increasing microwave power and vacuum degree, while increased significantly with the increase of sample thickness. The L^* values of dried beetroots were higher than that of fresh beetroots. The values of a^* were found to increase with the increase of vacuum degree. The values of b^* increased with the increase of vacuum degree and microwave power, while reduced as the sample thickness added. The ΔE of dried beetroots reduced with increasing vacuum degree, and showed the lowest value at a vacuum degree of -0.09 MPa. Contents of betacyanin and betaxanthin decreased with the growth of microwave power, while increased with the increase of vacuum degree. The ascorbic acid displayed an increasing tendency with the increase of vacuum degree, while decreased with the growth of microwave power. And the total flavonoid content of beetroots showed a declining tendency with the increase of vacuum degree, microwave power and sample thickness. FRAP values of beetroots decreased significantly with the increase of microwave power, and the highest FRAP value of dried beetroots was obtained at a microwave power of 500 W.

In conclusion, appropriate microwave power, vacuum degree and sample thickness were conducive to maintaining better physicochemical properties and antioxidant activity of dried beetroots. Considering the bioactive compounds and antioxidant activity of dried beetroots, fresh beetroots with a thickness of 2 mm, dried at a microwave power of 500 W and a vacuum degree of -0.09 MPa, were proposed as the favorable drying conditions. Dried

beetroots with high amount of bioactive compounds and strong antioxidant activity can be utilized as functional foods and value-added food products.

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