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Influence of vacuum microwave drying parameters on the physicochemical properties of red beetroots

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In recent years, the consumption of red beetroots has increased significantly due to its good taste, high nutritional value and abundant active compounds. Red beetroot is prone to spoilage due to its high moisture content, making it perishable. Vacuum microwave drying is a gentle drying method by inducing fast water evaporation from food products at low temperature, which can improve the product quality. The objective of this study was to investigate the effects of vacuum microwave drying parameters, including microwave power (500, 1000, and 1500 W) and vacuum degree (50, 70, and 90 KPa), on the physicochemical properties (drying time, rehydration ratio, color change, and contents of betalain and total phenolic) of red beetroots. The results showed that microwave power and vacuum degree had significant effects on the physicochemical properties of red beetroots. All the red beetroots after vacuum microwave drying had higher lightness (L^*), lower redness (a^*) and yellowness (b^*) than that of fresh red beetroots. The drying time, rehydration ratio, betacyanin content and betaxanthin content of red beetroots decreased significantly with the increase of microwave power ($P < 0.05$), while the rehydration ratio, color parameters (a^* , b^* , and chroma values), betacyanin content and betaxanthin content of red beetroots significantly increased with the increase of vacuum degree ($P < 0.05$). Compared with other microwave powers, the red beetroots dried at 500 W showed longer drying time, higher rehydration ratio, more yellowish hue, and higher contents of betacyanin and betaxanthin. The lowest values of total color difference (ΔE) and hue angle (H°) of dried red beetroots were obtained at microwave power of 1500 W. The dried red beetroots obtained at 90 KPa had the shortest drying time, the highest rehydration ratio, the best color, and the highest contents of betacyanin and betaxanthin. Meanwhile, the red beetroots dried at 50 KPa had the highest total phenolic content (12.47 ± 0.09 mg GAE/g). Based on the physicochemical properties of red beetroots, vacuum microwave drying at low microwave powers and high vacuum degree appears to be a suitable method for drying red beetroots.

Key words: red beetroots, vacuum microwave drying, betalain, color, microwave power, total phenolic.

Вплив параметрів вакуумної мікрохвильової сушки на фізико-хімічні властивості буряків

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В останні роки споживання червоного буряка значно зросло завдяки його хорошим смаковим якостям, високій харчовій цінності та великій кількості активних сполук. Червоний буряк схильний до псування через високий вміст вологи, що робить його швидкопсувним. Вакуумна мікрохвильова сушка – це щадний метод сушіння, який викликає швидке випаровування води з харчових продуктів при низькій температурі, що може покращити якість продукту. Метою цього дослідження було дослідити вплив параметрів

рів вакуумної мікрохвильової сушки, включаючи потужність мікрохвильової печі (500, 1000 та 1500 Вт) та ступінь вакууму (50, 70 та 90 КПа), на фізико-хімічні властивості (час висихання, регідратація) співвідношення, зміна кольору та вміст беталаїну та загального фенолу) буряків. Результати показали, що потужність мікрохвильової печі та ступінь вакууму мали значний вплив на фізико-хімічні властивості буряків. Усі червоні буряки після вакуумної сушки в мікрохвильовій печі мали вищу освітленість (L^*), нижчу червоність (a^*) та жовтоту (b^*), ніж свіжа червона буряк. Час висихання, коефіцієнт регідратації, вміст бетацианіну та вміст бетаксантину в червоному буряці значно змінилися із збільшенням потужності мікрохвильової печі ($P < 0,05$), тоді як коефіцієнт регідратації, параметри кольору (значення a^* , b^* та хроматичність), вміст бетацианіну та вміст бетаксантину в червоному буряку значно збільшилися зі збільшенням ступеня вакууму ($P < 0,05$). Порівняно з іншими потужностями мікрохвильової печі, червоний буряк, висушений при 500 Вт, показав більший час висихання, більший коефіцієнт регідратації, більш жовтуватий відтінок та більший вміст бетацианіну та бетаксантину. Найнижчі значення загальної різниці кольорів (ΔE) та кута відтінку (H°) сушеного червоного буряка були отримані при потужності мікрохвильової печі 1500 Вт. Висушені червоні буряки, отримані при 90 кПа, мали найкоротший час висихання, найвищий коефіцієнт регідратації, найкращий колір та найвищий вміст бетацианіну та бетаксантину. Тим часом червоний буряк, висушений при 50 кПа, мав найвищий загальний вміст фенолу ($12,47 \pm 0,09$ мг GAE/g). Виходячи з фізико-хімічних властивостей червоної буряка, вакуумне мікрохвильове сушіння при малих потужностях мікрохвильового випромінювання та високому ступені вакууму представляється відповідним методом сушіння червоної буряка.

Ключові слова: червоний буряк, вакуумна мікрохвильова сушка, бетален, колір, потужність мікрохвильовки, загальний фенол

Introduction

Drying is an effective method for preserving the quality of vegetables and fruits and works by applying heat to remove moisture (Madhava Naidu et al., 2016), which plays a vital role in prolonging shelf life of fresh perishable foods, reducing packaging costs as well as reducing the weight of transportation (Jin et al., 2018). Vacuum microwave drying or microwave vacuum drying is an efficiently and gentle drying process. The intensive heating of microwave and low boiling point generated by the vacuum make the material to be dried in a short time and at relatively low temperature, which helps to maintain a high level of healthy nutrition and sensorial quality (Scaman & Durance, 2005). Vacuum microwave drying has been widely used in drying vegetables and fruits, which confirming to preserve color, ascorbic acid, total phenolic, and total flavonoids (Hu et al., 2006; Tekgül & Baysal, 2019; Zienska & Zielinska, 2019).

Red beetroot (*Beta vulgaris* L.) is a highly nutritious and antioxidant-rich vegetable which is originated in Southern and Eastern Europe and Northern Africa (Oliveira et al., 2021). Nowadays, red beetroot is grown in a lot of countries all over the world and frequently consumed in daily life. Red beetroot is commonly consumed fresh as well as cooked, pickled, or canned (Paciulli et al., 2016), which is especially used as the main ingredient of borsch in Eastern Europe. Red beetroots are widely used as food colorant or additive in food products, such as yogurts, ice cream and other products, which can improve the redness in soups, jams, desserts, sauces, tomato pastes, jellies, sweets and breakfast cereals (Chhikara et al., 2019). Due to the high moisture content, fresh red beetroot is exposed to spoilage and normally dried to prevent the microbial growth, maintain the desirable quality and reduce the storage volume. Dried red beetroots can be consumed directly in the form of chips as a substitute of traditional snacks that are rich in fatty acids, or after easy preparation as a component of instant food (Krejčova et al., 2007).

During the vacuum microwave drying process, the physicochemical properties of red beetroots might be change. The aim of this study was to investigate the effect of vacuum microwave drying parameters, including microwave power and vacuum degree, on the physicochemical properties of red beetroots.

Material and Methods

Materials and reagents: Fresh red beetroots (obtained from a local market in Xuzhou city, Jiangsu province, China); Folin-Ciocalteu reagent and gallic acid (Shanghai yuanye Bio-Technology Co., Ltd, Shanghai, China); Ethanol (Tianjin Zhiyuan Chemical Reagent Co., Ltd, Tianjin, China); Sodium carbonate (Sinopharm Chemical Reagent Co., Ltd, Shanghai, China).

Test equipment: Microwave vacuum dryer (WBZ-10, Guiyang Xinqi Microwave Industry Co., Ltd, Guiyang, China); Moisture analyzer (HX204, Mettler Toledo Co., Ltd, Switzerland); Colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan); Centrifuge (L550, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China); Vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China); Visible spectrophotometer (722N, Shanghai Youke Instrument Co., Ltd, Shanghai, China); Electric thermostatic water bath (HWS-26, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China); Electronic balance (Sartorius Scientific Instruments Co., Ltd, Beijing, China).

Design of vacuum microwave drying: To investigate the physicochemical properties of red beetroots, a three-level factorial experimental design with two factors, namely microwave power and vacuum degree were constructed. The levels of microwave power were 500, 1000, and 1500 W, respectively, and vacuum degree were 50, 70, and 90 KPa, respectively. Before drying, red beetroots were stored in a refrigerator at 4 °C. At the beginning of each experiment, red beetroots were washed and peeled, and then cut into slices with diameter of 60 mm and thickness of 2 mm. Weighed slices of red beetroots (800.0 ± 2.0 g) were spread evenly on the tray (61 cm × 43 cm × 5 cm). Fresh red beetroots were dried to a final moisture content of below 7.0 % (wet basis). All drying experiments were conducted in triplicate.

Determination method of moisture content. The moisture content of red beetroots was determined by a moisture analyzer at 105 °C. The average initial moisture content of red beetroot was 90.07 ± 0.72 %.

Determination of rehydration ratio. Rehydration capacity was investigated following a previous report with minor modifications (Xu et al., 2019). Dried red beetroots (2.0 g) were put into 200 mL of distilled water at 80 °C for 15 min. The rehydrated beetroots were taken

out and absorbed the surface moisture with absorbent papers, and then weighed. The test was performed thrice. Rehydration ratio was calculated by Equation (1):

$$RR = \frac{W_2}{W_1} \quad (1)$$

Where, *RR* is the rehydration ratio; *W*₁ is the weight of dried red beetroots, g; *W*₂ is the weight of red beetroots after rehydration, g.

Determination of color parameters. The dried red beetroots and fresh red beetroots were grounded, and then measured color parameters. The color of red beetroots was measured by a colorimeter with CIE Lab system. Value of *L** represents lightness, varies from 0 (black) to 100 (white). The parameter *a** refers to the region ranging from green (-*a**) to red (+*a**). The parameter *b** refers to the region ranging 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 evaluated by Equation (2) (Caparino et al., 2012). Chroma (*C*) and hue angle (*H*^o) were calculated by Equation (3) and (4), according to (Pathare et al., 2013). *C* value ranges from 0 (dull) to 60 (vivid), while *H*^o changes from 0° (red), 90° (yellow), 180° (green) to 270° (blue).

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

$$C = \sqrt{a^{*2} + b^{*2}} \quad (3)$$

$$H^{\circ} = \tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (4)$$

*L**, *a**, and *b** are the values of dried beetroots, while *L*₀*, *a*₀*, and *b*₀* are the values of fresh beetroots. The values of the basic color parameters *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.

Extraction of betalains and phenolic compounds. Dried red beetroots obtained from triplicate were mixed, ground into powder, and then pass through a 80-mesh sieve to obtain samples with representative chemical components for particular drying conditions. 1.0 g of beetroot powder was put into a 50-mL centrifuge tube, and 15 mL of 50 % ethanol was added, and then mixed for 2 min by a vortex mixer. After centrifugation at 5000 rpm for 10 min, the supernatant was collected and the sample residue was extracted twice with 15 mL of 50 % ethanol. The combined supernatants were adjusted to 50 mL with 50 % ethanol, and stored at 4 °C for further analysis.

Analysis of betalain content. The betalain content of dried red beetroots was determined by a colorimetric method (Stintzing et al., 2005). Red beetroot extracts were diluted with 0.05 mol/L phosphate buffer solution (pH 6.5) to obtain absorption values of 0.8 ≤ *A* ≤ 1.0 at 538 nm, and the absorbance was read at 480 nm, 538 nm and 600 nm, respectively.

Determination of total phenolic content. Total phenolic content was determined by Folin-Ciocalteu method (Alvarez-Parrilla et al., 2011). Diluted red beetroot extracts (0.5 mL) were mixed with 2.5 mL of 10 % Folin-Ciocalteu's reagent (v/v), and then 2 mL of

7.5 % sodium carbonate (w/v) was added. The mixture was incubated for 15 min at 50 °C and cooled to room temperature, and the absorbance was recorded at 760 nm. Gallic acid with concentration of 0–0.1 mg/mL was used as the standard curve. Results were expressed as milligrams of gallic acid equivalent (GAE) per gram of dry weight.

Statistical analysis. All experiments were conducted at least in triplicate and results were expressed as mean ± standard deviation (SD). SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA) was used to determine significant differences among groups according to the Tukey test (*P* < 0.05). Figures were drawn using Origin 9.0 (Origin Lab, MA, USA).

Results and Discussion

1. Effect of microwave power on the physicochemical properties of red beetroots

In order to determine the influence of microwave power on the physicochemical properties of red beetroots, fresh red beetroots were dried at slice thickness of 2 mm and vacuum degree of 80 KPa, and microwave power ranged 500, 1000, and 1500 W.

Effect of microwave power on drying time and rehydration ratio of red beetroots are shown in Fig. 1. It can be seen that drying time decreased significantly with the increase of microwave power, and varied from 34 ± 1.0 min to 87.3 ± 1.5 min. The time to dry fresh red 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 was only 38.9 % of that the microwave power of 500 W.

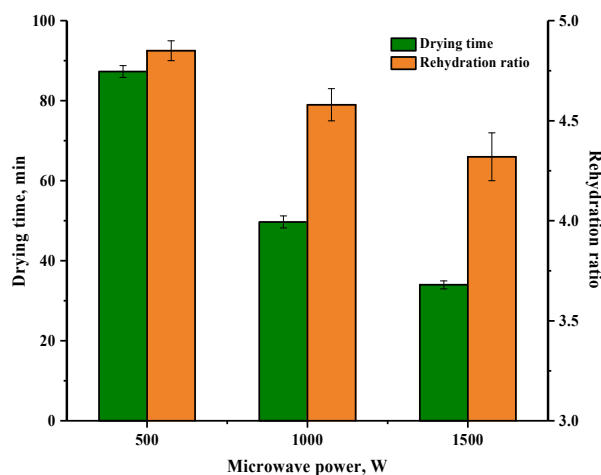


Fig. 1. Drying time and rehydration ratio at different microwave powers

The drying process will damage the cell structure of the sample. The more severe the cell structure damage, the lower the rehydration ratio. It was observed that rehydration ratio decreased as microwave power increased from 500 to 1500 W. The lowest rehydration ratio (4.32 ± 0.12) occurred when the microwave power was 1500 W, which meant that the microwave power of 1500 W had the greatest damage to the cell structure of red beetroots.

It can be seen in Table 1, L^* values of dried red beetroots were found to be higher than fresh red beetroots. The color of red beetroots became lighter after drying. Similar results were also found for obtaining beetroot powder (Ng & Sulaiman, 2018; Seremet et al., 2020).

The beetroots dried at microwave power of 1000 W showed the highest L^* value (43.44 ± 0.56), which had a lighter color than that of other microwave powers. There was no significant difference in L^* value at microwave power of 500 W and 1500 W. The a^* values of red beetroots dried by 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 red beetroots obtained at 1000 W was larger, representing a greater redness. The lowest b^* value (2.83 ± 0.08) was obtained from the red beetroots dried at microwave power of 500 W, which was significantly different from other microwave powers ($P < 0.05$).

The individual analysis of L^* , a^* and b^* parameters is no comprehensive enough to explain the color changes of red beetroots after drying. The chroma (C) value is a good illustration of the amount of color, distinguishing vivid and dull color (Abers & Wrolstad, 2006). The lower C

value of dried red beetroots at 500 W indicated lower saturation and a duller appearance compared with dried beetroots obtained at other microwave powers. H° values of dried red beetroots showed a slight decrease as the microwave power increased. The H° value of red beetroots dried at 1500 W was the lowest (6.52 ± 0.29), indicating that the red beetroots were much more red. During the different microwave powers the total color difference (ΔE) are between 6.46 ± 0.42 and 7.95 ± 0.33 in comparison with the fresh red beetroots. It was reported that the ΔE parameters were between 5.06 and 13.39 for microwave vacuum dried red beetroot samples (Székely et al., 2019). The red beetroots dried at 1500 W showed the lowest ΔE value, while the red beetroots dried at 1000 W had 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 red beetroots submitted to microwave power of 1000 W. Red beetroots dried at microwave power of 1500 W had the most desirable color, with the lowest ΔE , the lowest H° , and values of L^* , a^* and b^* were close to that of fresh red beetroots.

Table 1

Color changes of red 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
ΔE	7.35 ± 0.37^a	7.95 ± 0.33^a	6.46 ± 0.42^b

Note: Results are expressed as Mean \pm SD ($n = 8$). Different superscript letters in the same row indicate significant differences at $P < 0.05$ according to the Tukey test

Contents of betalain and total phenolic of red beetroots as affected by different microwave powers are exhibited in Table 2. As can be seen, betacyanin content decreased significantly with the increase of microwave power ($P < 0.05$). The highest content of betacyanin (4.65 ± 0.03 mg/g) was obtained from beetroots dried at microwave power of 500 W. Dried red beetroots obtained at 500 W showed the highest betaxanthin content (3.34 ± 0.06 mg/g) as compared to other microwave powers. It can be explained that energy radiation from microwave had the power to weaken polar bonds in a molecule, such as betalains, ascorbic acid and flavonoid compounds that have several polar bonds, and those bonds can vibrate dramatically under microwave

irradiation, which caused the bond rupture to induce chemical reactions (Dudley et al., 2015). There was no significant difference in betaxanthin content of red beetroots obtained at 1000 W and 1500 W ($P > 0.05$). As can be seen from Table 3, the total phenolic content of dried red beetroots ranged from 8.19 ± 0.08 to 11.37 ± 0.08 mg GAE/g. The red beetroots dried at 1000 W exhibited the lowest total phenolic content (8.19 ± 0.08 mg GAE/g), significantly lower than that of red beetroots dried at 500 W and 1500 W ($P < 0.05$).

As a result, the red beetroots dried at microwave power of 500 W showed higher betalain and total phenolic contents in comparison with other microwave powers.

Table 2

Impact of microwave power on betalain and total phenolic contents of red beetroots

Microwave power, W	Betacyanin, mg/g	Betaxanthin, mg/g	Total phenolic, mg GAE/g
500	4.65 ± 0.03^a	3.34 ± 0.06^a	11.26 ± 0.18^a
1000	4.29 ± 0.07^b	2.85 ± 0.04^b	8.19 ± 0.08^b
1500	4.02 ± 0.04^c	2.82 ± 0.01^b	11.37 ± 0.08^a

Note: Results are expressed as Mean \pm SD ($n = 3$). Different superscript letters in the same column indicate significant differences at $P < 0.05$ according to the Tukey test

2. Effect of vacuum degree on the physicochemical properties of red beetroots

To explore the effect of vacuum degree on the physicochemical properties of red beetroots, the experiments were carried at microwave power of 1500 W, and slice thickness of 2 mm. Three different levels of vacuum degree, namely, 50, 70, and 90 KPa, were investigated.

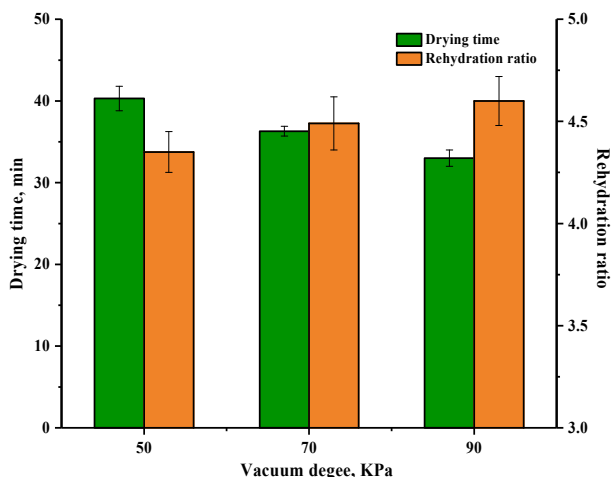


Fig. 2. Drying time and rehydration ratio at different vacuum degrees

Effect of vacuum degree on the drying time and rehydration ratio of red beetroots are illustrated in Fig. 2. The drying time of red beetroots decreased progressively with rising vacuum degree. It took only 33.0 ± 1.0 min to dry fresh red beetroots to the final moisture content (below 7.0 %) at vacuum degree of 90 KPa, reduced by 18.1 % and 9.1 % as compared with the drying time at vacuum degree of 70 KPa (36.3 ± 0.6 min) and 50 KPa (40.3 ± 1.5 min). As observed in Fig. 2, as vacuum degree increased, rehydration ratio of dried red beetroots gradually increased. Rehydration ratio of dried beetroots ranged from 4.35 ± 0.10 to 4.60 ± 0.12 with the increase

of vacuum degree from 50 to 90 KPa. This may be that as the vacuum degree increases, reduces the damage to the structure of the tissue, resulting in an increase in rehydration ratio.

Color parameters are very important properties that determine the quality losses and the physical refection of some chemical changes in the foods with the processing (Köprüalan et al., 2021). Table 3 shows the color parameters of red beetroots dried at different vacuum degrees. L^* , a^* and b^* values of dried red beetroots were found to be higher than that of fresh red beetroots. The highest L^* value (41.17 ± 0.90) of dried red beetroots was obtained at vacuum degree of 50 KPa, while the lowest value (38.62 ± 1.02) was obtained at vacuum degree of 70 KPa. Value of a^* was found to increase with the increase of vacuum degree. Red beetroots dried at 90 KPa showed the largest a^* value (23.99 ± 0.35). There was a decrease in yellowness (b^*) with an increase in vacuum degree. Significant difference ($P < 0.05$) was observed in b^* value of red beetroots dried by different vacuum degree. It was also observed that increasing vacuum degree significantly decreased C value of dried red beetroots ($P < 0.05$). C value of red beetroots dried at vacuum degree of 90 KPa was the highest (24.28 ± 0.35). It can be seen from Table 3 that values of H° and ΔE had the same trend, both decreased significantly with the increase of vacuum degree ($P < 0.05$). The H° values ranged from 6.39 ± 0.18 to 8.49 ± 0.34, indicating that all dried red beetroots were in purple-red range. The red beetroots obtained at vacuum degree of 90 KPa presented the lowest H° value (6.39 ± 0.18), indicating a more red hue. The highest ΔE value (5.90 ± 0.27) of red beetroots dried at vacuum degree of 90 KPa, while the lowest value (7.61 ± 0.37) was obtained at vacuum degree of 50 KPa,

As a result, the red beetroots dried at vacuum degree of 90 KPa showed a greater tendency towards red, yellow, greater color saturation, a more red hue and smaller total color difference in comparison with the red beetroots dried at other vacuum degrees.

Table 3

Color changes of red 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
ΔE	7.61 ± 0.37 ^a	6.20 ± 0.33 ^b	5.90 ± 0.27 ^c

Note: Results are expressed as Mean ± SD ($n = 8$). Different superscript letters in the same row indicate significant differences at $P < 0.05$ according to the Tukey test

The effect of different vacuum degrees on the betalain content and total phenolic content of red beetroots are given in Table 4. It was observed that betacyanin content and betaxanthin content increased significantly with the increase of vacuum degree ($P < 0.05$). The reason is that betalains are sensitive to exposure to high temperature and long-term processing. Therefore, the highest contents

of betacyanin (4.09 ± 0.03 mg/g) and betaxanthin (2.91 ± 0.01 mg/g) were observed in the red beetroots dried at vacuum degree of 90 KPa. The highest total phenolic content (12.47 ± 0.09 mg GAE/g) was determined in the red beetroots dried at vacuum degree of 50 KPa. It can be explained that the degradation of betacyanins leads to other phenolic compounds (Nistor et al., 2017). The

degradation of phenolics in red beetroots dried at 70 KPa and 90 KPa was higher than that of red beetroots dried at 50 KPa. There was no significant difference in total phenolic content between red beetroots dried at vacuum degree of 70 KPa and 90 KPa ($P > 0.05$).

Thus, it was found that the dried red beetroots obtained at 90 KPa showed higher betacyanin content and betaxanthin content, and lower total phenolic content.

Table 4

Impact of vacuum degree on betalain and total phenolic contents of red beetroots

Vacuum degree, KPa	Betacyanin, mg/g	Betaxanthin, mg/g	Total phenolic, mg GAE/g
50	3.38 ± 0.02 ^c	2.57 ± 0.01 ^c	12.47 ± 0.09 ^a
70	3.65 ± 0.02 ^b	2.79 ± 0.01 ^b	9.56 ± 0.11 ^b
90	4.09 ± 0.03 ^a	2.91 ± 0.01 ^a	9.64 ± 0.06 ^b

Note: Results are expressed as Mean ± SD ($n = 3$). Different superscript letters in the same column indicate significant differences at $P < 0.05$ according to the Tukey test.

Conclusion

This study analyzes the influence of microwave power and vacuum degree on the physicochemical properties of red beetroots. The results of this study revealed that microwave power and vacuum degree have significant effects on physicochemical properties of red beetroots. The drying time, rehydration ratio, betacyanin content and betaxanthin content of red beetroots decreased with the increase of microwave power, while the rehydration ratio, values of a^* , b^* and C , betacyanin content, and betaxanthin content of red beetroots increased with the increase of vacuum degree. In other words, low vacuum degree prolonged drying time, resulting in low rehydration ratio, more yellowish hue, larger total color change, and more loss in betacyanin and betaxanthin. The red beetroots dried at microwave power of 500 W showed longer drying time, higher rehydration ratio, more yellowish hue, higher contents of betacyanin and betaxanthin in comparison with other microwave powers. Meanwhile, the dried red beetroots obtained at vacuum degree of 90 KPa presented the shortest drying time, the highest rehydration ratio, the best color appearance, the highest contents of betacyanin and betaxanthin.

Based on the results, vacuum microwave drying at low microwave power and high vacuum degree seems to be the most suitable method for obtained dried red beetroots, in terms of physicochemical properties. Therefore, finding a suitable vacuum microwave drying parameters to retain the highest physicochemical properties of red beetroots is a multi-objective optimization problem.

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