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THE INFLUENCE OF DIFFERENT DRYING METHODS ON THE QUALITY ATTRIBUTES OF BEETROOTS

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Beetroot is recognized as a health-promoting vegetable due to its abundant source of bioactive compounds. Drying methods significantly influence the quality of products. Therefore, it is important to choose a suitable drying method to obtain high quality of dried beetroots. The aim of this research was to investigate the influence of different drying methods on the quality attributes of beetroots. Fresh beetroots were dehydrated by freeze drying (FD), heat pump drying (HPD), vacuum drying (VD), microwave drying (MD) and microwave vacuum drying (MVD), respectively. The drying time, final moisture content, rehydration ratio, color, microstructure, betalain content and total flavonoids content of beetroots prepared by different drying methods were analyzed. The results showed that MVD and MD were superior to VD, HPD and FD in terms of drying time. The drying time (0.77±0.03 h) of MD was reduced by 97.40 % compared with FD, which was only 9.83 % of VD and 11.27 % of HPD. No significant differences in the final moisture content among beetroots dried using different drying methods were observed. Beetroots dried by FD showed the most desirable color and porous structure. Besides, beetroots dried by MVD exhibited the largest rehydration ratio, while the lowest rehydration ratio appeared in the beetroots obtained using MD. In addition, beetroots prepared by HPD illustrated the highest contents of betacyanin, betaxanthin and total flavonoids, which were 5.48±0.03 mg/g, 2.40±0.02 mg/g and 24.71±0.47 mg rutin equivalent/g, respectively. These results identify that it is difficult to achieve the best quality dried beetroots using a single drying method. Therefore, considering the quality attributes, the combined drying method (HPD+MVD) would be a very promising alternative method for obtaining dehydrated beetroots

Keywords: beetroot, heat pump drying, rehydration ratio, total phenolic content, betalain

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1. Introduction

Beetroot (*Beta vulgaris L.*) is one of the most popular vegetables among many people in a lot of countries worldwide, which contains significant amounts of nutritious and bioactive compounds, such as betalains, phenolic compounds, carotenoids, ascorbic acids, flavonoids, alkaloids, coumarins, terpenoids, saponins, nitrates, volatile constituents and tannins [1]. In recent decades, there has been an increase in the research on using beetroot in disease prevention and health promotion. It has been reported that bioactive compounds in beetroots exhibit anticancer, anti-inflammation, antidiabetic, antioxidative, antiviral, anti-obesity, blood pressure and lipid lowering, and immunomodulatory activities [2]. Beetroot plays an important role in the diet of humans, provides the diet with color, phytochemicals, and nutrients. The average beetroot composition is water (88 %), carbohydrate (9.56 g/100 g), sugar (6.76 g/100 g), protein (1.16 g/100 g), fiber (2.80 g/100 g), fat (0.17 g/100 g), vitamin C (4.90 mg/100 g), and phytosterols (25.00 mg/100 g) [3].Statistics showed that the annual production of beetroots reached 307 million tons in 2017 [4]. Beetroot is consumed in raw and cooked form, and is rich in betalains pigment, which has been approved as a natural colorant E-162 by the European Union [5]. The betalains can be used in dry mixes, sweets, jam, and jellies, but are sensitive to various environmental and technological process conditions [6].

Fresh beetroot will deteriorate rapidly due to its high moisture content, continuous metabolism and microbial attack. Therefore, it is necessary to process the beetroot to prolong the storage period and reduce the loss. Drying is one of the most effective methods for food preservation, because removing water will reduce the volume of the final product and decrease the availability of water for chemical, enzymatic and microbial reactions, thereby improving the stability, transportation and storage of the product [7]. The use of drying technology to process fresh beetroots can not only extend the shelf life of beetroot, reduce transportation costs and storage costs, but also provide opportunities for the development of new beetroot products. However, it is very important to choose the proper drying method to obtain high-quality dehydrated beetroots.

2. Literature review and problem statement

A variety of drying methods are used in fruit and vegetable processing. As the best dehydration method for heat-sensible food, freeze drying (FD) involves high energy consumption, high equipment costs, and long drying time, which can only be used to produce high-value products [8]. Heat pump drying (HPD) is based on the inverse Carnot cycle principle, it could recover energy from the exhaust, improve the energy efficiency and independently control the drying temperature and air humidity [9], which is especially suitable for the retention of bioactive compounds in heat-sensitive vegetables and fruits, because the drying process can occur at a low temperature. In recent years, there have been many researches on the use of the HPD system to dry vegetables and fruits. In [10], the effects of different heat pump drying temperatures (45, 50, 55, 60 and 65 °C) on the color, active substances and volatile components of *Alpinia officinalis* were analyzed using sun-drying as the control approach. The results showed that *Alpinia officinalis* dried at 50 °C showed the highest rehydration rate of 2.39±0.03 and the rehydration ratio decreased with an increase in the heat pump drying temperature; Drying at 50 °C led to the highest contents of total phenols (19.33±0.21 mg/g) and flavonoids (8.44±0.19 mg/g). The content of galangin in *Alpinia officinalis* dried at 50 °C was 6.29±0.07 mg/g, and was higher than by sun-drying (5.54±0.1 mg/g). In the study [11], jujube slices dried by HPD presented a significantly lower color difference (ΔE) and shrinkage ratio than hot air drying. The authors of [12] studied the use of a heat pump with CO_2 as a working medium to provide heating and cooling in the drying cabinet for typical food drying temperatures of 50–70 °C and for various ratios of moist air being bypassed. In [13], banana slices were dried at different temperatures (37, 40 and 43 °C) in a closed-loop heat pump drying system. As the temperature and the slice thickness increased, the drying time also increased. It was found that Midilli & Kucuk model was the best model to explain the experimental data. According to various studies, the color and flavor quality of agricultural products dried by the HPD system were better than those dried by the conventional hot air dryer. Vacuum drying (VD) operates at lower pressure and the boiling point of water is lower, therefore, the evaporation of water can be carried out at a lower temperature, which 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]. Vacuum drying has been widely used in drying various fruits and vegetables. In the paper [16], artificial neural networks (ANNs) were used to predict celeriac drying curves in vacuum drying. The air temperature, chamber pressure and time values were used as ANN inputs. The multilayer feedforward backpropagation neural network was used to predict the moisture content. The network with the Levenberg-Marquardt learning algorithm, hyperbolic tangent sigmoid transfer function, and 3-6-9-1 topology offered superior results. In [17], the effect of pulsed electric fields (PEF) on the kinetics of vacuum drying (VD) of carrot and the preservation quality of dried carrot tissue was investigated. The authors of [18] investigated the effect of different drying methods (hot air drying, vacuum drying, ultrasound-assisted vacuum drying and freeze drying) on drying kinetics and quality of raspberry samples. USVD showed a significantly lower drying time than VD and HAD. FD had higher bioactive compound retention than other methods. In vitro bioaccessibility of the VD and USVD was higher than FD and HAD. USVD showed the lowest ΔE value. This study suggested that USVD could be used as an alternative drying method since it showed lower drying time and shrinkage, higher bioactive compounds, and color retention than VD and HAD. Microwave drying (MD) is widely used in the drying of agricultural products. It is generally recognized as fast drying rate, short drying time, rapid process control, and fast-switching [19]. However, MD causes uneven heating, textural damage, nutrient loss and limited penetration depth [20]. Microwave vacuum drying (MVD) is a modern, efficient and gentle method for food preservation. During the microwave vacuum drying process, the microwave energy is absorbed by water located in the whole volume of the material being dried, and large vapor pressure is generated in the center of the material, allowing rapid transfer of moisture to the surrounding vacuum and preventing structural collapse. Moreover, with the expansion phenomenon in the rapid dehydration process, the porous structure of food is formed, which helps to obtain a crisp and delicate structure, and reduces the density and shrinkage of the product [21].

According to literature reports, there have been various types of drying methods used in beetroot drying. The paper [22] presents the results of the influence of atmospheric, vacuum and microwave vacuum drying methods on the quality of dried beetroots. The results showed that the microwave vacuum method reduced the total time of drying and decreased the shrinkage compared to the other drying methods, and the combined method (hot-air at 60 °C followed by microwave vacuum finish drying) was the most suitable method to preserve the investigated parameters of dried beetroots in the highest amount. However, there are only three drying methods for drying beetroots in this study. The authors of [23] studied the influence of three drying methods, namely free convection (at 50, 60, and 70 °C), forced convection at 40 °C and 315 W microwave power, on the physicochemical properties of red beetroot. The results showed that convection at 60 °C followed by microwave wattage 315 W/9 min led to better preservation of bioactive compounds content, which meant combined drying methods led to significant preservation of the phytochemical content as compared to the traditional methods. In this research, only convection drying and microwave drying were taken into consideration. In the study [24], the red beetroot powders were prepared by tray-drying, freeze-drying, drum-drying, and continuous vacuum-belt drying. It was found that vacuum-belt drying could be used to produce a continuous stream of beetroot powder with good color and betalain content similar to that of freeze-dried products. However, the effects of microwave drying and microwave vacuum drying on the physicochemical properties of beetroot powders were not considered. There are few studies in the literature on the effect of different drying methods on the quality of dried beetroots. Therefore, we carried out different drying methods to dry beetroots, explored the impact of different drying methods on the quality attributes of beetroots, and expected to obtain high-quality dried beetroots in this study.

3. The aim and objectives of the study

The aim of this study was to evaluate the influence of different drying methods on the quality attributes of beetroots. This will make it possible to obtain high-quality dried beetroot products.

To achieve this aim, the following objectives are accomplished:

– to explore the drying time, final moisture content, rehydration capacity and color characteristics of dried beetroots prepared by different drying methods;

– to investigate the effect of different drying methods on the microstructure of dried beetroots;

– to evaluate the influence of different drying methods on the bioactive compounds (betalain content and total flavonoids content) of dried beetroots.

4. Materials and methods of research

4. 1. Raw materials

In this study, fresh beetroots were purchased from a farm in Xuzhou city, Jiangsu province, China. The fresh beetroots were washed, peeled, and cut into slices 75 mm in diameter and 4 mm in thickness. Rutin (purity≥98.0 %) was obtained from Shanghai Yuanye Bio-Technology Co., Ltd, Shanghai, China. All reagents used in this experiment were of analytical grade.

4. 2. Drying procedures

Freeze drying (FD): Fresh beetroot slices (300 g) were frozen at –20 °C for 12 h and then placed in the cavity in the freeze dryer (FDU-2110, Tokyo Rikakikai Co., Ltd, Tokyo, Japan) at 4 Pa. The condenser temperature was set at –80 °C.

Heat pump drying (HPD): Fresh beetroot slices (300 g) were spread evenly as a thin layer on a polyethylene tray (74×50×4 cm) of a heat pump dryer (L3.5AB, Guangdong IKE Industrial Co. Ltd, China). The temperature of heat pump drying was set at 60 °C.

Vacuum drying (VD): Fresh beetroot slices (300 g) were spread as a thin layer on a tray (31×29×2 cm) of a vacuum drying oven (BPZ-6033B, Shanghai Yiheng Scientific Instrument Co., Ltd, Shanghai, China). The vacuum degree was –95 kPa. The temperature of vacuum drying was set at 60 °C.

Microwave drying (MD): Fresh beetroot slices (300 g) were spread evenly as a thin layer on a circular fiberglass tray (30 cm in diameter) of a microwave drying system (SAM-255, CEM Corporation, USA). The microwave power of microwave drying was set at 390 W.

Microwave vacuum drying (MVD): Fresh beetroot slices (1,000 g) were placed uniformly on a tray (61×43×5 cm), and the tray was put into a microwave vacuum dryer (WBZ-10, Guiyang Xinqi Microwave Industry Co., Ltd, Guiyang, China). Microwave power of 1,000 W was investigated in microwave vacuum drying for beetroots at a constant vacuum degree of –90 kPa.

When the final water content of beetroots was lower than 6.00 % on a wet basis, all drying processes stopped. All drying experiments were repeated three times.

4. 3. Determination of moisture content

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 a constant weight. The average initial moisture content of fresh beetroots was 90.07±0.72 % (wet basis).

4. 4. Determination of rehydration ratio

Dried beetroots (2.0±0.1 g) were dipped in 200 mL distilled water in a 250 mL beaker. The beaker was placed in the water bath at 80 °C for 15 min [25]. The rehydrated beetroots were taken out, absorbed the superficial water with absorbent papers, and then weighed. Rehydration experiments were conducted at least in triplicate for each sample. Rehydration ratio (RR) was calculated according to formula (1):

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

where W_1 is the mass of dried beetroots, g; W_2 is the mass of beetroots after rehydration, g.

4. 5. Color determination

In order to ensure the uniformity of color, fresh beetroots were mashed into pulp and then determined, and dried beetroots were ground into powder to determine the color. Color parameters were measured using a colorimeter (CR-400, Konica Minolta Sensing, Inc., Tokyo, Japan) equipped with a D65 illuminant system and an 8 mm measuring area in the CIE L*a*b* scale. Color parameters were expressed as L^*, a^*, and b^*, where L^* indicates brightness of color, which ranges from 0 (black) to 100 (white), a^* ranges from – 100 (greenness) to 100 (redness), and b^* ranges from –100 (blueness) to 100 (yellowness). The measurements were done 8 times for each sample. Total color change (ΔE) indicates the magnitude of color change after drying, and was calculated by the formula (2) [26]:

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

where L^*, a^* and b^* are the values of dried beetroots; L_0^*, a_0^* and b_0^* refer to the values of fresh beetroots. Chroma (C^*) and hue angle ($h°$) were calculated according to formulas (3) and (4) [27]:

$$C^* = \sqrt{a^{*2} + b^{*2}}, \tag{3}$$

$$h° = \tan^{-1}\left(\frac{b^*}{a^*}\right), \tag{4}$$

where a^* and b^* are the values of dried beetroots prepared by different drying methods.

4. 6. Microstructure analysis

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 drying methods. Dried beetroots were cut into thin slices and fixed on a copper tube with the cross-section upward, and then plated with gold through an ion sputtering apparatus. The scanning was performed at an accelerating voltage of 20 kV. The magnification was set at 500×.

4. 7. Preparation of sample extracts

Dried beetroots were ground into powder (passed through a 60-mesh sieve). Sample powder (1.0 g) was dissolved in 15 mL of 50 % ethanol (v/v), and then fully mixed by a vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China) for 2 min. The homogenate was centrifuged using a centrifuge (H1850, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China) at 5,000 rpm for 10 min. After centrifugation, the supernatant was collected, and the precipitate was extracted two more times with 15 mL of 50 % ethanol (v/v). The supernatants obtained from three extractions were combined and diluted to 50 mL with 50 % ethanol (v/v). The extracts were stored at 4 °C until further analysis.

4. 8. Determination of betalain content

Betalain is a natural water-soluble nitrogen-containing pigment, which consists of two main groups: red-violet betacyanin and yellow betaxanthin [28]. The betalain content was determined using the colorimetric method as described in [29]. The extract was diluted with 0.05 mol/L phosphate buffer solutions (pH 6.5) to obtain an absorbance reading between 0.8 and 1.0 at 538 nm, and then the absorbance of the diluted extract was measured at 480, 538 and 600 nm. The betalain content was expressed as milligrams per gram of dry weight.

4. 9. Determination of total flavonoids content

The total flavonoids content of dried beetroot was determined using a modified colorimetric method [30]. Diluted sample extract (0.5 mL) was mixed with 30 µL of 5 % $NaNO_2$ solution (w/v), then allowed to stand for 5 min. Thereafter, 30 µL of 10 % $AlCl_3$ solution (w/v) was added and mixed for 6 min. Finally, 0.4 mL of 1.0 M NaOH solution and 40 µL of distilled water were added. The mixture was allowed to stand at room temperature for 15 min. The absorbance was read at 510 nm using a visible spectrophotometer (722, Shanghai Youke Instrument Co., Ltd, Shanghai, China). A calibration curve was obtained using different concentrations (0–1.0 mg/mL) of rutin. Results were expressed as milligrams rutin equivalent (RE) per gram of dry weight.

4. 10. Statistical analysis

The results were expressed as mean±standard deviation. Analysis of variance (ANOVA) and Duncan's multiple range test were performed using SPSS Statistics Version 20 (IBM Corporation, Chicago, IL, USA) to determine significant differences at a 95 % level ($p<0.05$). Figures were drawn by Origin 9.0 (Origin Lab, MA, USA).

5. Results of the quality attributes of beetroots prepared by different drying methods

5. 1. Influence of drying methods on drying time, final moisture content, rehydration capacity and color parameters of beetroots

The drying time of beetroots influenced by different drying methods is displayed in Fig. 1.

The drying time required by FD to reach the final moisture content (below 6.00 %) was the longest of 29.67±0.58 h. MD and MVD were much faster drying methods than FD, VD and FD. Significant differences ($p<0.05$) in drying time were noted among different drying methods, except VMD and MD. The shortest drying time (0.77±0.03 h) was required for MD to reach the final moisture content, while the drying time for VMD was 1.09±0.01 h and was very close to MD. This indicated that the drying time was significantly reduced as a microwave was used. The drying time of MD was reduced by 97.40 % compared to FD, which was only 9.83 % that of VD and 11.27 % that of HPD. The drying time required for MVD was about 3.67 % of FD time, and reduced up to 84.04 % and 86.08 % in comparison with HPD and VD, respectively.

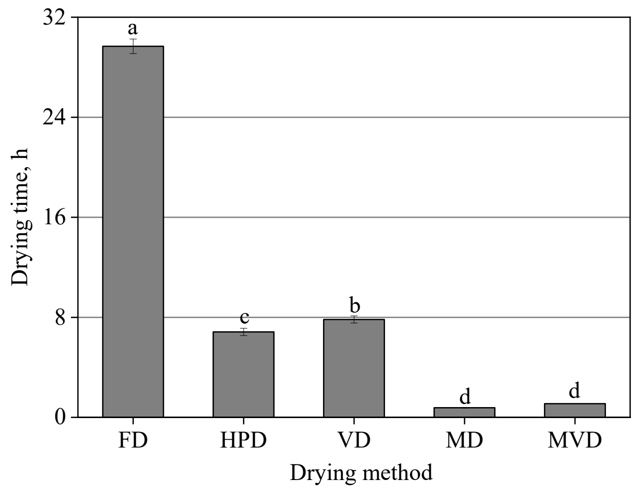

Fig. 1. Drying time of beetroots affected by different drying methods, different letters indicate significant differences at $p<0.05$ according to Duncan's multiple test

It is well known that moisture content is essential for the quality control and stability of dried products. Table 1 shows the final moisture content of dried beetroots. According to the results, the final moisture content ranged from 4.31±0.61 to 5.44±0.68 %. Dried beetroots prepared by VD and FD had slightly lower final moisture content compared to that of MD, HPD and MVD. There were no significant differences ($p>0.05$) in the final moisture content among all beetroots dried by different methods.

Table 1

Moisture content of dried beetroots affected by different drying methods

Drying method	Final moisture content, %
FD	4.31±0.61^a
HPD	4.64±0.78^a
VD	4.41±0.81^a
MD	4.82±0.60^a
MVD	5.44±0.68^a

Note: Same superscript letters in the same column indicate that the mean values are not significantly different

Drying process usually leads to irreversible changes in the structure and restricts the material from restoring its original shape. Rehydration capacity is one of the major quality parameters of dried products, which can indicate the ability of the material to maintain its original shape and reflect the damage degree of cell material during drying [31]. The effect of different drying methods on the rehydration ratio of beetroots is presented in Fig. 2.

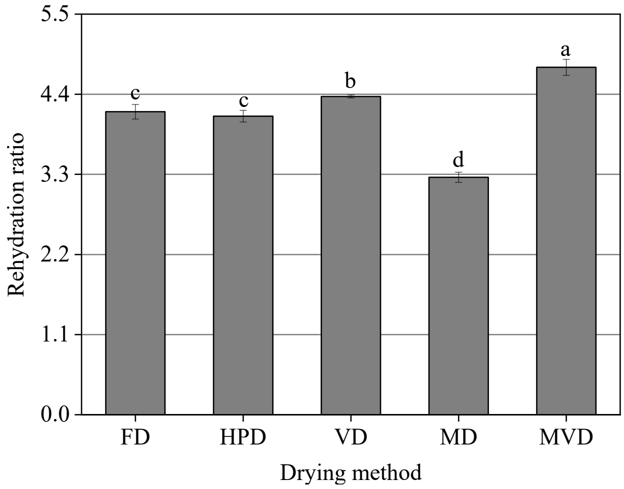

Fig. 2. Rehydration ratio of dried beetroots affected by different drying methods, different letters indicate that the mean values are significantly different at $p<0.05$

It was observed that the rehydration ratio of dried beetroots ranged from 3.26±0.07 to 4.77±0.11 for different drying methods. The difference was not statistically significant ($p>0.05$) between the rehydration ratio of the beetroots dried by FD and HPD. As shown in Fig. 2, the MVD beetroots had a significantly higher ($p<0.05$) rehydration ratio than that of beetroots prepared by other drying methods. Meanwhile, the lowest rehydration ratio (3.26±0.07) appeared in the beetroots dried by MD, indicating the most severe damage to the cell structure of the beetroots.

The color of dried food has a great impact on the quality and acceptability of the product by consumers [32]. Color parameters of beetroots affected by drying methods are presented in Table 2.

Table 2

Color parameters of beetroots prepared by different drying methods

Drying method	L^*	a^*	b^*	C^*	$h°$	ΔE
Fresh beetroot	$37.54±0.69^d$	$28.62±0.61^a$	$6.09±0.20^a$	$29.27±0.63^a$	$4.63±0.11^e$	–
FD	$43.52±0.62^a$	$27.76±0.68^b$	$4.02±0.16^b$	$28.05±0.66^b$	$6.88±0.39^d$	$6.43±0.53^c$
HPD	$39.65±0.53^c$	$21.92±0.69^d$	$1.07±0.08^f$	$21.94±0.69^d$	$20.60±0.98^a$	$8.65±0.68^a$
VD	$41.00±0.60^b$	$25.46±0.45^c$	$1.95±0.11^e$	$25.53±0.46^c$	$13.07±0.61^b$	$6.28±0.46^c$
MD	$41.82±0.91^b$	$21.94±0.44^d$	$3.49±0.24^c$	$22.22±0.43^d$	$6.26±0.43^d$	$8.38±0.66^a$
MVD	$40.97±0.99^b$	$22.79±0.33^d$	$2.93±0.13^d$	$22.98±0.33^d$	$7.75±0.69^c$	$7.50±0.69^b$

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)

The L^* values of dried beetroots ranged from 39.65±0.53 to 43.52±0.62, where the lowest value was in beetroots dried by HPD and the highest value using FD. There were no significant differences in L^* values among the beetroots prepared by VD, MD and MVD. Obviously, it can be seen that the L^* values of beetroots after drying were significantly higher than that of fresh beetroots, demonstrating that the color of dried beetroots turned brighter after the drying process.

The a^*, b^* and C^* values of beetroots after different drying methods were decreased significantly ($p<0.05$) in comparison with fresh beetroots. The decrease of a^* and b^* values might be due to the degradation of pigments. The a^* values of dried beetroots prepared by different drying methods ranged from 21.92±0.69 to 27.76±0.68, and the beetroots obtained by FD showed the largest a^* value of 27.76±0.68 among all the beetroots obtained by five drying methods. It is noted in Table 2 that the b^* values of beetroots dried by different drying methods varied significantly ($p<0.05$). The highest b^* value (6.68±0.35) was obtained from beetroots dried by FD, while the lowest b^* value of beetroots was obtained by HPD. The C^* values of dried beetroots varied from 21.94±0.69 to 28.05±0.66. The beetroots prepared by HPD displayed the lowest C^* value of 21.94±0.69, indicating the smallest saturation and the dullest appearance, while the beetroots prepared by FD showed the highest C^* value among all the dried beetroots. C^* of beetroots decreased after drying, resulting in a lower saturation and a duller appearance.

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

As a result, dried beetroots prepared by FD showed the most ideal color with the highest values of L^*, a^*, b^* and C^*, and relatively lower $h°$ and ΔE as compared with the beetroots dried by other drying methods.

5. 2. Influence of drying methods on the microstructure of dried beetroots

In order to comprehensively study the effect of different drying methods on the quality of beetroots, the microstructure of dried beetroots was analyzed by scanning electron microscope (SEM). The results are displayed in Fig. 3.

The beetroots dried by FD displayed a porous structure with thin pore walls, indicating that FD played an active role in maintaining the porous cellular structures of beetroot tissue. Compared with FD beetroots, the beetroots dried by HPD had thicker pore walls and denser structures, which was due to the shrinkage and collapse of cells during water evaporation. During the process of MD and MVD, rapid moisture evaporation caused the microscopic holes, so similar to FD beetroots, the beetroots dried by MVD and MD also had porous structures. The VD beetroots were found with thin porous walls and a few large microscopic holes, resulting in negative effects on the product texture.

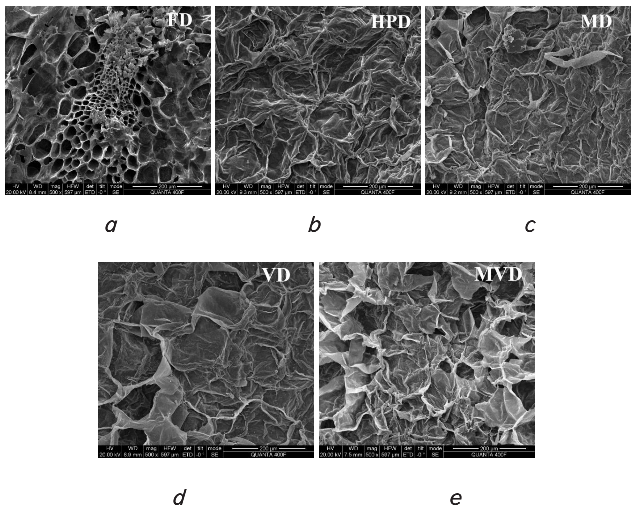

Fig. 3. Microstructure (500× magnification) of dried beetroots prepared by different drying methods: *a* — FD; *b* — HPD; *c* — MD; *d* — VD; *e* — MVD

5. 3. Influence of drying methods on the betalain content and total flavonoids content of dried beetroots

Beetroots have a high content of betalains, which can be used as food colorants and food additives [33]. Drying processing changes the content of betalains and consequently the color of the products. The influence of different drying methods on the betalain content of dried beetroots is presented in Fig. 4.

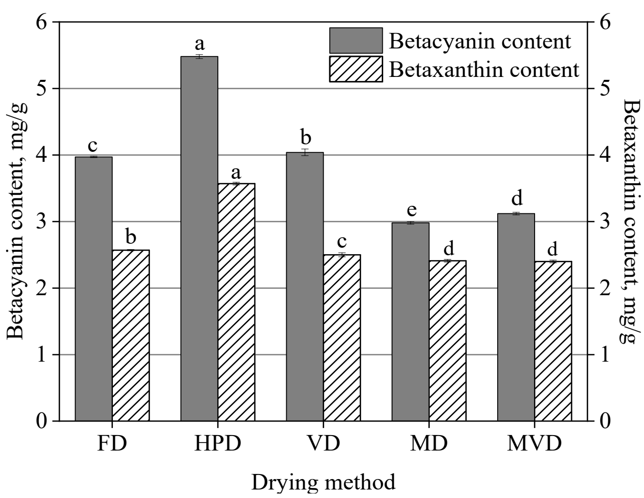

Fig. 4. Betalain content of dried beetroots prepared by different drying methods, different letters indicate significant differences at $p<0.05$ according to Duncan's multiple test

As shown in Fig. 4, different drying methods significantly affected the betacyanin content of dried beetroots ($p<0.05$). The betacyanin content of dried beetroots obtained using different drying methods ranged from 2.98±0.02 to 5.48±0.03 mg/g. Meanwhile, the betaxanthin content of dried beetroots prepared by different drying methods ranged from 2.40±0.02 to 3.57±0.20 mg/g. It is worth noting that the beetroots prepared by HPD illustrated the greatest betacyanin content of 5.48±0.03 mg/g and the highest betaxanthin content of 3.57±0.20 mg/g, demonstrating that HPD played a remarkable role in the betalains preservation during drying. The lowest betaxanthin content (2.40±0.02 mg/g) of dried beetroots was observed in MVD, and no significant difference was observed in betacyanin content between MVD and MD ($p>0.05$).

Flavonoids are bioactive compounds in beetroots with numerous health benefits. The influence of different drying methods on the total flavonoids content of beetroots was investigated and the results are displayed in Fig. 5.

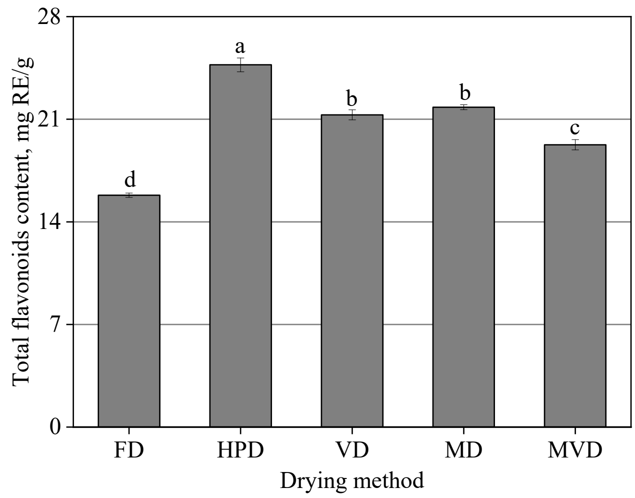

Fig. 5. Total flavonoids content of dried beetroots prepared by different drying methods, different letters indicate significant differences at $p<0.05$ according to Duncan's multiple test

The results showed that the beetroots prepared by HPD displayed the highest total flavonoids content of 24.71±0.47 mg RE/g, followed by MD, VD, MVD, and FD beetroots of 21.82±0.17, 21.30±0.34, 19.26±0.35, and 15.82±0.15 mg RE/g, respectively. Beetroots prepared by VD and MD showed relatively higher total flavonoids content than that of FD and MVD, and there was no significant difference in total flavonoids content between VD and MD ($p>0.05$). Besides, FD led to the lowest content of total flavonoids in dried beetroots.

6. Discussion of the results of the study of quality attributes of beetroots prepared by different drying methods

This research evaluated the effects of different drying methods on the changes in quality attributes, including physical properties, microstructure, bioactive compounds of beetroots. Based on the current research results, it is concluded that different drying methods have a profound impact on the quality attributes of beetroots.

The results showed that MD and MVD can better save drying time compared to FD, VD and FD. MD and MVD can improve drying rates and reduce drying time, while also reducing energy requirements significantly. In the following study, it is necessary to consider the energy consumption of different drying methods. There was no significant difference in the moisture content of dried beetroot obtained by different drying methods, indicating that the effect of moisture content on the quality of dried beetroot was negligible.

The color of food is determined by natural pigment compounds that can be degraded or oxidized during the pre-treatment and drying process, many parameters can influence the color rendering of the final products, such as drying method, drying time, temperature, and oxygen [34]. It can be found that the L^* values of beetroots after drying were significantly higher than that of fresh beetroots, demonstrating that the color of dried beetroots turned brighter over the drying process. Similar results were also found in beetroot powder [35, 36]. The a^*, b^* and C^* values of beetroots after different drying methods were decreased significantly ($p<0.05$) in comparison with those of fresh beetroots. This color change trend was consistent with the results in [37].

The C^* value is a good illustration of the amount of color, representing vivid and dull color [38]. The C^* values of dried beetroots prepared by different drying methods ranged from 21.94±0.69 to 28.05±0.66, which were close to the range (21.33–30.62) reported by Kerr and Varner for the beetroot powders [39]. The beetroots dried by FD and VD had no significant difference in ΔE and showed lower values than that of beetroots dried by MVD, MD and HPD. The beetroots dried by HPD showed the highest ΔE, indicating that HPD led to the greatest changes in color.

It has been reported that the porous microstructure of the FD sample was formed by ice sublimation in the vacuum environment without cell shrinkage and external force collapse [40]. The beetroots dried by HPD had thicker pore walls and denser structures, which was due to the shrinkage and collapse of cells during water evaporation. A similar phenomenon occurred in the drying of apple peel [41]. Heating and moisture loss make pressure in the cell structure of the food, resulting in changes and shrinkage of the microstructure. At the same time, the microstructure and porosity of the dried products are related to the water migration mechanism and changes in external pressure [42, 43].

The contents of betacyanin (2.98±0.02–5.48±0.03 mg/g) and betaxanthin (2.40±0.02–3.57±0.20 mg/g) of dried beetroots obtained using different drying were higher than the range proposed in [44] for seven beetroots varieties: 2.3±0.2–3.9±0.5 mg/g for betacyanin content, and 1.5±0.2–2.4±0.3 mg/g for betaxanthin content. The results showed that the beetroots prepared by different drying methods varied from 15.82±0.15 to 24.71±0.47 mg RE/g, which were significantly lower than the range proposed by Hamid and Nour [45] of sun-dried, oven-dried and freeze-dried beetroots with the values of 34.74±0.54, 33.28±0.72 and 36.11±0.95 mg RE/g, respectively. The greatest total flavonoids content was observed in HPD beetroots, which can be explained by the fact that the thermal treatment of beetroots resulted in the acceleration of the release of bound flavonoid compounds because of the breaking down of the cellular constituents, as well as the inactivation of endogenous oxidative enzymes increased the flavonoid content in the beetroots [5]. There are so many kinds of bioactive compounds in beetroots, two bioactive compounds (betalain and total flavonoids) were considered in this study. However, other bioactive compounds such as total phenolic, ascorbic acid, carotenoids, nitrates and saponins are also worthwhile further research.

The limitations of this study are that this research is only in the laboratory small-scale experiment stage and the experimental design was based on the existing equipment in the laboratory. Therefore, if the research results are applied to actual production, the differences in equipment need to be considered, and further experimental verification is required. In addition, the cost of different drying equipment was not considered in this research, and the cost is a crucial consideration in actual production.

7. Conclusions

1. It has been shown that MVD and MD were significantly better than other drying methods in shortening the drying time. There was no significant difference in the final moisture content of dried beetroots prepared by different methods ($p>0.05$). Beetroots obtained by MVD showed the highest rehydration ratio of 4.77±0.11. The color results indicated that beetroots prepared by FD displayed a better color appearance.

2. According to the microstructure results, the beetroots prepared by FD, MD and MVD displayed porous structures, while the beetroots dried by HPD had denser structures. Moreover, the beetroots obtained using VD had thin porous walls and a few large microscopic holes.

3. In terms of bioactive compounds, different drying methods can significantly affect the bioactive compounds of beetroots. The beetroots dried by HPD exhibited the highest contents of betacyanin, betaxanthin and total flavonoids, which were 5.48±0.03 mg/g, 3.57±0.20 mg/g and 24.71±0.47 mg RE/g, respectively.

Considering the quality attributes and drying time, the combined drying methods (HPD+MVD) may guarantee high quality of beetroots and a short drying time. This study could provide a theoretical basis for the processing of fresh beetroots, and facilitate the further development and application of dried beetroots.

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