Effect of microwave-assisted drying methods on the physicochemical properties of beetroots

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Abstract. In this study, fresh beetroots were dried by five different microwave-assisted drying methods, including high-power microwave drying followed by low-power microwave drying (HMD—LMD), high-power microwave drying followed by hot-air drying (HMD—HD), hot-air drying followed by low-power microwave drying (HD—LMD), high-power microwave drying followed by vacuum drying (HMD—VD), and vacuum drying followed by low-power microwave drying (VD—LMD). After drying, moisture content, color, and rehydration ratio as well as betalains and total phenolic contents of the dried beetroots were investigated. The drying time of each microwave-assisted drying method was also investigated. As for drying time, HMD—LMD lasted 46.0 min compared to VD—LMD which lasted 308.0 min. HD—LMD took 185.0 min less than HMD—HD (230.0 min) and HMD—VD (265.0 min). The beetroots obtained by VD—LMD showed the best color appearance, the highest betalain content and total phenolic content, but its drying time was the longest and rehydration ratio was the lowest. The beetroots obtained using HD—LMD showed the highest rehydration ratio. Considering physicochemical properties of dried beetroots and economics, HD—LMD is a recommended and suitable drying method.

1. Introduction
Beetroot (Beta vulgaris L.) is a root vegetable, originated in Europe and Asia [1]. Beetroot contains a variety of bioactive compounds, such as flavonoids, phenolic compounds, betalains, saponins, carotenoids, ascorbic acid and nitrate [2]. Fresh beetroot is very easy to deterioration due to its high moisture content. It has been reported that beetroot has many potential therapeutic effects, including antioxidative, antihypertensive, anticancer, anti-obesity, lipid lowering, cognitive improvement, anti-inflammatory, and antidiabetic [3].

Drying is one of most widely used methods for preservation of fresh vegetables and fruits, which can prevent microbial spoilage and deterioration reactions and allow their use during off-season [4].

Although as the most widely used method for dehydration of agricultural products, hot-air drying (HD) has the disadvantages of high drying temperature and long drying time, which leads to reduced dehydration capacity, flavor and nutritional value of the product, and changes color [5]. Vacuum drying is available for drying fruits and vegetables. The pressure created by vacuum drying helps to evaporate water at lower temperatures [6], which is suitable for drying heat sensitive materials. Vacuum drying can prevent oxidation reactions and raw material degradation caused by high
temperature [7]. Microwave drying is an efficient drying method that can enhance heat and mass transfer [8], but it is easy to cause hot spots, product overheating, and undesirable changes in quality [9]. Microwave drying is usually used in combination with other drying methods, including vacuum, hot-air and freeze drying, to achieve the purpose of uniform and effective drying without significantly losing quality [10].

Any single drying method has its advantages and disadvantages, so it is necessary to consider the combination of existing drying methods[11]. A lot of studies have reported the use of combined drying technologies, such as a combination of HD and intermittent microwave to dry carrot slices, while showed the shortest drying time and relatively low energy consumption, and provided the best final product quality [12], and a method of combining microwave vacuum drying (MVD) combined with air jet impingement drying (AJID) was used to dry apple slices while maintaining the quality of apple slices better than that obtained by MVD [13].

This research proposed a method to improve the physicochemical properties of beetroots by applying microwave-assisted drying. The purpose of this research is to evaluate the influence of different microwave-assisted drying methods on physicochemical properties (Moisture content, color, rehydration capacity, contents of betalains and total phenolic) of beetroots.

2. Materials and Methods

2.1. Materials
Fresh beetroots (Beta vulgaris L.) were obtained from a local farm in Xuzhou, China. Before drying, beetroots were stored in a refrigerator at 4 °C. At the beginning of each experiment, the whole fresh beetroots were washed by running water. The washed beetroots were peeled and then cut transversely with a stainless steel slicer, chopped into round slices with thickness of 2 mm and diameter of 65 mm.

2.2. Drying experiments
The average initial moisture content of fresh beetroots was 89.51% on a wet basis (wb). The beetroot slices were dried by different microwave-assisted drying methods until the final moisture content was under 7.00% (wb). About 300 g of fresh beetroot slices were spread evenly on the tray and dried by different microwave-assisted drying methods as below:

- **High-power microwave drying followed by low-power microwave drying (HMD—LMD):** The fresh beetroot slices were dried at 650 W and then dried at 325 W in a microwave drying system (SAM-255, CEM Corporation, North Carolina, USA); the transition point of moisture content was 28% (wb).
- **High-power microwave drying followed by hot-air drying (HMD—HD):** The fresh beetroot slices were dried at 650 W in the above microwave drying system and then dried at 60 °C in a hot-air drying oven (DHG-9245A, Yiheng Scientific Instrument Co., Ltd, Shanghai, China); the transition point of moisture content was 28% (wb).
- **Hot-air drying followed by low-power microwave drying (HD—LMD):** The fresh beetroot slices were dried at 60 °C in the hot-air drying oven as mentioned above and then dried at 325 W in the microwave drying system as described above; the transition point of moisture content was 28% (wb).
- **High-power microwave drying followed by vacuum drying (HMD—VD):** The fresh beetroot slices were dried at 650 W and then dried at 60 °C in a vacuum drying oven (DZF-6050B, Yiheng Scientific Instrument Co., Ltd, Shanghai, China); the transition point of moisture content was 28% (wb).
- **Vacuum drying followed by low-power microwave drying (VD—LMD):** The fresh beetroot slices were dried at 60 °C in the vacuum drying oven as described above and then dried at 325 W in the microwave drying system as described above; the transition point of moisture content was 28% (wb).
2.3. Moisture content
Moisture content was measured by a moisture analyzer (HX204, Mettler Toledo Co. Ltd., Switzerland). The samples (2-5 g) were put into the moisture analyzer and dried to constant weight at 105 °C.

2.4. Color analysis
Color of beetroots was measured by a colorimeter (CR-400, Konica Minolta Sensing, Inc., Osaka, Japan). The Hunter $L^*$, $a^*$, $b^*$ values represent lightness, redness and yellowness, respectively. Total color change ($\Delta E$) represents the extent of color change after drying and was evaluated by the Equation (1) [14].

$$\Delta E = \sqrt{(L' - L_0^*)^2 + (a' - a_0^*)^2 + (b' - b_0^*)^2}$$  (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. Each sample was measured 5 times.

2.5. Rehydration ratio
Dried beetroots were rehydrated by immersing into 200 mL of distilled water, and then incubated at 80 °C for 15 min. The weight used for each rehydrated experiment was 2.0 ± 0.1 g. The rehydrated beetroots were taken out, the surface moisture of rehydrated beetroots were absorbed with the help of absorbent papers, and then weighed. Rehydration ratio of dried beetroots was calculated by the Equation (2) [15].

$$RR = \frac{m_1}{m_0}$$  (2)

Where $RR$ is the rehydration ratio; $m_0$ and $m_1$ are the mass of dried beetroots and rehydrated beetroots, respectively, g.

2.6. Extractions
Dried beetroots obtained by different microwave-assisted drying methods were ground into powders (pass through a 60-mesh sieve), respectively. 2.0 g of beetroot powder was placed in a centrifuge tube, 20 mL of 50% ethanol was added, and then mixed by a vortex mixer (VORTEX-5 Kylin-Bell Instrument Manufacturing Co., Ltd, Jiangsu, China) for 2 min. After centrifugation (H1850, Xiangyi Centrifuge Instrument Co., Ltd, Hunan, China) at 5000 rpm for 10 min, the supernatant was collected and the insoluble residue was extracted twice with 20 mL of 50% ethanol. The combined supernatants were adjusted to 100 mL with 50% ethanol. The extracts were stored at 4 °C until further analyzed contents of betalains and total phenolic.

2.7. Determination of betalains
Betalains can be divided into two groups: red-violet betacyanins ($\lambda_{max}=538$ nm) and yellow-orange betaxanthins ($\lambda_{max}=480$ nm). The betalains content was measured colorimetrically according to the method described by Stintzing et al [16]. The 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. Absorption of betaxanthin, betacyanin, and nonbetalainsic substance were recorded at 480, 538 and 600 nm, respectively. The betalains content ($BC$) was calculated by the Equation (3).

$$BC(\text{mg} / L) = \frac{AXDF \times MW \times 1000}{\varepsilon \times l}$$  (3)

Where, $A$ is the absorption value at the absorption maximum corrected by the absorption at 600 nm. $DF$ is the dilution factor, and $l$ is the path length (1 cm) of the cuvette. For quantification of betacyanins and betaxanthins, the molecular weights ($MW$) and molar extinction coefficients ($\varepsilon$) of betanin ($MW = 550$ g/mol; $\varepsilon = 60000$ L/(mol·cm) in H$_2$O; $\lambda = 538$ nm) and indicaxanthin ($MW = 308$ g/mol; $\varepsilon = 48000$ L/(mol·cm) in H$_2$O; $\lambda = 480$ nm) were applied. The content of betalains was
expressed as mg betanin equivalent (BE)/g for betacyanins and mg indicaxantin equivalent (IE)/g for betaxanthins.

2.8. Determination of total phenolic content
Total phenolic content (TPC) was determined by Folin-Ciocalteu method [17]. 2.5 mL of 10% Folin-Ciocalteu reagent (v/v) was mixed with 0.5 ml of diluted extract, and then 2 ml of 7.5% sodium carbonate (w/v) was added. The mixture was incubated at 50 °C for 15 min and then cooled to room temperature. The absorbance was measured at 760 nm. TPC was expressed as mg of gallic acid equivalent (GAE) per g of dry weight based on a calibration curve with a concentration of 0–0.1 mg/mL gallic acid as the standard.

3. Results and Discussion

3.1. Drying time, moisture content and rehydration ratio
The drying time, moisture content and rehydration ratio of beetroots dried by different microwave-assisted methods are shown in Table 1.

As illustrated in Table 1, HMD—LMD was the fastest drying rate among the five microwave-assisted drying methods. It took only 46.0 min to dry fresh beetroot slices to the final moisture content for HMD—LMD, reduced by 75.1, 80.0, 82.6, and 85.1% as compared with the drying time for HD—LMD (185.0 min), HMD—HD (230.0 min), HMD—VD (265.0 min) and VD—LMD (308.0 min). Furthermore, there were significant differences in drying time under different microwave-assisted drying methods (p < 0.05).

Fresh beetroots had a moisture content of 89.51% (wb), which were dried to a moisture content of less than 7.00% (wb). As shown in Table 1, the final moisture content of beetroots ranged from 6.32% to 6.55% on a wet basis, with no significant differences among all microwave-assisted drying methods.

Rehydration capacity is widely used as a quality indicator for dehydrated products, which can indicate the degree of cellular and structural disruption caused by drying process [18]. The beetroots dried by HD—LMD absorbed a higher quantity of water than those of beetroots dried by other four microwave-assisted drying methods. The beetroots dried by HD—LMD illustrated the highest rehydration ratio and followed by those dried by HMD—HD, while the beetroots dried by VD—LMD illustrated the lowest rehydration ratio. Similar results were reported by Maskan et al [19] and Zhao et al [12].

The drying methods had significant influences on the rehydration ratio of beetroots. Compared with HMD—HD, HD—LMD had shorter drying time and better rehydration ratio. The beetroots obtained by VD—LMD showed the lowest rehydration ratio and longest drying time.

3.2. Color changes of beetroots
Color is an important parameter for the acceptability of dehydrated products, which is considered as the key quality attribute due to its relation with aroma and flavor, and dried products are easy to color.

| Drying methods | Drying time (min) | Moisture content (% wb) | Rehydration ratio |
|----------------|------------------|------------------------|------------------|
| HMD—LMD        | 46.0 ± 1.7c       | 6.41 ± 0.45a           | 3.90 ± 0.13b     |
| HMD—HD         | 230.0 ± 8.7d      | 6.32 ± 0.55a           | 3.95 ± 0.11b     |
| HD—LMD         | 185.0 ± 6.2a      | 6.39 ± 0.59a           | 4.15 ± 0.05a     |
| HMD—VD         | 265.0 ± 17.3b     | 6.44 ± 0.55a           | 3.81 ± 0.08bc    |
| VD—LMD         | 308.0 ± 6.2a      | 6.55 ± 0.39a           | 3.55 ± 0.14c     |

Means in the same column with different superscript letters are significantly different according to Tukey's test (p < 0.05).
deterioration [20]. Fresh beetroots revealed an $L^*$ brightness of 36.83, $a^*$ value of 28.78 and $b^*$ value of 6.35. The color of beetroots after drying became brighter, and there was no significant difference in the $L^*$ values obtained using different microwave-assisted drying methods. Meanwhile the beetroots after drying had lower values of $a^*$ and $b^*$ than fresh beetroots. The decrease in $a^*$ and $b^*$ values was due to the degradation of pigments, such as betacyanins and betaxanthins. The $a^*$ values of beetroots obtained using VD—LMD and HD—LMD were significantly higher than those of beetroots dried using HMD—HD. The $b^*$ values obtained using HMD—HD and HMD—VD were significantly lower than that dried by HMD—LMD, HD—LMD and VD—LMD. The minimum value of $\Delta E$ (7.77) was obtained using VD—LMD, while the maximum $\Delta E$ value was 10.77 dried by HMD—HD.

Beetroots dried by VD—LMD had the most desirable color among the beetroots dried by the five different microwave-assisted drying methods, with the lowest $\Delta E$ and the values of $L^*$, $a^*$ and $b^*$ close to the fresh beetroots, owing to lower temperature. In addition, the second best color of beetroots was obtained by HD—LMD and the worst color of beetroots was dried by HMD—HD, indicating that the different combinations of hot air and microwave had a great influence on the color of final dried products.

| Drying methods  | $L^*$      | $a^*$     | $b^*$     | $\Delta E$   |
|-----------------|------------|-----------|-----------|--------------|
| 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—HD          | 43.59 ± 1.62<sup>a</sup> | 21.62 ± 0.32<sup>d</sup> | 2.10 ± 0.25<sup>c</sup> | 10.77 ± 1.28<sup>a</sup> |
| HD—LMD          | 42.12 ± 1.26<sup>e</sup> | 23.37 ± 0.85<sup>be</sup> | 3.55 ± 0.40<sup>b</sup> | 8.08 ± 1.50<sup>b</sup> |
| HMD—VD          | 41.54 ± 0.99<sup>a</sup> | 22.06 ± 0.50<sup>ad</sup> | 2.20 ± 0.25<sup>c</sup> | 9.21 ± 0.97<sup>ab</sup> |
| VD—LMD          | 41.87 ± 1.05<sup>a</sup> | 23.80 ± 0.77<sup>b</sup> | 3.19 ± 0.31<sup>b</sup> | 7.77 ± 1.25<sup>b</sup> |
| Fresh beetroot  | 36.83 ± 1.06<sup>f</sup> | 28.78 ± 1.25<sup>a</sup> | 6.35 ± 0.72<sup>a</sup> | —            |

Means in the same column with different superscript letters showed significant differences according to Tukey’s test ($p < 0.05$).

### 3.3. Content of betalains

Beetroot is one of the richest sources of the betanin pigment, used as the red colorant E162. The ratio of betacyanins and betaxanthins determine the varieties and redness of beetroots [20]. The results of betalain contents in the beetroots dried by different microwave-assisted drying methods are exhibited in Table 1.

The betacyanin contents ranged from 2.97 to 4.09 mg BE/g, while betaxanthin contents ranged from 2.51 to 3.45 mg IE/g. These values were close to the range of those proposed by Wruss et al [21] for seven beetroot varieties: 2.3–3.9 mg BE/g for betacyanin contents, 1.5–2.4 mg IE/g for betaxanthin contents, and higher than the content of betalains reported by Vallespir et al [22]. No significant differences were observed in the betacyanin contents of beetroots obtained by HMD—LMD and HD—LMD. There were significant differences ($p < 0.05$) in the contents of betacyanin in beetroots obtained by HMD—HD, HMD—VD and VD—LMD. Betaxanthin contents of beetroots obtained using HMD—HD and HD—LMD were significantly lower than that of beetroots dried by HMD—LMD, HMD—VD and VD—LMD. The beetroot contents of HMD—VD—LMD were resulted in the highest contents of betacyanins (4.09 mg BE/g) and betaxanthins (3.45 mg IE/g), higher than that of other microwave-assisted drying methods. The beetroot contents dried by HD—LMD were shown lower contents of betacyanins and betaxanthins than those of beetroot dried by other microwave-assisted drying methods.
Fig. 1 Betalains contents of dried beetroots as affected by different microwave-assisted drying methods. 
(Different letters indicate significantly different according to Tukey's test)

3.4. Total phenolic content

TPC of beetroots dried by different microwave-assisted drying methods are illustrated in Figure 2. It can be seen that the TPC of dried beetroots ranged from 7.48 to 9.26 mg GAE/g, slightly higher than the values (4.1–6.3 mg GAE/g) reported by Wruus et al [21]. TPC of beetroots dried by HMD—HD and HMD—VD were lower than that of other three microwave-assisted drying methods. The TPC of dried beetroots obtained by HMD-LMD and HD-LMD was not significantly different (p> 0.05). The beetroots dried by VD—LMD had the highest TPC (9.26 mg GAE/g).

Fig. 2 TPC of dried beetroots under different microwave-assisted drying methods. 
(Different letters indicate significantly different at p < 0.05 according to Tukey's test)
4. Conclusions

In this study, the physicochemical properties of dried beetroots obtained by five different microwave-assisted drying methods (HMD—LMD, HMD—HD, HD—LMD, HMD—VD, and VD—LMD) were compared. Different microwave-assisted drying methods had significant influences on the physicochemical properties of dried beetroots. The drying time of beetroots dried by VD—LMD was the longest (308.0 min), followed by HMD—VD, HMD—HD, HD—LMD, and HMD—LMD, which was 265.0 min, 230.0 min, 185.0 min, and 46.0 min, respectively. Results showed that the beetroots dried by HD—LMD had a higher rehydration ratio than those dried using other microwave-assisted drying methods. Compared with the other four microwave-assisted drying methods, the beetroots obtained using VD-LMD had the most ideal color, and the lowest \( \Delta E, L^*, a^* \) and \( b^* \) values are close to that of fresh beetroots. Overall, the VD—LMD provided the best quality of dried beetroots, with the best color appearance, the highest total phenolic, betacyanins and betaxanthins contents, but with the longest drying time and lowest rehydration ratio. Considering the balance between physicochemical properties of dried beetroots and energy consuming, HD—LMD is a potential drying method to achieve high-quality dried beetroots as well as save energy, which can be widely applied to industrial production.

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