A Comparative Study of Four Drying Methods on Quality Characteristics of Taro Slices

Lingjun Wei1, Tian Sang1, Dongming Yuan1, ChunFang Song1*

1. Jiangsu Key Laboratory of Advanced Food Manufacturing Equipment and Technology, Jiangnan University, Wuxi, Jiangsu, China

Abstract: The dried taro slices were obtained at water content below 0.11kg water/kg dry solids using hot-air drying (AD), microwave drying (MWD), microwave vacuum drying (MWVD), Freeze drying (FD). The chosen drying methods provided wide variation in residence time, from 15min (in MWD) over 14h (in FD). The influence of drying conditions and various drying methods on the polysaccharide content, color, shrinkage, sensory evaluation and micrographs of dried taro slices was studied. The colors of AD dried taro slices were comparable to the MWVD slices, but were significantly different from MWD (darker) and FD (lighter) counterparts. MWVD and VFD of dries taro slices were higher than AD and MWD in terms polysaccharide content, moreover, there are no significant differences between MWVD and FD. The microstructure of FD and AD dried taro slices was smooth and flaky, Particles of FD-dried taro slices were porous compared to the other three products. The study concludes that MWVD drying can produce taro slices with quality comparable to that obtained via freeze drying, and better than the MW and AD-dried taro slices.

Keywords: taro, microwave vacuum drying; freeze drying; microstructure; polysaccharide

1. Introduction

Taro (Colocasia esculenta (L.) Schott) is a major tuber crop cultivated in the tropical and subtropical regions of the world. Planting of taro is very broad in many countries, such as Africa, and Asia. Taro is not only edible, but also can be medicinal [1-2]. Taro contains polysaccharide, which can improve the body's immune ability and strengthen the body's ability to resist disease. Taro's output is up to 6 million tons in China. Taro tubers are known to start rotting as early as two weeks post-harvesting, recorded post-harvest losses of about 90% during six months of storage. Moreover, most of the taro cuticula contains vegetable base. The human body skin contact vegetable base will cause tickling, which limits the taro's consumption and edible, thus demand of taro are not in proportion with the intensive processing, and deep processing of taro is imperative. To prevent loss of nutrients, taro can be made dry products. But because of the limitation of processing levels and the market ability, local taro production always stays on the original stage of processing. Traditional drying method is simple, and the dried taro products have the poor quality and large deformation, which cannot satisfy the demand of market for high quality. Thus the development and application of new drying technology can solve the current problem of taro effectively. Several drying technology can be viable commercial options for manufacture of dried taro, including hot-air drying (AD), microwave drying (MWD), microwave vacuum drying (MWVD) and freeze drying (FD). The final product obtained may be differ in physicochemical or nutrition properties and microstructure [3-4]. Freezing drying is generally considered as the best method for production of high quality dried product [5]. But it suffers from high production costs, high energy consumptions and low throughputs.

Hot-air drying (AD) has been to date the most common drying method used for food materials. However, this method has many disadvantages, including poor quality of dried products, low energy efficiency and long drying time. Prolonged exposure to elevated drying temperature of hot-air drying results in substantial deterioration of quality attributes as color, nutrient concentration, flavor and texture [6].

In order to eliminate these problem, use of microwaves technology is increasing for its preventing significant quality loss and achieving fast and effective thermal processing. The energy supplied during MW heating reaches all the parts of dried material at the same time. It enables to shorten dehydration time and to control desirable biological transformation [7,8]. Microwave-assisted vacuum drying (MWVD) drying has been investigated as a potential method for obtaining high-quality dried foodstuffs [9-11]. It permits a shorter drying time and a substantial improvement in the quality of dried materials, in related to those dried with AD and MWD [12].

Studied were reported that compared the influence of different drying methods on various quality attributes of fruits and vegetables, including the color of dehydrated apple[13], banana[14] peeled longan [15]and potatoes[6]. However, no study has been conducted to evaluate the effect of drying method on taro slices in term of color, bulk density, microstructure. Thus the objective of this work was to investigate the influence of four drying methods (MWD, MWVD, AD, and FD) on the physical properties and microstructures of resulting taro slices to provide better understanding in selecting drying technology that can be applied toward the manufacture of high quality taro slices.

2. Materials and methods

2.1 Materials

Fresh taros were purchased from a local supermarket in Wuxi, Jiangsu Province. Those with no damage part, no mildew points and uniform shape taros were selected as the raw materials. The samples were washed, peeled, sliced, then stored in the refrigerator (5°C) for sample preparation. Three replications were run for each experiment.

2.2 Drying methods

The taro slices were dried by four different drying methods (AD, MWVD, MWD, FD) and the drying process continued until the final sample's moisture content reached 0.11kg water/kg dry solids. A series of preliminary drying experiments were done to ensure dried products in almost the same final moisture content. The original weight of the taro slices was 150 g. Three different drying trials were conducted, averaged and the drying parameters were determined triplicate and average. These methods are described as follows:

- AD drying was carried out using a electro thermostatic blast oven (Model no. DHG-9076A, Shanghai Jing Hong Laboratory Instrument Company, Shanghai, China). The airflow velocity of dryer was 1.5 m/s and the temperature was 60 °C.
- The lab-scale MWV dryer in which the samples to be dried can be rotated in the cavity was described in detail elsewhere[16]. The actual measured full power output of the magnetron was 380 W. The vacuum pressure was operated at 10 kPa and the rotation speed of the turntable was 5 rpm.
- A laboratory-scale freeze dryer (Model no. 6L, Labconco Instrument Company, Kansas City, KS, USA) was used for drying tarp slices. The vacuum pressure of dryer was set at 20 KPa, the plate temperature was 20°C, and the condenser was at -50 °C.
- Domestic MW over was utilized in this experiment ((Model no.EM-208 whirlpllo Co., LTD, Hefei, Anhui, P.R.China). The actual measured full power output of the magnetron was 380 W and the rotation speed of the turntable was 5 rpm.
2.3 Physical properties of taro slices

2.3.1 Moisture content

Moisture content of samples was determined by the method (AOAC, 1995). The samples were placed into a vacuum oven at 70°C and 57.6 kPa gauge pressure until reach a constant weight. The initial moisture contents of taro slices were 5.21 (d.b.). Weighing was performed on a digital balance, and then moisture content (w.b.) was calculated. The tests were performed in duplicate.

2.3.2 Color

Color was measured by a colorimeter (WSC-S system, Shanghai Precision Instrument Co. Ltd., Shanghai, China). Each sample was placed at the light port and tested for color values at three different points along the radius for three times to avoid inhomogeneity. The instrument was initially calibrated with a white standard plate \((L_0=8.28, a_0=1.51, b_0=0.68)\). The information given by \(L, a\), and \(b\) is commonly expressed as color values of taro slices, and \(L\) represents the brightness or dullness, \(a\) for redness to greenness, and \(b\) for yellowness to blueness\[18,19\].

The total color difference \((\Delta E)\) was then determined using the following equation

\[
\Delta E = \sqrt{(L_0-L)^2 + (a_0-a)^2 + (b_0-b)^2}
\]

The subscript “0” in both equations refers to the original taro.

2.3.3 Sensory evaluation

To evaluate the acceptability of the final products, a preliminary sensory evaluation by a taste panel of 20 experienced judges was used. They were instructed to indicate their preferences for each sample based on the quality attributes of texture, flavor, and overall acceptability. A balanced seven-point hedonic rating was employed for all the indexes evaluated where “1=very poor, 2=poor, 3=fair, 4=satisfactory, 5=good, 6=very good, and 7=excellent.”[19] The judges were asked to give their scores for each sample.

2.3.4 Polysaccharide

The total polysaccharide content was determined using the phenol-sulfuric acid method[17]. Data were calculated on a dry basis and expressed as micrograms per 100 g solids. The analyses were carried out in duplicate. Polysaccharide content of the dried taro was converted to the polysaccharide content per 100 g fresh taro. Polysaccharide value of taro slices after blanching was used as the control value.

2.3.5 Shrinkage

Determination of shrinkage of each citrus peel taro cube was achieved by using an electronic digital slide gauge of 10−2 mm accuracy. Shrinkage of volume (VS) of citrus peels cube was calculated according to Eq. (2)

\[
VS(\%) = \frac{(V_i - V_f)}{V_i} \times 100
\]

Where \(V_i\) and \(V_f\) are the volume of peeled stitches before and after drying respectively[18].

2.3.6 Microstructure

Scanning electron microscopy (SEM) was used to analyze microstructure changes after drying. Small slices of inner part were cut from the dried taros. The sample was coated with a very thin layer of gold and analyzed using a scanning electron microscope (model SU151, HITACHI high-tech, Tokyo, Japan) with an accelerating voltage of 5 kV.

Finally, the specimen fragments were mounted on aluminum stubs, coated with gold and photographed by using an scanning electron microscope SEM (Quanta-200, FEI, Eindhoven, The Netherlands) using an accelerating voltage of 5 kV[20,21].

2.4 Statistical analysis

All experiments were carried triplicate, the data were statistically analyzed using the general linear model procedure of SAS (SAS Institute Inc., Cary, NC) and Difference among the mean values of the samples was performed by the ANOVA procedure. Mean values were considered significant different for \(P<0.05\).

3. Results and discussions

3.1 The resident time

The dried taro slices were obtained at water content below 0.11kg water/kg dry solids using AD, MWD, MWVD, FD. The chosen drying methods provided wide variation in residence time (Table 1), from 15min (in MWD) over 14h (FD). The resident time of MWD is slightly shorter than that of MWVD.

3.2 Colors

Color is one of the critical quality parameters that affects consumer acceptance degree and the market value of the products. The highest possible value \(L\) and lowest color difference \((\Delta E)\) are considered to be the bench mark in the industry for the color
Table 1 Colors (L*, a*, b*) and color difference (ΔE) of taro slices using different drying methods compared to fresh taro slices.

<table>
<thead>
<tr>
<th>Drying methods</th>
<th>Resident time</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
<th>ΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh</td>
<td>-</td>
<td>94.23±2.56a</td>
<td>11.44±0.56a</td>
<td>40.56±0.98a</td>
<td>-</td>
</tr>
<tr>
<td>AD</td>
<td>11h</td>
<td>73.39±1.51a</td>
<td>8.72±0.34a</td>
<td>29.14±1.26a</td>
<td>23.92±1.16a</td>
</tr>
<tr>
<td>MWD</td>
<td>15min</td>
<td>65.61±2.14a</td>
<td>10.07±0.85a</td>
<td>41.38±1.73a</td>
<td>28.66±1.37a</td>
</tr>
<tr>
<td>FD</td>
<td>14h</td>
<td>92.37±1.62a</td>
<td>9.17±0.48a</td>
<td>26.86±1.47a</td>
<td>14.01±1.45a</td>
</tr>
<tr>
<td>MWVD</td>
<td>20min</td>
<td>76.75±1.76b</td>
<td>10.34±0.73a</td>
<td>28.94±0.89a</td>
<td>21.02±1.79b</td>
</tr>
</tbody>
</table>

a, b Different letters in the same column indicate a significant difference (p≤0.05).

Table 2 The results of sensory evaluation on different drying process.

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Color</th>
<th>Flavor</th>
<th>Appearance</th>
<th>Texture</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD</td>
<td>4.2±0.5b</td>
<td>5.2±0.3b</td>
<td>3.3±0.2a</td>
<td>4.5±0.2b</td>
<td>17.2±0.4a</td>
</tr>
<tr>
<td>MWD</td>
<td>1.4±0.2a</td>
<td>4.8±0.4b</td>
<td>1.5±0.3a</td>
<td>4.5±0.5a</td>
<td>12.2±0.6a</td>
</tr>
<tr>
<td>MWVD</td>
<td>4.8±0.5b</td>
<td>5.5±0.6b</td>
<td>4.6±0.5a</td>
<td>6.2±0.3b</td>
<td>21.1±0.3a</td>
</tr>
<tr>
<td>FD</td>
<td>6.5±0.3a</td>
<td>5.0±0.5b</td>
<td>5.6±0.7a</td>
<td>5.2±0.6a</td>
<td>22.3±0.5a</td>
</tr>
</tbody>
</table>

a, b Different letters in the same column indicate a significant difference (p<0.05).

The quality of dried foods [23,24]. The surface color parameters of AD, MWD, MWVD, and FD taro slices can be seen from Table 1. In general, dried taro slices showed lower lightness (L value), redness (a values) and yellowness (b values) compared to fresh taro slices. Moreover, there were significant differences (p < 0.05) in L, a, and b values of the four different drying methods. FD taro slices exhibited the highest L values and lowest ΔE values, followed by MWVD. In addition, the color parameters of FD were close to those of fresh taro samples. MWVD presents the highest L and lower ΔE values compared to MWD. This can be explained by the fact that less oxygen in a vacuum drying chamber leads to a less enzymatic browning reaction, which is the main cause of color degradation of dried samples [25]. The lowest L values and highest ΔE values were gained for the taro slices dried by MWD. This clearly indicated that more browning occurred because of non-enzymatic browning. The non enzymatic Maillard reaction occurs between proteins or amino acids and reduce saccharides during drying, which leads to brown compounds in foods [26]. For AD, the long resident time may have caused AD taro slices to darken. Drying temperature and the resident time are critical in the development of browning. The lower color degradation of the MWVD product might, therefore, also be caused by the short drying time.

3.3 Sensory evaluation

The quality assessment of the taro slices treated by different drying methods was evaluated mainly in terms of the colour, flavor, appearance and texture. Moisture content was fixed below below 0.11 kg water/kg dry solids. It can be seen from Table 2 that the FD samples showed the highest product quality. While the score of MWVD samples is very near to that of FD, which may be due to the short drying time, low drying temperature, and less oxygen in microwave vacuum drier. In other words, MWVD can be considered as a potential efficient process for commercial taro slices manufacturing. MD got the lowest score, meaning that MD cannot be accepted for drying taro slices. Figure1 also showed that the color of taro slices dried by MD is brown and shrink greatly. Compared with MWVD and FD, AD samples curl significantly. FD samples has the better color, flavor and uniform, while the surface of sample is rough.

3.4 Shrinkage and polysaccharide

Figure2 shows these four drying methods resulted in volume shrinkage and polysaccharide content of taro slices. During the drying process, food materials undergo changes in volume (shrinkage or expansion) along with water loss.
The shrinkage of taro slices dried using AD, MWD, MWVD, and FD was calculated based on the initial volume of the fresh samples. MWD showed the highest shrinkage ratio (40.16%), followed by MWVD products (28.44%), while FD taros showed the lowest shrinkage ratio (15.36%), followed by AD samples (22.56%). Food drying involves complicated processes relevant to the mass, heat, and momentum transfer within the food material because multiple phases are usually present in the form of solids, liquid water, and gas [26]. Therefore, shrinkage is relevant to moisture content of food and the different heating transfer mode. AD provided a moderate drying condition but long shrinkage time, which was explained by the fact that the long drying time gives more time for the taro slices product to shrink [27]. The water molecules in the form of sublimation from taro slices leads to reduce the amount of deformation of samples in FD. During the MWD process, Evaporation of water within the food is accelerated by the preferential absorption of microwave energy, accelerating the transport of water vapor, which promoted the shrinkage of taro slices. However, negative pressure was exerted within the taro slices, which offsets the shrinkage of samples due to the effects of the puffing. Hence, shrinkage of MWVD samples is lower than that of MWD. Overall, MWD taro slices were greater than that of MWVD and AD taros, and significantly greater than FD in terms of volume shrinkage.

The polysaccharide content changed in taro slices dried by different drying methods was shown in Figure 1. It can be seen that the polysaccharide content in FD taro slices was the highest and the value was 17 g/100 g d.b., MWVD and AD taro slices obtained the polysaccharide content was 16.5 g/100 g d.b. and 12.4 g/100 g d.b.. The polysaccharide content of MWD reached a minimum value of 8 g/100 g d.b.. MWD had the lowest soluble polysaccharide content. High microwave power alone leaded to a severe temperature increase in taro slices to produce Maillard and caramelization reactions, thus some polysaccharides were converted to oligosaccharides or part of caramel. However, MWVD may maintain better retention of polysaccharides due to the high drying rate and low drying temperature in vacuum conditions, which implied that MWD was a better method for maintaining the polysaccharides from taro slices. FD permitted the water in food material freeze condition then sublimated under the low temperature. Thus, FD preserve the highest polysaccharide content compared the other three drying methods.
compact structure and the cells were tightly packed, which may be due to the higher diffusion rate generated by the microwave power. FD, MWVD, MWD and AD was clearly visible. The samples dried by MWD exhibited collapsed and great and soft. For MWVD, internal moisture evaporated rapidly under the vacuum and the microwave energy. Expansion power of the steam brought the degeneration of high polymer material between components, which formed honeycomb structure.

3.5 Microstructure analysis

Figure3. shows SEM (scanning electron microscopy) images of dried taro slices samples obtained from different processes. The difference in microstructure after FD, MWVD, MWD and AD was clearly visible. The samples dried by MWD exhibited collapsed and compact structure and the cells were tightly packed, which may be due to the higher diffusion rate generated by the microwave power. FD, AD and MWVD samples revealed a clear porous structure, indicating that smaller shrinkage occurred during vacuum and AD drying. Ice crystals between cells directly sublimated in freeze drying, which resulted in minimum structural shrinkage [28]. The cells dried by FD were great and soft. For MWVD, internal moisture evaporated rapidly under the vacuum and the microwave energy. Expansion power of the steam brought the degeneration of high polymer material between components, which formed honeycomb structure.

4. Conclusion

Based on the experiments investigated in this article, it is observed that the drying methods significantly affects the drying characteristics and quality properties of dried taro slices. MWD is the fastest means of drying in term of drying time, followed by MWVD. On the basis of product quality, MWVD presents the better quality in term of color, shrinkage, sensory evaluation, polysaccharide content. The polysaccharide content of MMVD and VFD was similar and high. The polysaccharide content of MWVD reached a minimum value of 8%. MWD presents the best quality properties. Among different drying methods, microwave vacuum drying seemed to be a more suitable method to preserve the better quality attributes of dried taro slices.

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