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# Hot air drying combined vacuum-filling nitrogen drying of apple slices: Drying characteristics and nutrients

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## *Abstract*

*In this paper, hot air drying (HAD) was applied when moisture content of apple slices range from 50% to 86%, and then vacuum-filling nitrogen drying (VFND) was used till moisture content reaching 7%. Results showed that, the drying rate of apple slice during VFND period increased with temperature increment and decreased with increment of slice thickness; compared to freezing dried samples, samples dried in this research were owned lower Vc and higher flavonoid; when HAD (70℃,3.0m/s)+VFND(relative pressure 0.08MPa, 50℃) and thickness of 6.0mm, nutrients reached better levels: retentions of Vc, total phenolics and flavonoid were 1.63mg/100g, 4.07mg/100g and 2.10mg/100g, respectively.*

***Keywords:*** *apple slices, hot air drying, vacuum-filling nitrogen drying, drying rate, nutrients*

## 1. Introduction

Apple is a main fruit in many countries. As the results from Wang and others, till 2013, the annual production of fresh apple fruit in China is about 39.7 million t, accounting for 49% of the global production[1]. Fresh apple fruits are usually graded for higher economic benefit. Fresh apples with the better quality would just be fresh consumed while the apples with the poor quality are generally used to produce juice, jam, and dried products for examples apple chips or nature apple powder and so on. Drying process of apple is a better way to prolong storage. And the main drying techniques used to dehydrate apple slices include FD, HAD, VD, HAD combined VD, and so on. HAD apple slices is the conventional technology studied widely in the past two decades[2-4], however, browning and oxidation even hardening happened during HAD[5-7], which induced undesirable quality. Freeze drying can produce perfect quality dried fruits and vegetables[8,9], but it also high energy consumption. So, various combine drying methods applied to dry fruit and vegetable appear in recent years. Hazervazifeh et al. studied combined microwave-hot air and other drying methods dehydration of apple slices and found that, microwave power 2000W at 70℃ with the air velocity of 2.0m/s can induce the minimum drying time[10]. However, fruit and vegetable dried by microwave combined hot air does not always maintain the better quality, for example low rehydration[11]. Huang and others investigated effects of combined drying methods on composition, aroma, eating quality of apple slices[12]; in their studies, freeze-drying, freeze-drying + microwave vacuum drying and microwave vacuum drying + freeze-drying were used to dry apple slices; and the results showed that, microwave had significant effects on aroma, total phenols and pectin, and longer drying time high temperature at desorption drying stage and short time higher temperature at microwave vacuum drying period during freeze-drying + microwave vacuum drying induced lower retention of both aroma and reducing sugar. It was proved that vacuum drying can afford a low oxygen environment and the retention of various nutrients in vegetables and fruits could be better. Nitrogen is an inert gas and if it was filled with vacuum drying circumstance, it may be induce dried products with better quality.

The aim of this work is to study the drying characteristics of HAD + VFND dried apple slices and the quality of apples slice including retention of vitamin C, total phenolics and flavonoid. For this purpose, experiments of apple slices dried after HAD and then dried in VFND under different conditions were conducted and nutrients were also determined.

## 2. Materials and methods

### 2.1. Samples preparation

Fresh apples malus pumila mill were obtained from local market and stored at 3-4℃ in a refrigerator and were used within 14 days. The initial moisture contents of fresh apples were within 85 to 87% (wet basis), which were determined by hot air oven method at 103-105℃ until the constant mass. Samples were sliced to the thicknesses of 2.0-8.0mm after peeling and then immersed into 0.2% ascorbic acid solution for 2minites to restrain browning.

### 2.2. Hot air drying

Apple slices were dried with hot air at 70℃ with the velocity of 3.0m/s after immersed into 0.2% ascorbic acid solution for 2 minutes and the moisture contents were declined from about 86% to 50%w.b. During hot air drying, the weights of samples were obtained by electronic balance with an accuracy of 0.001g every 10 minutes.

### 2.3. Vacuum-filling nitrogen drying

The half dried apple slice samples were dried in vacuum-filling nitrogen drying oven until the moisture contents were about 7% w.b. In vacuum-filling nitrogen drying method, materials were put into vacuum oven, and then vacuuming(10kPa)→filling with nitrogen (near 0.1MPa)→vacuuming(10kPa)→filling with nitrogen (near 0.1MPa)→vacuuming (10kPa). Temperatures were range from 50 to 80℃ during VFND. While during vacuum-filling nitrogen drying, the weights of samples were obtained every 20 minutes.

### 2.4. Nutrients assay

Dried apple slices were crushed by a pulverizer, and nutrients in nature apple powder were determined.

In this research, vitamin C was determined by Philin's reagent colorimetry according to the methods of Benassi & Antunes[13]and Marfil, Santos &Telis[14] with some modifications. Apples powder of 0.500g was homogenized with the extraction solution (2 g oxalic acid/100g solution) and diluted to 50ml with the extraction solution in a volumetric flask, and then vacuum filtered after 30 minutes' standing. Filtrate of 10ml was taken for titration with 2,6-dichlorophenolindophenol solution (50mg 2,6-dichlorophenolindophenol/250ml pure water). When the pink color of filtrate did not disappear in 15s, the titration end point was determined. All analyses were performed in triplicate.

The flavonoid content of apple powder was analyzed according the method described by Jia etal[15] with slight amendments. 1.000g apple powder was homogenized with 50ml of ethamol (7:10) for 60 minutes and then vacuum filtrated. 1.0ml of the filtrate was placed in a 25ml volumetric flask, 10ml of ethamol (7:10) and 1ml of NaNO2(1:20) were added and shaken well, 10ml of 1 mole per litre NaOH was added after 6 minutes, and the total volume was made up to 25ml with ethamol (7:10). After 15 minutes' standing, this sample was placed in colorimetric tube and the absorbance was measured at 510nm.

Total phenolics content of natural apple powder were determined by the Folin-Ciocalteau method[16]. Apple powder of 1.000 grams were added to the ethanol solution with the content of 75% and diluted to 50ml. 5ml of sample was taken into volumetric flask，50ml of pure water and 4ml of Folin-Ciocalteu reagent were also added. After 3-4minutes' standing, 8ml of 10% sodium carbonate was put into the volumetric flask. And the final volume was made up to 100ml with pure water. After 120 minutes of reaction at 25℃, absorbance at 765nm was measured and used to calculate the phenolic contents using a standard curve prepared with gallic acid. All measurements were conducted in triplicate.

## 3. Results and discussion

### 3.1. Hot air drying characteristic of apple slice

In this paper, drying rate was expressed as follow:

$$DR = \frac{MC_{t-\Delta t} - MC_t}{\Delta t} \quad (1)$$

Where $MC_{t-\Delta t}$ and $MC_t$ represented moisture content at the time of $t$-$\Delta t$ and $t$, separately, dry basis, %; $t$ was drying time, min; and $\Delta t$ was time interval, min.

During HAD apple slices, there existed significant falling rate period, and the constant rate period was obvious for apple slices with the thickness of 2.0mm, while it was not evident for the apple slices with the thicknesses of 4.0-8.0mm, such as figure 1. Because, there exists longer path and greater resistance in the thicker slices for water molecules migrating. Moisture content of apple slices declined more slowly as the increase of the slice thickness.

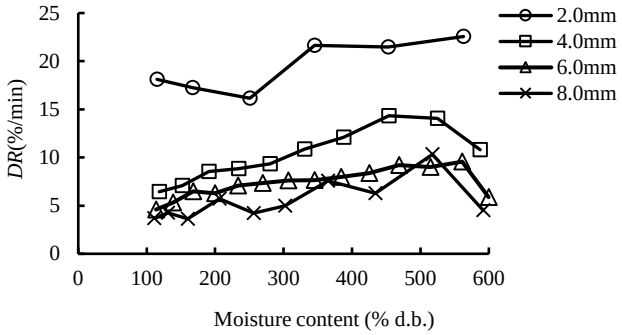


***Fig. 1 Curves of dehydration rate of apple slices with different thicknesses during HAD(70 ℃, 3.0m/s)***

### 3.2. Vacuum-filling nitrogen drying characteristics of apple slice

After HAD, apple slices were dried with VFND until the moisture content lower than 7.0%w.b. And there is only falling rate period for apple slices during VFND, showed in figures 2 and 3, owning to bound water in apple slices in this period.

During VFND, dehydration rate of apple slices declined as the decrease of temperatures and the increase of the slices thickness. As the analyzed above, there are the longer path and greater resistance for moisture to transfer to surface in the thicker apples slices. And when the thickness was 2.0mm, the greatest dehydration rate appeared which is approximate twice of that with the thicknesses of 6.0, 8.0mm. The higher temperature, the greater drying rate is for apple slices dried in vacuum-filling nitrogen condition, and it was the same as the results from apple slices vacuum drying[17].

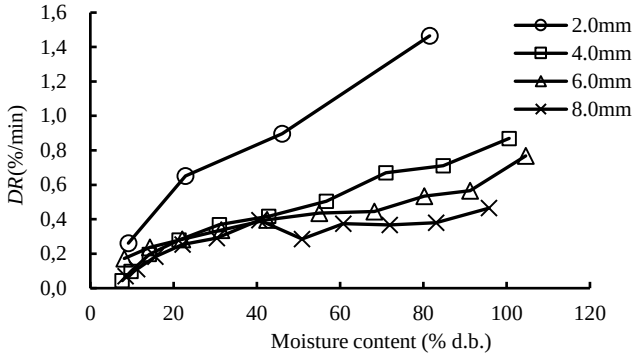


***Fig. 2 Drying rate curves of apple slices during VFND with different thicknesses (60°C)***

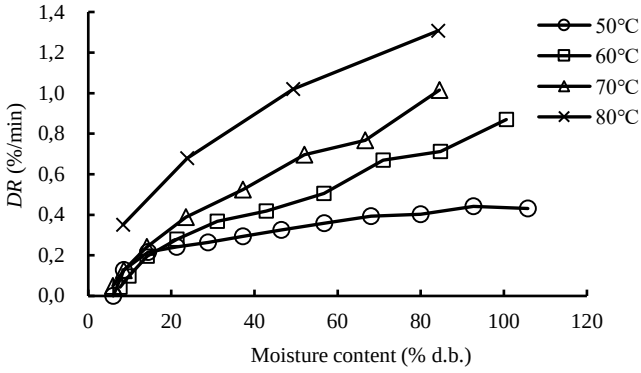


***Fig. 3 Drying rate curves of apple slices during VFND at different temperatures (4.0mm)***

### 3.3. Nutrients of apple slice dried with combined drying methods

Nature apple powder was made by the dried apple slices dried with different drying methods. And the nutrients of Vc, total phenolics, flavonoid in apple powder were expressed as mg/100g of initial fresh samples, showed in table 1. From table 1, it was found that, retentions of Vc in samples dried with HAD+VFND were lower than that of samples dried with FD, while the retentions of total phenolics of both samples dried with HAD+VFND and FD were at the same levels, and flavonoid retentions of samples dried with combined drying were almost higher to that of FD. Results reviewed that the combined method of HAD+VFND could be an available method for maintain flavonoid and total phenolics of apples; although vitamin C in samples dried with HAD+VFND was lose seriously, just only about 30% to 52% of that in fresh apples. And when HAD at 70℃, 3.0m/s combined with VFND at temperature 50℃, relative pressure -0.08MPa and slice thickness of 6.0mm, nutrients in dried sample were better: the vitamin C content of 1.63mg/100g, total phenolics content of 4.07mg/100g and the flavonoid content of 2.12mg/100g. In generally, it is available for HAD combined VFND to dehydrate apple slice.

***Table 1. Contents of nutrients in nature apple powder produced by various drying methods***

| **Thickness** (mm) | **Temperature** (℃) | **Vc** (mg/100g) | **total phenolics** (mg/100g) | **flavonoid** (mg/100g) |
|---|---|---|---|---|
| 2.0 | 50 | 1.38±0.03 | 3.57±0.14 | 2.10±0.06 |
| 2.0 | 60 | 1.50±0.03 | 3.61±0.05 | 1.71±0.03 |
| 2.0 | 70 | 1.29±0.03 | 4.03±0.06 | 1.55±0.04 |
| 2.0 | 80 | 1.04±0.05 | 3.52±0.06 | 1.39±0.03 |
| 4.0 | 50 | 1.81±0.03 | 3.43±0.06 | 1.20±0.02 |
| 4.0 | 60 | 1.32±0.09 | 3.29±0.09 | 1.21±0.04 |
| 4.0 | 70 | 1.26±0.06 | 3.19±0.05 | 1.03±0.04 |
| 4.0 | 80 | 1.66±0.06 | 3.35±0.04 | 1.08±0.02 |
| 6.0 | 50 | 1.63±0.09 | 4.07±0.00 | 2.12±0.07 |
| 6.0 | 60 | 1.49±0.02 | 2.83±0.02 | 1.55±0.01 |
| 6.0 | 70 | 1.58±0.02 | 3.61±0.07 | 1.77±0.09 |
| 6.0 | 80 | 1.58±0.02 | 3.36±0.06 | 1.83±0.08 |
| 8.0 | 50 | 1.74±0.05 | 3.01±0.01 | 1.46±0.04 |
| 8.0 | 60 | 1.55±0.08 | 3.33±0.03 | 1.58±0.04 |
| 8.0 | 70 | 1.38±0.03 | 3.41±0.00 | 1.67±0.09 |
| 8.0 | 80 | 1.23±0.09 | 3.57±0.04 | 1.80±0.05 |
| 2.0mm , FD | | 2.81±0.06 | 3.72±0.02 | 1.49±0.04 |
| fresh sample | | 3.51±0.21 | 19.52±0.11 | 6.39±0.22 |

Effects of temperatures during VFND period on vitamin C retention of apple slices dried with HAD+VFND showed in table1. It was clearly found that, when the temperature was set 50 ℃ during VFND period, vitamin C content of samples dried with combined method was higher than others. Because, vitamin C is heat sensitive material and is decomposed seriously as the increase of the drying temperature[18]. However, the difference of vitamin C among all samples was not obvious when apples were sliced with different thicknesses.

Total phenolics in apple slice slightly declined with the increase of slice thickness. As thickness of apple slice became greater, drying time was longer that mean samples were exposed to high temperature condition for longer time, and it would induce lower retention of total phenolics.

Retention of flavonoid in samples was decreased firstly and then increased with the increase of slice thickness, showed in table1. When slice thickness was 2.0mm, flavonoid retention in

apples slice was decreased with the increase of temperature, while the result was on the contrary when slice thickness was 8.0mm. The main reasons were that, it took short drying time to reach moisture content safe level when slice thickness was 2.0mm at different drying temperatures during VFND period, and lower temperature can keep flavonoid at better level; however, the drying time became longer when slice thickness was 8.0mm at all temperatures, especially at lower temperature, that means samples were exposed in the high temperature condition for long time.

## 4. Conclusion

In combined drying method of HAD+VFND, the drying rate of apples slice in VFND period was significantly affected by thickness and temperature. Retention of total phenolics and flavonoid in both samples dried with HAD+VFND and FD were at same levels although vitamin c was lower in samples dried with combined method. VFND might be an available drying technique for resisting oxidation reaction during drying process of fruits and vegetables.

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