Drying features of microwave and far-infrared combination drying on white ginseng slices

Xiaofeng Ning¹ · Yulong Feng¹ · Yuanjuan Gong¹ · Yongliang Chen¹ · Junwei Qin¹ · Danyang Wang¹

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Abstract In this study microwave and far-infrared combination drying were conducted to investigate the effect of microwave and far-infrared heating mode switching point water content (SW), ginseng slice thickness, and far-infrared drying temperature on drying indicators (surface colour difference, ginsenosides content, and surface shrinkage rate) and drying efficiency (drying time) during the process of drying white ginseng slices. Regarding microwave drying, the microwave drying time cannot exceed 150 s, and the ginseng slice water content cannot be less 50%. For the combination drying, SW, far-infrared drying temperature and slice thickness increased, the colour difference and surface shrinkage rate first decreased and then increased, and the content of ginsenosides first increased and then decreased. In addition, the combination drying showed faster drying rate, higher ginsenosides contents value, colour difference (ΔE) value and lower surface shrinkage rate than single far-infrared drying.

Keywords Microwave · Far-infrared · Combination drying · White ginseng slice

Introduction

Ginseng is an important tonic herb with high economic value. Its main components are ginsenosides, polysaccharides, vitamins, polyacetylenes, and flavonoids. Ginseng

processing includes cleaning, sorting, steaming, drying, wetting and pruning, of which the most important processing step is drying (Sui, 2016; Tack et al., 2004).

At present, ginseng drying mainly involves natural air drying and hot-air drying, but the natural drying method takes a long time, giving rise to rot and mildew issues during the drying process. The hot-air drying method is better than the natural air drying method in terms of drying rate but is very energy intensive (Choi et al., 1992). Although specialized drying equipment has been developed, a single drying method leads to a long drying time and low drying efficiency. In addition, the process is not time-efficient and requires significant manpower. The long drying time further causes uneven drying in ginseng products. Moreover, the drying process can easily lead to drastic colour changes, curling and even scorching of the ginseng product. Ginseng has great medicinal and cosmetic value, which are dependent on its nutritional content, especially the ginsenosides content. The traditional method of drying poses great damage to ginsenosides. To preserve the tonic effect of the ginseng product to meet the needs of all parties, an appropriate drying technique is the key to solving the problem (Li, 2009; Ning et al., 2015).

Microwave drying relies on microwave heating with a completely different drying mechanism from that of the traditional drying methods (convection, conduction and radiation). The process utilizes microwaves radiated onto the surface of the material. Given that water molecules are polar molecules and chaotically distributed, these polar molecules respond to the frequent external changes upon exposure to repeated changes of external radiation, in which friction among the molecules generates a large amount of heat and subsequently increases the temperature of the material. Therefore, microwave drying has a fast drying rate and uniform material heating and has been

✉ Yuanjuan Gong
yuanjuangong@163.com

¹ Department of Agricultural Mechanization Engineering, Shenyang Agricultural University, 120 Dongling-road, Shen-yang 110-866, Liaoning, China

widely used in the drying of agricultural products. However, due to high drying intensity and difficulties in power control, microwave drying has been mainly used in the initial stage of preheating in the drying of agricultural products (Ning, 2012; Zhang et al., 2012).

Far-infrared drying achieves dehydration through the conversion of electrical energy to far-infrared energy, in which the heating is achieved through the resonance between the material and the far-infrared radiation that diffuses moisture and thus completes the drying process. During the drying process, the internal portion and the surface of the material are heated simultaneously, leading to uniform drying. The extensive applications of far-infrared drying are based on its following advantages: (1) high efficiency, fast heat conduction, and a drying time that is half of that of hot-air drying; (2) high quality of the dried product; (3) only requires simple drying equipment and minimal investment (Kang et al., 2011; Raksakantong et al., 2012).

Li (2009) studied the drying technique for cultured ginseng root and demonstrated that under the same drying temperature condition, the drying rate of far-infrared was increased 1.3-fold compared with that of hot-air drying. Ning et al. (2015) investigated the drying characteristics of red ginseng and concluded that dried red ginseng via far-infrared drying was better in a variety of quality indicators, such as chroma, ginsenosides content and anti-oxidation, compared with the hot-air drying method.

Occasionally when drying a material, the use of a single method of drying cannot meet the drying requirements. In addition, a single method often requires high energy consumption and offers low drying quality. To obtain high-quality dried finished products, combined drying, i.e., combining two or more drying techniques, not only saves energy but also improves the quality of the material after drying. Thus, a combination of methods improves the overall drying process, especially for materials containing a high level of heat-sensitive ingredients. Combination drying technologies offer broad prospects for development and are applicable to various industries. Kassem et al. (2011) applied a single hot-air drying method and a drying method combining hot-air drying with microwave oven drying of Thompson seedless grapes and confirmed that the combined drying method greatly improved the drying rate while consuming considerably less energy compared with the single drying method. Mujumdar (2004) adopted phased combined drying on soybean samples, in which the materials were first dried at 70 °C for 20 min via hot-air drying followed by vacuum drying. The results showed that the combination drying method improved not only the drying efficiency but also the quality of dried products.

Thus, in order to improve the drying and post storing quality of ginseng, based on the characteristics of

microwave and far-infrared drying methods, we adopted the combined method of microwave and far-infrared drying on ginseng slices in this study. Through experiments, the effect of microwave and far-infrared heating mode switching point water content (SW), ginseng slice thickness, far-infrared drying temperature on drying indicators (surface colour difference, ginsenosides content, surface shrinkage rate) and drying efficiency (drying time) were examined during the drying process of white ginseng slices.

Materials and methods

Materials

Panax ginseng samples (15–20 mm in diameter and 50–70 mm in length) with an average initial wet basis water content of 74.83% produced in Fusong County, Changbaishan City, were purchased from the NanHu ginseng wholesale market of Shenyang. Fresh ginseng was washed clean with tap water, and the ginseng surface was gently brushed to remove all the dirt. Then, the top and the fibrous roots of the cleaned ginseng were removed.

Market research indicated that the thickness of ginseng slices sold at the market were approximately 3 mm. When the slices were thinner than 1 mm, the slices tended to curl and deform, affecting the appearance. However, when the slices were thicker than 5 mm, the slices required very long to dry and dried unevenly. Thus, the slice thickness was set to four levels: 1 mm, 2 mm, 3 mm, and 4 mm.

Equipment

A domestic microwave oven (WD900B, Gelanshi, Guangzhou, China) with an output power of 750 W and adjustable heating time periods was used as the microwave drying device. The power of the far-infrared dryer (HY-1B, Saibo, Tianjin, China) was 1500 W, and the temperature setting range of the dryer was 0–120 °C. The wind speed setting range was 0–1.2 m/s.

Experimental methods of microwave drying of white ginseng slices

Ginseng slice samples from the same batch were chosen and dried from the same initial weight. The slices were evenly placed in a tray in the drying chamber to dry. Sample slices that were 2 mm thick were used in the microwave drying experiment. Microwave heating was performed at a moderate power level, with varying heating times of 90, 120, and 150 s. After drying, quality indicators

(surface colour difference, ginsenosides content, and surface shrinkage rate) were determined.

Single factor experiment of microwave and far-infrared combination drying on white ginseng slices

To examine the effect of various factors on drying quality indicators, single factor experiments were performed on the SW, slice thickness, and far-infrared drying temperature of the microwave and far-infrared combination drying method.

In the single factor experiment of the SW, ginseng slice thickness was set at 2 mm, and the far-infrared drying temperature was set at 60 °C. Four levels of SW, i.e., 50%, 55%, 60%, and 65%, were used in the experiment, and the microwave drying time for four levels were 150 s, 115 s, 85 s, and 60 s, respectively. For the experiment on ginseng slice thickness analysis, the SW was fixed at 50%, and the far-infrared drying temperature was set at 60 °C. Four levels of ginseng slice thickness, i.e., 1 mm, 2 mm, 3 mm, and 4 mm, were used. In the experiment on far-infrared drying temperature, the SW was fixed at 50%, and the ginseng slice thickness was set at 2 mm. Four levels of far-infrared drying temperature, i.e., 50 °C, 55 °C, 60 °C, and 65 °C, were used for this propose.

Determination of quality indicators

Drying time

The initial water content was determined as follows. After determining the initial weight, the ginseng sample was dried for 24 h at 105 °C to obtain the dry weight. The initial water content was calculated by dividing the dry weight by the initial weight with reference to GB/T5009.3-2003, which was national stipulation about determination of moisture in foods, and made by National Health Commission of the People's Republic of China (NHCPRC, 2003). During the drying process, ginseng slices were quickly weighed on an electronic balance every 5 min. Based on the weights, water content was calculated. When the ginseng slice water content reached $5 \pm 1\%$, the drying time was obtained. The water content was calculated using the following formula (Choi et al., 2008; Kim, 2003):

$$\text{Water content (Wt)} = \frac{Mt - Mg}{Mt} \times 100 = \frac{Mt - Mo(1 - Wo)}{Mt} \times 100 \quad (1)$$

where Mt is the weight of ginseng slices at time t (g); Mg is the dry weight of the ginseng slices (g); Mo is the initial weight of the ginseng slices (g); Wo is the initial water content of the ginseng slices (%).

Colour difference

The surface colour of ginseng slice was measured using a colorimeter (CR400, C.T.S. Co., Tokyo, Japan). Surface colour was measured on the basis of lightness (L) [black (0) to white (100)], redness (a) [red (60) to green (− 60)] and yellowness (b) [yellow (60) to blue (− 60)] values from 3 parts of the ginseng slice before and after drying, and 6 samples were used to measure the colour values. Total colour difference (ΔE) was calculated using the following equation (Le and Jittanit, 2015; Serowik et al., 2017):

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \quad (2)$$

where ΔE is total colour difference and ΔL , Δa , and Δb indicate the changes in lightness, redness and yellowness, respectively, before and after drying.

Ginsenosides content

In this study, the ginsenoside content of the ginseng sample was first determined using a chemical method and then analysed using a spectrum-based non-destructive ginsenoside detection model established through hyperspectral imaging technology (Liu, 2015).

Sample pretreatment One gramme of ginseng was added to 10 mL of distilled water in a mortar and grinded to a paste. The mixture was transferred to a conical flask and diluted with 90 mL of distilled water. Then, the mixture was incubated for 15 min in a 60 °C water bath. After cooling to room temperature, the homogenate was centrifuged for 10 min using a H-1650 benchtop centrifuge to obtain a clear extract.

Ginsenoside extraction A standard curve was first generated as described below. Briefly, 10.5 mg of the reference ginsenoside Re was weighed precisely, transferred to a 10-mL volumetric flask, dissolved in methanol and diluted to the mark. Using deionized water as a blank, different volumes of the reference ginsenoside Re solution were taken. Each volume was added to 5.0 mL of 5% (W/V) vanillin glacial acetic acid and 0.5 mL of 70% (V/V) aqueous sulfuric acid solution. The solution was incubated for 15 min in a 60 °C water bath, cooled for 10 min, placed at room temperature for 10 min, and then analysed on a TU-1810 (Ha et al., 2014; Sun and Xu, 2012).

Surface shrinkage rate

The determination of the actual area shrinkage of a ginseng slice during the drying process is rather complicated. In this study, the projected area shrinkage was adopted as the

test indicator using the following calculation formula (Sappati et al., 2017):

$$R = (1 - S'/S) \times 100\% \quad (3)$$

where R is the surface area shrinkage rate (%); S' is the projection area of the dried ginseng slice (mm^2); S is the initial projection area of the ginseng slice (mm^2).

As shown in Fig. 1, to use Matlab image processing functions, ginseng slices were first arranged on a standard plate and photographed to obtain the original image as well as the background image. Then, the background image was removed using the Matlab program, and the image that had background removed was subject to binarization. Given the known area of the standard plate, the proportion of the ginseng slice area to the standard plate area was obtained using the Matlab program. Thus, the ginseng slice area was obtained (Sui, 2016).

Statistical analysis

The results reported here are mean values of 3 independent experiments. Statistical analysis was conducted using SAS 9.1.3 (Charlotte, Cary, USA). Differences among mean value of data were determined using Duncan's multiple range test and one-way analysis of variance (ANOVA) with a significance level of 0.05.

Result and discussion

Microwave drying of ginseng slices

The experiment was conducted according to the experimental plan and repeated thrice. The average of the measurements was used as the result, as shown in Table 1.

Table 1 demonstrated that in terms of the effect of different time periods of microwave drying on the drying quality of ginseng slices (surface colour, ginsenosides content, and surface shrinkage rate), as the drying time

Fig. 1 Illustration of the ginseng slice area measurement by MATLAB image processing function

Table 1 Changes in the test indicators in the drying process

Indicators	Drying time (s)		
	90	120	150
Colour difference (ΔE)	2.65 ^b	3.05 ^b	4.09 ^b
Ginsenosides content (mg mL ⁻¹)	0.14 ^c	0.09 ^c	0.025 ^c
Surface shrinkage rate (%)	5.3 ^a	12.26 ^a	25.83 ^a

Means with different letters are significantly different by Duncan's multiple range test ($p < 0.05$)

increased from 90 to 150 s, the surface colour difference increased from 2.65 to 4.09, and the surface shrinkage rate increased from 5.3 to 25.83%. These observations can be explained by the fact that the stability of pigments reduced and cell tissue destroyed with increasing drying duration and temperatures (Gálvez et al., 2008). For the ginsenosides content, UV-visible spectrophotometer to measure the absorbance at the wavelength of 544 nm based a standard curve; i.e., $Y = 0.48 + 2.836 X$. The correlation coefficient (r) of the curve was 0.999. The ginsenosides content decreased from 0.14 to 0.025 mg mL⁻¹, when the drying time increased from 90 to 150 s. This was probably the result of the ginsenosides denaturalization and the first-level glycosidic bond damage produced by high drying temperature and long drying time (Gao et al., 2015). In addition, severe curling and deformation occurred on the edge of the slice. Therefore, the microwave drying time cannot exceed 150 s, and ginseng slice water content cannot be less than 50%.

The analysis demonstrates that the longer the microwave drying time, the lower the water content of the ginseng slice. Drying increased the temperature on the interface of the ginseng slice, increasing the surface colour difference and the loss of main nutrient components as well as deforming the slice edge. The microwave test indicated that the microwave drying time cannot exceed 150 s. The water content of the ginseng slice cannot be less than 50%; otherwise, it will cause overheating in some areas of the

slice, leading to scorching and curling as well as severe damage to the nutritional ingredients.

Single factor experiment on microwave and far-infrared combination drying

Effect of SW on drying quality indicators was shown in Table 2. It demonstrates that changes in SW had a significant impact on surface colour difference. When the SW 50%, the surface colour difference was the highest. When the SW was 55% or 60%, the surface colour difference was the lowest. This finding is attributed to the fact that when the SW was 50%, the microwave drying time of the white ginseng slice was the longest, requiring a microwave drying temperature that is too great and increased variation in the surface colour difference of the slices. When the SW was too high or too low, the surface colour difference was increased, thus reducing the quality of the product. When the SW was 55%, the colour difference was the lowest. The pattern of the influence of SW on drying time revealed that as the water content increased from 50 to 65%, the drying time continued to increase. This finding is due to the fact that the microwave drying rate was faster than that of far-infrared drying. If the microwave drying time is increased, the water content is more rapidly reduced, thereby reducing the total drying time. However, as described above, a long microwave drying time would cause qualitative changes in the nutritional ingredients of ginseng. Thus, microwave drying should not be conducted for too long if the water content of ginseng slices is less than 50%. In addition, as the SW increased from 50 to 65%, the ginsenosides content first increased significantly and then decreased. The maximum content of ginsenosides emerged when the SW was 60%. In contrast, as the SW increased from 50 to 60%, the surface shrinkage rate significantly decreased. When the SW decreased to 60%, the surface shrinkage rate started to increase. When the SW is too low, such that microwave drying takes too long, the high temperature causes the ginseng slice to curl and even to char. Thus, the SW cannot be too low. Generally, when the SW was 60%, it showed a

Table 2 Effect of heating mode switching point water content on drying quality indicators

Switching point water content (%) ¹	Indicators			
	Colour difference (ΔE)	Surface shrinkage rate (%)	Ginsenosides content (mg mL ⁻¹)	Drying time (min)
50	12.05 ^{a2}	17.36 ^a	0.33 ^c	43 ^d
55	6.34 ^c	15.28 ^b	0.53 ^b	65 ^c
60	6.73 ^c	9.63 ^d	0.64 ^a	80 ^b
65	9.79 ^b	12.34 ^c	0.27 ^c	90 ^a

¹The Switching point water content is the moisture content at the conversion point between the microwave and far-infrared techniques

²Means with different letters are significantly different by Duncan's multiple range test ($p < 0.05$)

Fig. 2 Effect of slice thickness on drying quality indicators. Means with different letters (A–D) are significantly different by Duncan's multiple range test ($p < 0.05$). The vertical bars represent the standard errors of three replicates

smaller colour difference, lower surface shrinkage rate and higher ginsenosides content.

The influence of slice thickness on surface colour difference, ginsenosides content and surface shrinkage rate are shown in Fig. 2. As slice thickness increased from 1 to 4 mm, the colour difference first decreased significantly and then increased. The lowest point was noted when slice thickness was 2 mm. As the drying time continued to increase as slice thickness increased, the internal moisture migration process within the ginseng slice was slower, making it even more difficult for moisture to evaporate and thereby increasing the total drying time (Kamil and Ahmet, 2004). As slice thickness increased from 1 to 4 mm, ginsenosides content first significantly increased to 0.61 mg mL^{-1} and then declined. The maximum value was achieved when slice thickness was 3 mm. When the

slice is thin, the amount of ginseng tissue is reduced. Thus, its nutritional ingredients are more vulnerable to heat damage. However, when slice thickness reaches 4 mm, ginsenosides loss increases due to the elongated total drying time, leading to the reduction in ginsenosides content. In contrast, as the slice thickness increased, the surface shrinkage rate first significantly decreased and then increased. The lowest point was noted when slice thickness was 3 mm. This result means that slice thickness had a significant effect on drying quality indicators ($p < 0.05$).

The influence of far-infrared drying temperature on surface colour difference, ginsenosides content and surface shrinkage rate are shown in Table 3. As far-infrared temperature increased from 50 to 65°C , the surface colour difference first significantly decreased. When the temperature was 55°C , the surface colour difference was the lowest and

Table 3 Effect of far-infrared drying temperature on drying quality indicators

Far-infrared drying temperature (°C)	Indicators			
	Colour difference (ΔE)	Surface shrinkage rate (%)	Ginsenosides content (mg mL^{-1})	Drying time (min)
50	13.5 ^{a1}	16.67 ^a	0.42 ^a	60 ^a
55	5.71 ^d	15.56 ^{ab}	0.45 ^a	55 ^{ab}
60	6.34 ^c	13.78 ^b	0.33 ^b	47 ^b
65	8.44 ^b	14.36 ^b	0.27 ^c	41 ^c

¹Means with different letters are significantly different by Duncan's multiple range test ($p < 0.05$)

began to increase. This finding is due to the fact that too high a drying temperature or too long a drying time will cause damage to the molecular structure of ginseng components, leading to the increased colour difference (Gálvez et al., 2008; Ning and Han, 2013). As the far-infrared drying temperature increased, the ginsenosides content first increased and then decreased. When the far-infrared drying temperature was 55 °C, the ginsenosides content reached its maximum value of 0.45 mg mL^{-1} . As the far-infrared drying temperature increased, the surface shrinkage rate initially increased and then decreased, reaching its lowest value of 13.78% when the far-infrared drying temperature was 60 °C. As the far-infrared drying temperature increased, the drying time exhibited a continuous decreasing trend. This result is attributed to the notion that an increased far-infrared drying temperature increases water molecule migration and subsequently reduces the total drying time.

Comparison of drying method on drying quality indicators

The comparison of drying method on drying quality indicators is shown in Table 4. The drying time for single far-infrared drying with drying temperature of 50 °C, 55 °C, 60 °C and 65 °C were 200, 177, 140 and 87 min, respectively. When the combination drying with SW was fixed at 50%, the total drying time were 63, 58, 46 and 36 min with the drying temperature of 50 °C, 55 °C, 60 °C and 65 °C, respectively. The single far-infrared drying time was 3–3.5 days longer than combination drying under the same far-infrared drying temperature. Because in the case of combination drying, the first drying stage was used microwave drying method, which drying rate is fast, heat efficiency is high, and the rate of heat loss is low (Ning, 2012). At the same time, the combination drying showed higher ginsenosides contents value, and lower surface shrinkage rate than single far-infrared drying. Because for the combination drying, the drying time was shorter, the destruction of ginsenosides components and surface tissue

Table 4 Effect of drying method on drying quality indicators

Drying method	Far-infrared drying temperature (°C)	Drying time (min)	Colour difference (ΔE)	Ginsenosides content (mg mL^{-1})	Surface shrinkage rate (%)
Combination drying ¹	50	63 ^{e2}	13.7 ^a	0.42 ^a	16.67 ^c
Single far-infrared drying		200 ^a	2.93 ^f	0.12 ^c	20.52 ^{b,c}
Combination drying	55	58 ^{e,f}	5.71 ^{c,d}	0.45 ^a	15.56 ^{c,d}
Single far-infrared drying		177 ^b	3.17 ^{e,f}	0.11 ^c	22.31 ^b
Combination drying	60	46 ^f	6.34 ^c	0.33 ^b	13.78 ^d
Single far-infrared drying		140 ^c	3.43 ^e	0.09 ^c	25.63 ^{a,b}
Combination drying	65	36 ^f	8.44 ^b	0.27 ^b	14.36 ^d
Single far-infrared drying		87 ^d	4.99 ^d	0.08 ^c	27.69 ^a

¹The heating mode switching point water content was fixed at 50%, and the ginseng slice thickness was set at 2 mm

²Means with different letters are significantly different by Duncan's multiple range test ($p < 0.05$)

were less than that of single far-infrared drying (Raksakantong et al., 2012). However, the ΔE values of combination drying were higher than single far-infrared drying. These observations can be explained by the fact that the microwave drying temperature is high, the stability of pigments reduced with high drying temperatures (Gálvez et al., 2008).

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