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# Drying of steamed Asian ginseng (*Panax ginseng*) roots by microwave-hot air combination

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Steamed Asian ginseng (*Panax ginseng*) roots were dried by a combined microwave-hot air method in a modified experimental microwave oven. Hot air drying was used as a reference method. The drying time to achieve the desired moisture level (10%) as well as the ginsenoside contents and the color of the final product were determined. The ginsenosides $Rb_1$, $Rb_2$, Rc, Rd, Re, Rf, $Rg_1$ and Ro were analyzed by HPLC. Compared with hot air drying, the combined microwave-hot air drying method resulted in a substantial decrease (approximately 30–40%) in drying time and had little influence on the ginsenoside contents and the color of the final product.

## 1. Introduction

Asian ginseng (*Panax ginseng*) is the most famous ginseng species in the world, whose roots and leaves are used as Chinese traditional medicine and health food. Asian ginseng is native to China, Korea and Russia, and its wild type is very rare. It is estimated that the annual worldwide production of dry wild Asian ginseng roots is less than 150 kg [1, 2]. Most of the Asian ginseng roots on the market are cultivated ones. China and South Korea are the main producers. The two countries produced about 20 000 metric tons fresh Asian ginseng roots in 1991 [3, 4]. The minor producers Japan, North Korea and Russia produced about 100–150, 50–70, 5–7 metric tons of dried roots, respectively [5].

Ginsenosides are the main active constituents of both Asian and American ginseng, which include neutral ginsenosides, malonyl-ginsenosides and the oleanolic acid-type ginsenoside. They have many important biological and pharmacological activities, including anti-tumor, chemopreventive, antiphlogistic, immunomodulating and antidiabetic activities, and activities on the cardiovascular system, the central nervous system and the endocrinal system [6–8]. The most abundant ginsenosides present in white Asian ginseng are the neutral ginsenosides $Rb_1$, $Rb_2$, Rc, Rd, Re, Rf, $Rg_1$, $Rg_2$, malonyl-ginsenosides m-$Rb_1$, m-$Rb_2$, m-Rc and oleanolic acid-type ginsenoside Ro.

Usually, high-quality fresh Asian ginseng roots are chosen for preparing red Asian ginseng, which is one of the most popular Asian ginseng products. Red Asian ginseng can reinforce the vital energy, remedy collapse, and restore the normal pulse, invigorate *'qi'* and arrest bleeding [9]. Production of red Asian ginseng involves two steps. First, fresh roots are steamed for 2 h, then the steamed roots are dried at 60 °C for long time until the moisture content of the roots drops to less than 13%.

Drying is a crucial step in red Asian ginseng preparation, and traditionally the drying methods are open air or hot air drying. The drawbacks are long drying time and/or large energy consumption. To save energy and shorten the treatment time, many new drying methods are introduced. In the 1980s, Korean ginseng researchers developed a closed solar collector system, by which red ginseng with good brown color was produced [10]. However, the drying process is apparently limited by weather conditions.

Combined microwave-hot air drying is a relatively new drying technique, which can greatly reduce the drying time of many plant materials, without damaging the quality attributes of the final products. Plant materials investigated using microwave techniques include grapes [11], carrots [12], potatoes [13, 14], blueberries [15], onion [16], American ginseng [17] and the other medicinal plants [18–20].

This new drying technology has not yet been applied to steamed Asian ginseng. The objective of this study was to investigate the drying time required, the ginsenoside contents and the color of the red Asian ginseng dried by the combined microwave-hot air method.

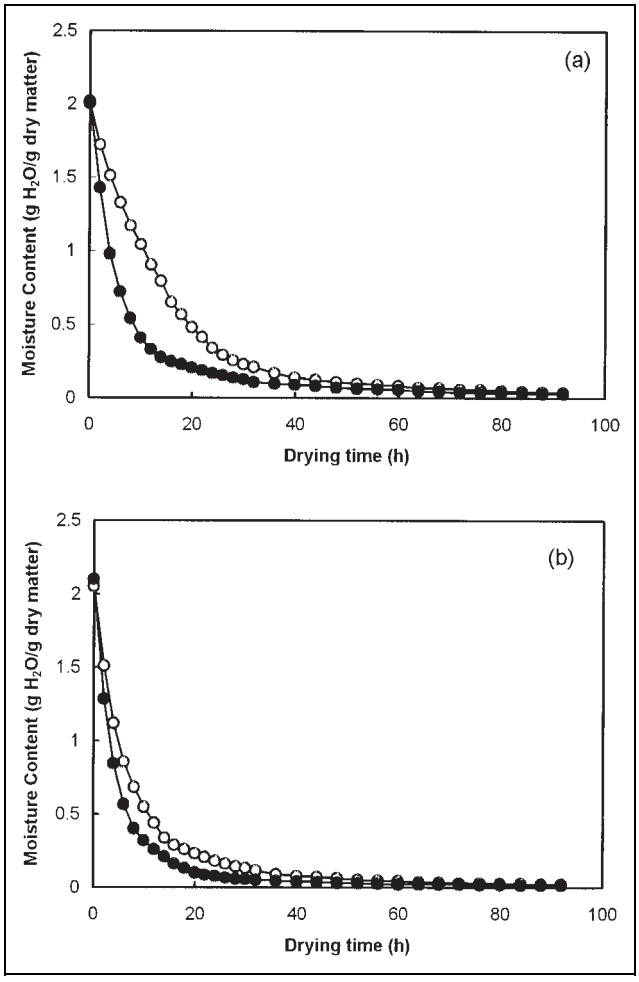


Fig. 1: Drying curves for small (●) and large (○) steamed Asian ginseng roots by hot air drying (a) and by combined microwave-hot air drying (b)

## 2. Investigations, results and discussion

### *2.1. Drying curves*

The steamed Asian ginseng roots were dried as follows: hot air drying of small ones (18 mm diameter) (HS); hot air drying of large ones (26 mm diameter) (HL); combined microwave-hot air drying of small ones (18 mm diameter) (MS); and combined microwave-hot air drying of large ones (26 mm diameter) (ML).

The moisture content versus time curves for drying of steamed Asian ginseng roots as influenced by size (18 and 26 mm in diameter) are shown in Fig 1. Obviously, as the size of the roots increases, the time required to achieve a certain moisture level will increase. For example, the drying times for reaching 10% moisture content of HS and HL were 33.8 h and 50.6 h, respectively. These results were similar to previous reports [21]. A similar trend was also found in American ginseng drying [17, 22].

The moisture content versus time curves for drying of steamed Asian ginseng roots as influenced by the drying method (hot air and combined microwave-hot air drying) are shown in Fig. 2. As the additional microwave power was introduced, the drying time was significantly reduced. For example, the drying times required for reaching a 10% moisture level for HL and ML were 50.6 and 34.4 h, respectively. The drying time was reduced by 32.0% by the combined microwave-hot-air drying. A similar result was obtained for HS and MS, where the drying time was reduced by about 40% with the new method.

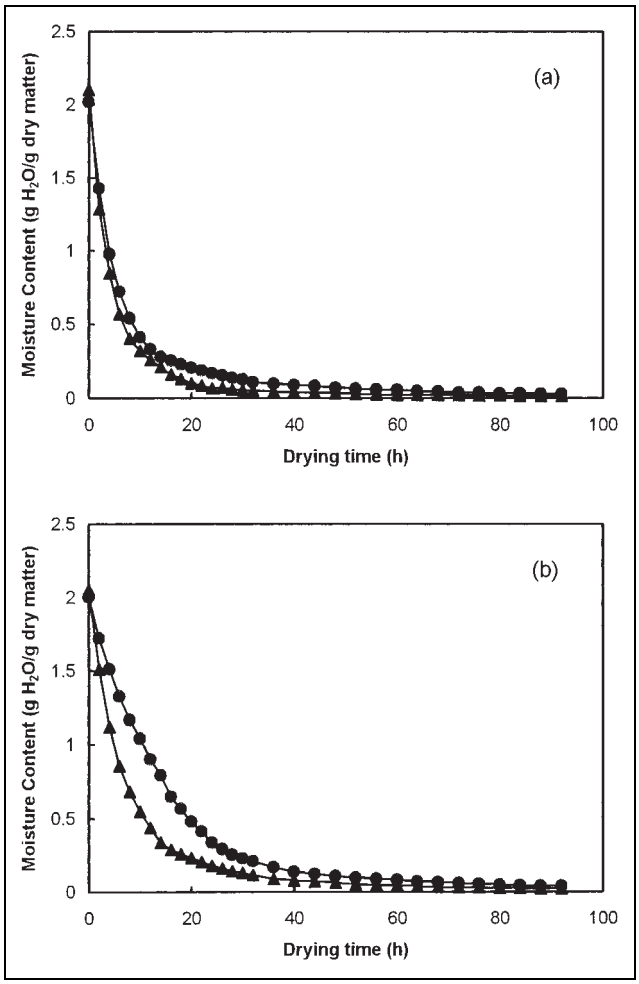


Fig. 2: Drying curves for small (a) and large (b) steamed Asian ginseng roots by hot air (●) and combined microwave-hot air (▲) drying

Usually, the desired final moisture content of dried red Asian ginseng is about 10% (dry basis). The drying time required for reaching this moisture content was significantly different from each other for all the above cases at a 0.01 level. This indicated that the drying time required was significantly reduced ($P < 0.01$) as microwave was introduced, and the drying time requirement was significantly prolonged ($P < 0.01$) as the root size increased (i.e. from 18 to 26 mm diameter).

Since the initial moisture content of steamed Asian ginseng roots used in this study was relatively constant, the different drying time required was mainly due to the difference in drying rate. The drying rate curves are shown in Fig. 3, which indicate that the drying rates were different from each other, and reduced during the drying process. The drying rates of HL and ML were lower than those of HS and MS, respectively. This may be caused by a higher internal resistance of bigger roots to water diffusion due to longer distance between the internal center and root surface. The accelerated drying rate of MS and ML exhibited in the initial stage. Similar phenomena were found in the case of grapes [11], carrots [12], potatoes [13, 14] and American ginseng roots [17]. The moisture content of the steamed Asian ginseng roots during the initial part of drying was higher, and this high moisture content was responsible for higher microwave absorption,

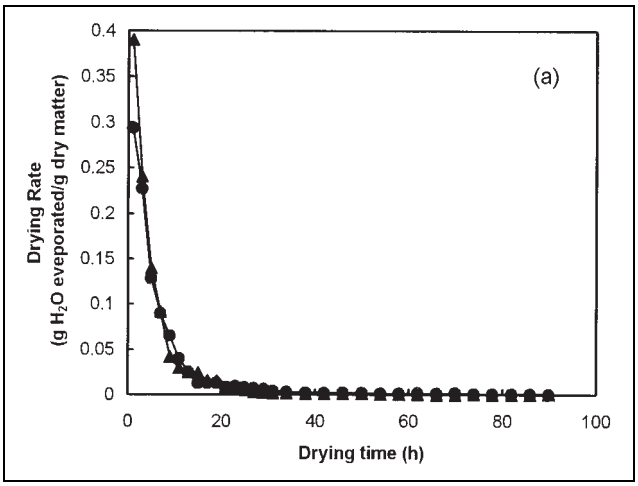


Fig. 3a: Drying rate curves for small steamed Asian ginseng roots by hot air (●) and combined microwave-hot air (▲) drying

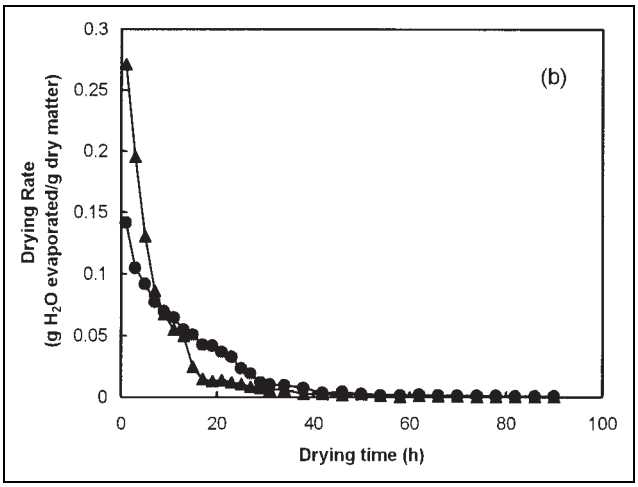


Fig. 3b: Drying rate curves for large steamed Asian ginseng roots by hot air (●) and combined microwave-hot air (▲) drying

**Table 1. Parameters of Page's model for drying of steamed Asian ginseng roots at 60 °C of inlet air temperature**

| Diameter of roots (mm) | Microwave power (W) | n | k | R |
|---|---|---|---|---|
| 18 | 0 | 0.6507 | 0.3375 | 0.97 |
| 18 | 60 | 0.6446 | 0.4117 | 0.98 |
| 26 | 0 | 0.8615 | 0.1797 | 0.99 |
| 26 | 60 | 0.6897 | 0.2932 | 0.98 |

which led to an increased heating temperature and moisture removal. The effect of microwave energy on drying rate was gradually reduced as the drying progressed.

### *2.2. Modeling drying curves*

The empirical Page's model described by eq. (1) has been used to characterize hot air drying kinetics [23] and the combined microwave-hot air drying kinetics [17] for American ginseng roots. That is,

$$MR = \exp(-kt^n) \quad (1)$$

where MR (moisture ratio $= (M - M_e)/(M_o - M_e)$; M = moisture content (kg moisture $kg^{-1}$ dry matter) at time t; $M_o$ = moisture content (kg moisture $kg^{-1}$ dry matter) at time =0; $M_e$ = equilibrium moisture content (kg moisture $kg^{-1}$ dry matter); and k and n are parameters.

The parameter data from the hot air drying and the combined microwave-hot air drying were used to test the applicability of eq. (1). The equilibrium moisture content was assumed to be the final moisture content (1.9–2.3%, dry basis) of each run. The parameters k and n of eq. (1) were evaluated using nonlinear regression. The results are shown in Table 1. The statistic analysis yielded high values of $R^2$ (0.97 and 0.99) for hot air drying. The fitness between the model prediction and experimental data is illustrated in Fig. 4. The values of $R^2$ for combined microwave – hot air drying of small and large sizes of the Asian ginseng roots were 0.98 and 0.98 (Table 1), respectively, which also indicated a good fit of the model. The fitness is also shown in Fig. 5.

### *2.3. Color of the products*

The color of the final product is crucial to its acceptance by the market. For steamed Asian ginseng drying, the temperature ranged from 55 °C to 75 °C [24], and 60 °C was considered as a suitable temperature, at which the color of the final products was used as a reference.

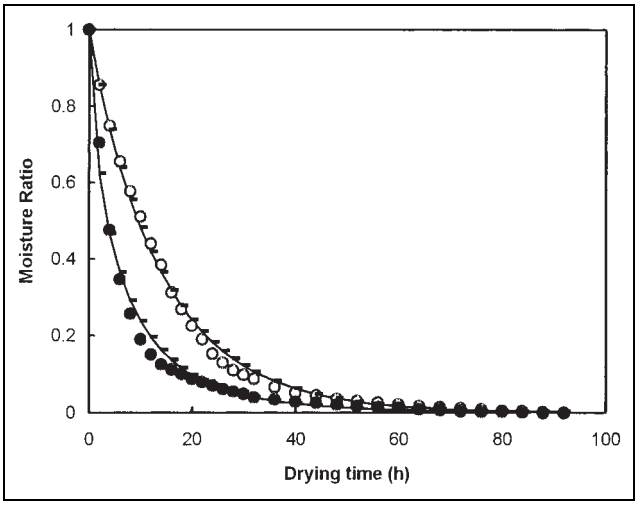


Fig. 4: Moisture ratio vs. time, comparing experimental curve with the predicted one (–) by Page's equation for hot air drying of small (●) and large (○) steamed Asian ginseng roots

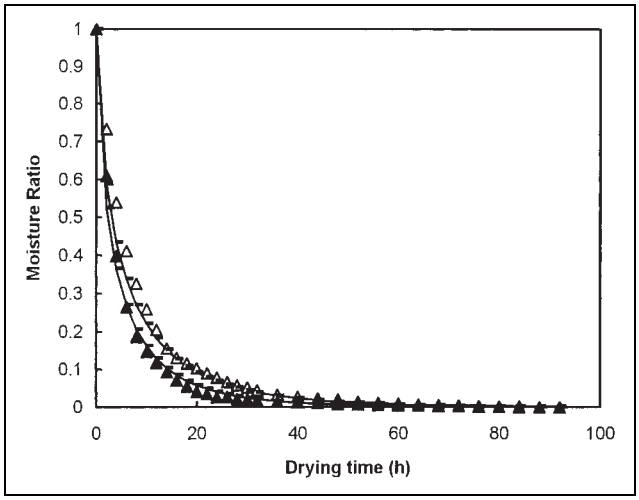


Fig. 5: Moisture ratio vs. time, comparing experimental curve with the predicted one (–) through Page's equation for combined microwave-hot air drying of small (▲) and large (△) steamed Asian ginseng roots

The effects of drying methods on the color attributes (L, a, b and a/b) of red Asian ginseng roots are shown in Table 2. Statistical analyses of the color parameters L, a, b and a/b revealed that the addition of microwave power did not affect product color. Color changes in the products are usually due to browning during drying, which largely depends on drying temperature and time. Browning increases with an increase in drying temperature and/or time [24]. Although the temperature in the central part of the ginseng roots under microwave-hot air drying conditions was higher than that under hot air drying conditions, the microwave-hot air drying required a much shorter time to reach the suitable moisture content.

**Table 2. Effects of drying methods on the color attributes ( L, a, b and a/b ) of dried Asian ginseng roots**

| Diameter of roots (mm) | Microwave power (W) | L | a | b | a/b |
|---|---|---|---|---|---|
| | | Mean | Mean | Mean | Mean |
| 18 | 0 | 81.45 | 3.85 | 25.00 | 0.15 |
| 18 | 60 | 80.69 | 4.17 | 26.54 | 0.16 |
| 26 | 0 | 81.96 | 3.91 | 25.28 | 0.15 |
| 26 | 60 | 81.17 | 3.83 | 25.57 | 0.15 |

By understanding the relationship between color and drying temperature, we can determine the suitable temperature range for drying of steamed Asian ginseng roots. In this study, the temperature in the central part of steamed Asian ginseng roots during combined microwave-hot air drying was about 66 °C, which was higher than the surface temperature of the ginseng roots. At this temperature, no undesirable color was observed.

### *2.4. Ginsenosides*

As shown in Fig. 6 (HPLC of white Asian ginseng extract) and Fig. 7 (HPLC of red Asian ginseng extract), the chromatographic separation of neutral ginsenosides, malonyl-ginsenosides and the oleanolic acid-type ginsenoside (Ro) in a single run was achieved by linear gradient elution. The peaks of the eight neutral ginsenosides, three

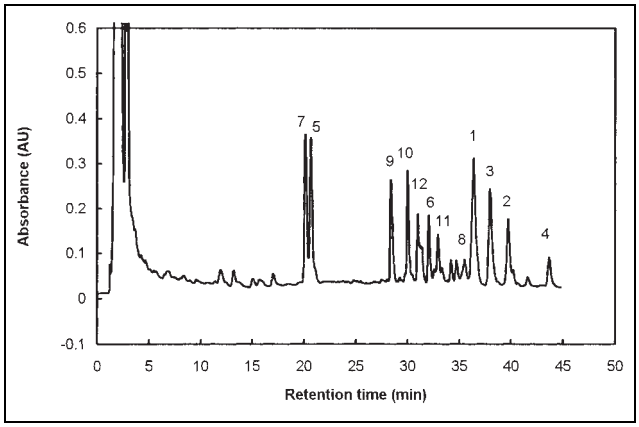


Fig. 6: HPLC chromatogram of ginsenosides in white Asian ginseng (*Panax ginseng*) extracts. $Rb_1$ (1), $Rb_2$ (2), Rc (3), Rd (4), Re (5), Rf (6), $Rg_1$ (7), $Rg_2$ (8), Ro (9), (10), m-$Rb_2$ (11), m-Rc (12)

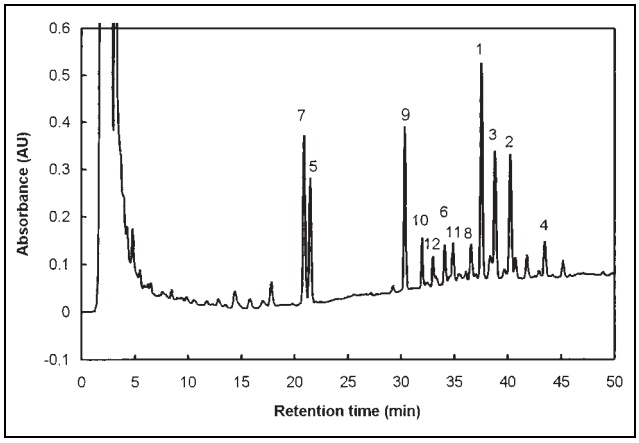


Fig. 7: HPLC chromatogram of ginsenosides in red Asian ginseng (*Panax ginseng*) extracts. $Rb_1$ (1), $Rb_2$ (2), Rc (3), Rd (4), Re (5), Rf (6), $Rg_1$ (7), $Rg_2$ (8), Ro (9), m-$Rb_1$ (10), m-$Rb_2$ (11), m-Rc (12)

malonyl-ginsenosides and one oleanolic acid-type ginsenoside were well resolved. In agreement with published results [25–27], the protopanaxtriol derivatives, $Rg_1$ and Re, eluted ahead of Ro, m-$Rb_1$, m-Rc, Rf, m-$Rb_2$ and $Rg_2$, and the protopanaxdilo derivatives, $Rb_1$, $Rb_2$, Rc and Rd, eluted last.

Figs. 6 and 7 also show that white Asian ginseng contains relatively high contents of malonyl-ginsenosides. This is because that malonyl-ginsenosides are thermally unstable, which degrade to corresponding neutral ginsenosides during red ginseng preparation (steaming and drying). The main active components of red Asian ginseng are the neutral ginsenosides $Rb_1$, $Rb_2$, Rc, Rd, Re, Rf, $Rg_1$ and Ro [26, 24, 28].

Fig. 8 shows the ginsenoside contents of large and small red ginseng dried by hot-air and combined microwave-hot air methods. No significant difference in ginsenoside content was found between the two methods ($p < 0.01$). The possible explanation may be as follows. Ginsenosides in steamed ginseng may thermally degrade during drying. The degradation depends on the drying time and temperature. The longer the drying time, the higher the degradation amount. In combined microwave-hot air drying, although the temperature is higher than for the hot-air method, the drying time is shorter. So the effects of a higher drying temperature may be compensated by the shorter drying time. The ginsenoside degradation in both water and ethanol-water were not enhanced by microwave radiation [29]. Degradation of many pharmacological active compounds in certain plants was not enhanced by microwave heating [20].

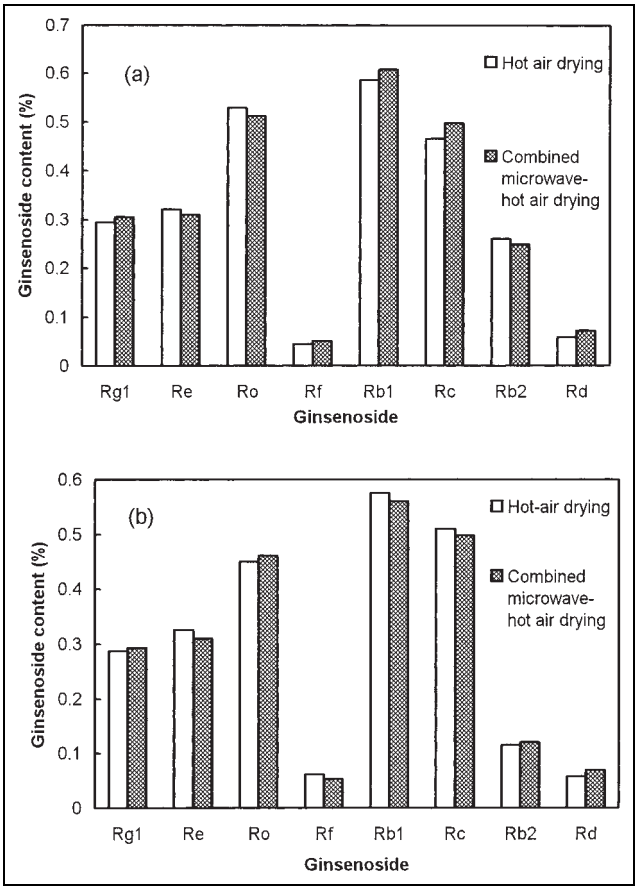


Fig. 8: Ginsenoside contents in small (a) and large (b) red Asian ginseng (*Panax ginseng*) dried by hot air and combined microwave -convective hot air methods

In conclusion, the combined microwave-hot air drying method is very efficient for preparing red Asian ginseng. By this method, the drying rate is enhanced and the drying time is reduced. The empirical Page's model could adequately describe the drying data. The combined microwave-hot air drying has little influence on the color and individual ginsenoside content of the final products (red ginseng) as compared to the hot air drying.

## 3. Experimental

### *3.1. Fresh Asian ginseng roots*

The fresh Asian ginseng (*Panax ginseng*) roots were obtained from the Institute of Special Plants and Wild Animals, Chinese Academy of Agricultural Sciences, Jilin City, People's Republic of China. They were stored at 4 °C in a refrigerator before use.

### *3.2. Drying apparatus*

The drying apparatus consisted of two parts – a laboratory microwave oven and a hot air drying unit. The laboratory microwave oven (Lavis-100 MultiQUANT) operated at 2450 MHz. The energy emission was microprocessor controlled from 10 W to 1000 W at 10 W increments. Three outlets were provided on the left upper side of the oven for insertion of temperature sensors, while another one was on the right top of the oven for introduction of hot air and a thermocouple. The dimensions of the microwave cavity were 345 mm × 340 mm × 225 mm. The microwave oven was operated by a control terminal which could control both microwave power level and emission time (1 s – 100 h).

The hot air drying unit consisted of a blower, a valve, an electric heater, a temperature controller, a rotameter, a glass tube and a sample container. The heater was a dual-element heating tape (Model 36050–10, Cole-Parmer International, U.S.A.) which twined about the glass tube. The temperature controller (WMZK-01, Shanghai Medical Instrument and Meter Plant)

was able to control the temperature range of 10–100 ± 1 °C. The rotameter (Model F-2560, Cole-Parmer International, U.S.A.) could measure the air flow from 3 l to 77 l/min ± 3%. The glass tube had an internal diameter of 20 mm and an external diameter of 24 mm. The sample container was a microwavable one (640 ml) which had one large hole (25 mm) and 16 small holes (2 mm each). The small holes were located on 4 sides (3 holes/side) and the top (4 holes), while the large hole was on the right central part of the top from which hot air was introduced through the glass tube.

### *3.3. Drying procedure*

Before the start of each drying run, about 200 g of the fresh Asian ginseng roots were selected, according to their diameters (i.e., 18 or 26 mm). The roots were washed to remove soil, and then steamed for 2 h. Half of the steamed roots were used for drying tests, while the rest were used for moisture determination (using a vacuum oven, 70 °C for 24 h).
The fresh Asian ginseng roots were dried by hot air and combined microwave-hot air, respectively. For hot air drying, the air temperature and flow rate were kept at 60 °C and 60 l/min, respectively. For combined microwave-hot air drying, an additional microwave power (60 W) was introduced. During drying, at an early stage, the roots were weighed every 2 h, and then weighed every 4 h. All the experiments were repeated for three times.

### *3.4. Color measurements*

The red Asian ginseng roots were cut into small pieces, then ground with a blender, and screened using a 200 mesh sieve. The chromaticity of the powder was measured in L (the degree of lightness), a (the degree of redness) and b (the degree of yellowness) coordinates using a Chroma Meter (Minolta Chroma Meter, CR-300, Minolta Camera CO. Ltd.). The Chrom Meter was calibrated against a standard calibration plate of a white surface with L, a and b values of 97.38, 0.02 and 1.55, respectively. The measurements were replicated three times, and the average for L, a and b of each sample were recorded.

### *3.5. Extraction of ginsenosides*

Ground ginseng samples (1.000 g) were transferred to 15-ml centrifuge tubes followed by addition of 10 ml of $CH_3OH/H_2O$ (7 : 3). The sample tubes were horizontally placed on a shaker at 100 rpm for 2 h at room temperature. The sample tubes were then centrifuged at 4000 rpm (10 min) and the solvent was removed. The extraction was repeated for additional two times. The combined extracts were concentrated to less than 10 ml at room temperature. The concentrated extracts were diluted to 10 ml with 70% methanol, and then kept at 4 °C in a refrigerator. Before ginenoside analysis, the concentrated ginseng extract was centrifuged at 13000 rpm for 10 min, and the supernatant (20 μl) was subjected to HPLC separation.

### *3.6. High-performance liquid chromatography*

HPLC was conducted on a Waters liquid chromatography equipped with two 510 pumps and a UV spectrophotometric detector. The Asian ginseng extract solution was separated and analyzed (20 μl aliquots) by using a Merck Superspher RP-18 endcapped column (250 × 4.0 mm; 5 μm) at room temperature. The mobile phase consisted of solvent A (acetonitrile) and solvent B (phosphate buffer solution). Solvent B was prepared by dissolving 3.50 g $KH_2PO_4$ in 2500 ml $H_2O$ and adjusting the pH to 5.81 with a concentrated solution of $K_2HPO_4$ (35 g/100 ml). For the simultaneous separation of ginsenosides and malonly-ginsenosides, the following gradient procedure was used: 0–25 min, 20–25% A, 80–75% B; 25–37 min, 25–32% A, 75–68% B; 37–50 min, 32–40% A, 68–60% B; 50–52 min, 40–100% A, 60–0% B; 62–65 min, 100–20%A, 0–80% B. The flow rate was kept constant at 1.0 ml/min. The absorbance was measured at a wavelength of 203 nm to facilitate the detection of ginsenosides. Chromatographic peaks were identified by comparing retention times against known standards, and by comparing their retention time with published data [25–27]. The standard ginsenosides $Rb_1$, $Rb_2$, Rc, Rd, Re, Rf and $Rg_1$ are purchased from Extrasynthese (Genay, France), and ginsenoside Ro was obtained from the Institute of Special Plants and Wild Animals, Chinese Academy of Agricultural Sciences, Jilin City, People's Republic of China.

### *3.7. Statistic analysis*

Modified LSD (Bonferroni) test was used for analyzing the drying time, the color parameters and ginsenoside contents. Sigma Plot (Scientific Graph System, version 5.00, Jandel Corp.) was used for mathematical modeling (Page's equation).

Acknowledgements: This research was supported by the research Grant Council of Hong Kong and the University of Hong Kong Committee on Research and Conference Grant.

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Received July 14, 1999
Accepted August 5, 1999

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