Effect of drying technologies on quality of green tea

Xiangyang Lin[1], Lijing Zhang[1], Hanwu Lei[2], Hong Zhang[1],
Yanling Cheng[3,4], Rongbi Zhu[1], Roger Ruan[3,5]

(1. *College of Biological Science and Engineering*, *Fuzhou University*, *Fuzhou*, 350108, *China*;
2. *Center for Bioproducts and Bioenergy and Department of Biological Systems Engineering*, *Washington State University*, *Richland*, *WA* 99354, *USA*;
3. *Center for Biorefining and Department of Bioproducts and Biosystems Engineering*, *University of Minnesota*, *St. Paul*, *MN* 55108, *USA*;
4. *Biochemical Engineering College*, *Beijing Union University*, *Beijing* 100023, *China*;
5. *National Key Laboratory of Food Science*, *Nanchang University*, *Nanchang,* 330047, *China*)

Abstract: The quality of green tea was investigated by comparing four drying processes including hot-air drying, vacuum drying, microwave drying, and microwave vacuum drying. Results indicated that using microwave drying not only retained more nutrients but also produced green teas with less astringent taste with the lowest phenol-ammonia ratio among four different drying methods. The structure of tea cells was uniform and better maintained by microwave drying with/without vacuum. The highest score of sensory evaluation was obtained for the green tea by microwave vacuum drying. The tea quality can be assured by using microwave vacuum drying, which is a potential technology for green tea production.

Key words: Green tea, hot-air drying (AD), vacuum drying (VD), microwave drying (MD), microwave vacuum drying (MVD), and quality

Citation: Lin Xiangyang, Lijing Zhang, Hanwu Lei, Hong Zhang, Yanling Cheng, Rongbi Zhu, Roger Ruan. 2010. Effect of drying technologies on quality of green tea. International Agricultural Engineering Journal, 19(3): 30－37.

1 Introduction

During the manufacture of green tea, the drying process is a critical step for physical and chemical changes which affect the final tea quality. Measures of tea quality include structural, visual, thermal, sensory, nutritional and rehydration characteristics (Liang, 2007). A proper drying process and control is necessary not only to preserve and promote quality but also to minimize energy inputs. A suitable process method can be concluded by comparing different drying methods in order to find the best way to process food materials, such as sliced carrots (Lin, Durance and Scaman, 1998), shrimp (Lin, Timothy and Christine, 1999) and garlic (Li and Xu, 2004). The traditional drying method (e.g. hot air drying) is mainly used to manufacture green tea, however inconsistence of tea quality and low process efficiency are common problems in the traditional drying process (Xiao, 2004).

The heat pump drying technology has been applied to tea production. 32% of energy can be saved by using water heat pump drying compared to hot air drying for tea leaves (Xie, Song and Yang, 2006). The drying temperature can be controlled at a level to prevent loss of quality and a burnt taste (Xie, Song and Yang, 2006). Despite obvious technical advantages of heat pump drying technology, the drying rate is limited because of the low drying temperature. The cost for equipment maintenance is high due to the complex heating system. Chlorofluorocarbons (CFCs) are used in most of the heat pump drying equipment. However, CFCs are the most destructive chemicals to the environment. It has been proved that CFCs are a major cause of depletion of the

Received date: 2010-10-20 **Accepted date:** 2010-12-28

Correspondence author: Xiangyang Lin, PhD, Associate Professor, College of Biological Science and Technology, Fuzhou University, Fuzhou 350108, China. Phone: 86-591-22866375, Email: xylin@fzu.edu.cn; ibfulin@163.com

earth's stratospheric ozone layer (Chua, Chou and Ho, 2002; Kloticker, Schmidt and Steimle, 2002).

Microwave drying (MD) is a relatively new drying method. The fundamental mechanism of microwave heating is the agitation of polar molecules which oscillate under the influence of an oscillating electric and magnetic field. In the existence of an oscillating field, particles always try to orient themselves with the field. The activity of particles is restricted by resisting forces (for example electric resistance or interaction), which restrict the activity of particles and generate random movement, thus producing heat. The key advantage of the microwave heating over conventional heating method is the nature of fast internal heating by microwave energy. Microwave energy deposition in the dielectric loss mode of heating can cause spatially uniform heating. When applying microwave energy to tea, water and other polar molecules of tea are induced for simultaneous high-speed rotation due to microwave irradiation, leading to the surface and interior heating at the same time, and resulting in a large number of water molecules escaped from the tea (Lou, 2002). However crumple zone may be produced to affect the quality of tea due to high heating rate (Cai, 2005). Microwave vacuum drying (MVD) combines the advantages of microwave and vacuum. The MVD process can be operated at low temperatures with high efficiency and with the original color of food and heat-sensitive nutrients being better retained (Xu, Zhang and Mujumdar, 2004; Mujumdar, 2006).

The objective of this paper is to systematically compare four different drying processes including hot-air drying (AD), vacuum drying (VD), microwave drying (MD), and microwave vacuum drying(MVD) methods on the changes of tea quality, and analyze the feasibility of MVD as a new drying technology for green tea production.

2 Materials and methods

2.1 Materials

Green tea (Category: *Fuyun 6*) was picked from Gardening Experiment Field of the Fujian Agriculture and Forestry University. The initial moisture content of the green tea was 70%. The fresh leaves were fixed by microwave under 400 W. Table 1 indicated the nutrients of green tea before and after fixation.

Table 1 Retention of the fresh leaves and fixation leaves

%

Tea components	Amino acids	TP	Soluble sugar	protein	Caffeine
Fresh leaves	3.06	23.58	3.92	1.18	4.55
Fixation leaves	2.66	22.83	2.11	1.16	3.62

2.2 Experiment procedures and methods

Hot-air drying (AD) was conducted using a blast oven (DHG-9123, Shanghai Jinghong Laboratory Instrument Corporation, China). Vacuum drying (VD) was conducted using the blast oven with a vacuum pump (TW-2A, Wenling Tingwei Vacuum Instrument Corporation, China). Microwave drying (MD) and microwave vacuum drying (MVD) were conducted by a microwave furnace with/without vacuum (MZ08S-1, Nanjing Huiyan Microwave Systerm Engineering Corporation, China).

Drying conditions were determined after pre-experiments and 15 g of each sample was used for drying. Green tea was dried to a moisture content of 4%–5% using AD (75℃), VD (75℃, 95 kPa), MD (600 W) and MVD (600 W, 60 kPa) after pretreatments including unfold and rolling. The nutritional value, rehydration ratio, color and organizational structure were then determined. The reported parameters are the mean values of three observations.

2.2.1 Determination of tea nutrition

Green tea nutrients were determined by standard methods: amino acids by GB/T 8314-2002, polyphenols by GB/T 8313-2002, caffeine by GB/T 8312-2002, and water soluble sugars by Anthrone colorimetric method.

2.2.2 Determination of rehydration ratio

Five grams (5 g) of dried samples were soaked in 150 mL boiling water for 30 min. Rehydration ratio (R) was calculated by $R=Ma/Mb$, where Ma is tea weight after soaking, g; and Mb is tea weight before soaking, g.

2.2.3 Determination of color

One gram (1 g) of dried samples was soaked in 50mL boiling water for 3 min. The color parameters determined for the green tea included L, a, b values using a WSC-S colorimeter (Beijing AYK photoeletric instrument Corporation, China) for dried tea and a TCP2 automatic color measurement colorimeter (Shanghai Precision and Scientific instrument Corporation, China) for the tea soup. The colorimeters provided the values of three-color components: *L* (black-white component, luminosity), the chromaticity coordinates, *a* (green to red component), and *b* (yellow to blue component).

2.2.4 Determination of organizational structure

The organizational structures of dried tea were observed by using an electron microscope (YS100, Nikon Corporation, Japan).

2.2.5 Assessment of sensory quality

Sensory evaluation was conducted according to a standard method (GB/T23776-2009) (China Standard 2009). Dried green tea was first judged by visible sensation for color, degree of regularity, and tenderness. The internal quality (Fu, 2005; Gong, 2001) of green tea was then evaluated by adding 3 g of tea into 150 mL water for the following factors: 1) Liquid color, brightness, and transparency; 2) aroma type, strength, and persistence; 3) taste; and 4) tenderness, evenness, and color of bottom leaves.

A percentile score system was used to judge the quality of green tea for each sensory factor (Table 2). Respective weights were used for each factor according to the standard method: 0.30 for the shape of tea, 0.10 for tea soup color, 0.25 for aroma, 0.25 for taste, and 0.10 for bottom leaves. Scores for sensory evaluation of green tea is equal to the sum of given scores of the various factors multiplied by their respective weights.

Table 2 Standard table of sensory assessment

Project level	Shape of tea (30%)	Tea soup color (10%)	Aroma (25%)	Taste (25%)	Bottom leaves (10%)
1st	95-100	95-100	95-100	95-100	95-100
2nd	90-95	90-95	90-95	90-95	90-95
3rd	85-90	85-90	85-90	85-90	85-90
4th	80-85	80-85	80-85	80-85	80-85
5th	75-80	75-80	75-80	75-80	75-80
6th	< 75	< 75	< 75	< 75	< 75

3 Results and discussion

3.1 Comparison of rehydration

Rehydration capacity is not only influenced by the product composition, water temperature and rehydration time, but also highly related to drying methods and processing parameters (Zhang, 1996). During the drying process, the water is gradually reduced, inducing irreversible cell damage and dislocation, and leading to structure collapse and integrity loss of cells, therefore resulting in the loss of the hydrophilic property. The product rehydration depends primarily on the degree of structure damage of cells (Krokida and Maroulis, 1999). In general, freeze dried product has good performance of rehydration due to its low temperature drying conditions and less damaged cell structures, however long-time cooling, drying and vacuuming make it high cost. The effect of different drying technologies on the rehydration capability is shown in Figure 1.

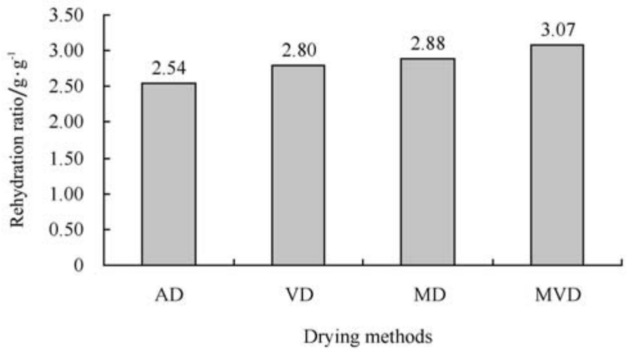


Figure 1 Effects of different drying technologies on the rehydration capability

It can be seen that rehydration ratios varied from different drying methods, and the rehydration ratios can be arranged by microwave vacuum drying>microwave drying>vacuum drying>hot-air drying. The results indicated the best rehydration capacity of green tea from microwave vacuum drying. The cell structure of green tea is expected to be less damaged due to short drying time and low temperature process of microwave vacuum drying. The lowest rehydration capacity of green tea was obtained from hot-air drying, which was conducted at a long time drying to reach desired moisture content and caused a serious contraction of the cell organization, resulting in a greatly damaged structure. It was noticed that rehydration ratios were increased by applying vacuum to both hot-air and microwave dryings. At a vacuum condition, the vaporization temperature is lower than those without vacuum, leading to less damaged organizational structure. The rehydration ratio of green tea from microwave drying was greater than that of hot air drying possibly due to the puffing role of microwave internal heating nature to make tea shrink less and produce more porous structure, leading to a reduced damage of tea structure and better rehydration capacity with better product quality.

3.2 Comparison of drying rate

The drying curves of moisture content vs. time were shown in Figure 2 for different drying methods to reach a final moisture content of about 4%–5%. It was observed that drying time was quite different from four drying methods to reach the final moisture content. The required drying time was about 100 min for hot air drying, 70 min for vacuum drying, 10 min for microwave drying, and 5 min for microwave vacuum drying, respectively. 5 min drying time to reach the desired final moisture content indicated the high efficiency of the microwave vacuum drying method, which was 20 times faster than hot air drying. The boiling point of water was decreased at the vacuum drying conditions, and the water migration rate was increased, resulting in a fast drying rate. The quality of tea was highly related to the drying time. The long drying time caused serious quality deterioration in color, nutritional composition and organizational structure. At the vacuum drying conditions it was very difficult to transfer heat from outside to materials at the low pressure environment using conventional drying methods; while the microwave drying using dielectric theory, the green tea was heated inside with electromagnetic energy, resulting in a fast heat transfer rate even at the vacuum conditions. Microwave vacuum drying combined two major advantages of vacuum and microwave heating, and greatly reduced the drying time. In addition, it can be seen that the different drying rates were resulted from microwave drying and microwave vacuum drying. In the early drying period, the drying rates were similar to microwave drying and microwave vacuum drying. But in the later drying period, microwave vacuum drying had a significant higher drying rate than microwave drying. It indicated that water was easily reduced with both microwave heating and vacuum sucking, resulting in short drying time and less damaged cell structure with improved green tea quality.

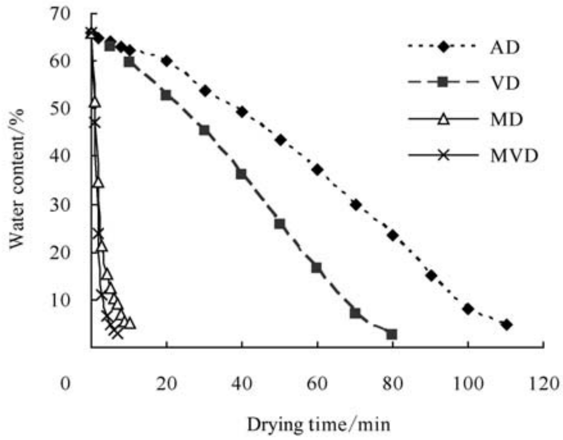


Figure 2 Drying curves from different drying time

3.3 Comparison of color

Color of dried tea and tea soup is an important indicator for the quality of green tea. The temperature and drying time are the main factors affecting the color change of material during drying process (Somkiat, Paveena and Somchart, 2004). Many authors used color as a quality control indicator of processes (Moss and Otten, 1989; Cammarn, Lange and Beckett, 1990).

The highest *L* value was found in dried green tea from microwave vacuum drying with decreased brightness followed by microwave drying, vacuum drying, and hot air drying. Long time drying by hot air resulted in the lowest *L* values (Figure 3). Long time drying at high temperature could result in non-enzymatic browning reactions, which are important phenomena that occur during food processing (Baisier and Labuza, 1990). Non-enzymatic browning includes a wide number of reactions such as Maillard reaction (MR), caramelization, maderization, and ascorbic acid oxidization. Non-enzymatic browning is stated to be dependent on the temperature and water activity of the food (Warmbier, Schnickels and Labuza, 1975; Saguy and Karel, 1980; Driscoll and Madamba, 1994; Rapusas and Driscoll, 1995). The process conditions, such as drying temperature and time were found to be the main factors to affect the color of dried green tea. Higher *L* values obtained from vacuum conditions suggested a favorable way to maintain color by drying with vacuum. The *L* value in microwave drying was higher than that in hot-air drying, corresponding to the short drying time by microwave. The *L* values for tea soups with four trying methods were not significantly different.

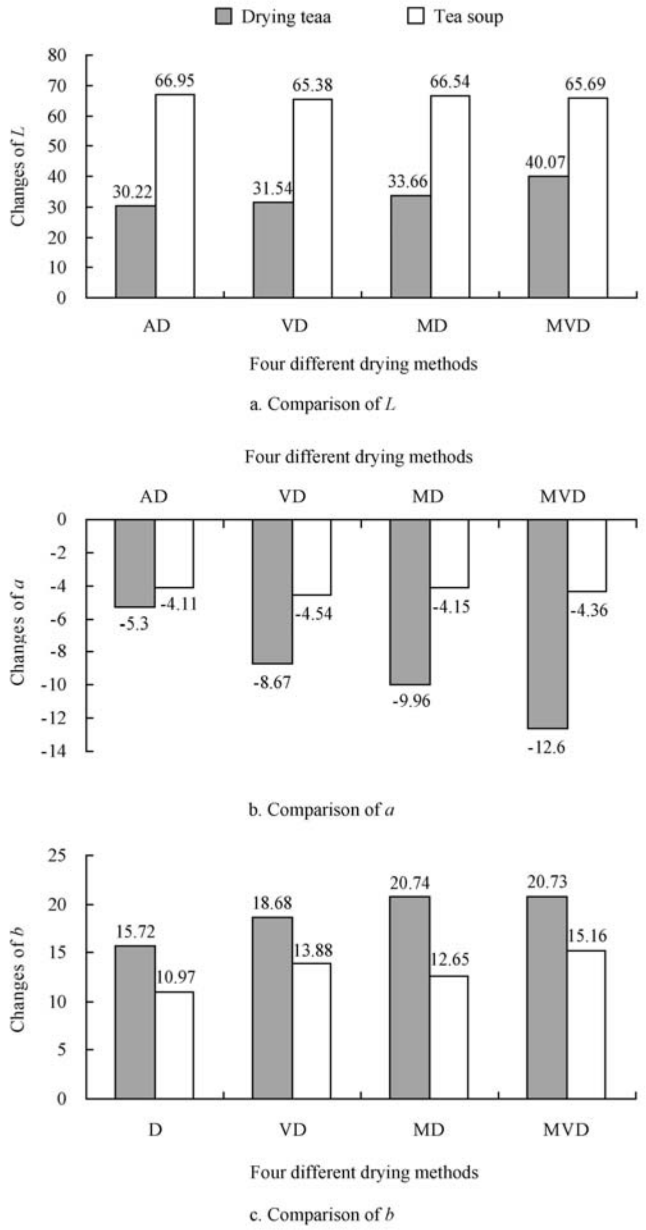


Figure 3 Effects of different drying technologies on parameter *L*, *a*, *b*

The *a* values indicating the greenness to redness of the green tea varied from –5.3 to –12.6, while the *a* value of the tea soups was about –4.0. All *a* values were negative, indicating that all tea colors were green. The lowest *a* values were obtained from microwave vacuum drying conditions with decreased greenness followed by microwave drying, vacuum drying, and hot air drying. The changes of *a* values were significantly affected by the drying conditions. It was noticed that a significant difference of greenness in dried teas existed between products from hot air and vacuum drying. Degradation of pigments, such as chlorophy II could be occurred during drying processes. More degradation of green pigments could be expected with long time drying of hot air. The *a* values for tea soups with four drying methods were not significantly different.

The *b* values indicating the yellowness of the samples varied from 15.7 to 20.7, while the *b* values of the tea soups were from 11.0 to 15.1. There was no significant difference of yellowness in green teas from microwave and microwave vacuum drying methods, while green tea from hot air had significantly lower *b* values than those from other three drying methods. The tea soup from green tea by hot air had the lowest *b* values among soups from green teas with different drying methods.

3.4 Comparison of nutritional components

As it can be seen from Table 3, the highest amounts of nutrients, such as amino acid, protein and caffeine were retained in green teas by microwave vacuum drying with decreased amounts of nutrients followed by microwave drying, vacuum drying, and hot air drying. Long time drying by hot air resulted in the lowest nutritional values. The process conditions, such as drying temperature and time were found the main factors to affect the nutritional values of dried green tea. Higher amounts of nutrients obtained from vacuum conditions suggested a favorable way to retain nutrients by drying with vacuum. The nutritional value in microwave drying was higher than that in hot-air drying, corresponding to the short drying time by microwave. The amounts of polyphenols and water-soluble sugars were found to be increased with the drying time and the highest amounts were observed in the green tea by hot air drying with/without vacuum. Polyphenol is an indicator of astringent taste. Results indicated that using microwave drying not only retained more nutrients but also produced green teas with less astringent taste.

Table 3 Effects of different drying technologies on the retention of nutrition

%

Drying methods	Nutritional component				
	Polyphenols	Amino acid	Water-soluble sugar	Protein	Caffeine
AD	24.92	3.17	3.19	1.80	4.25
VD	24.34	3.43	4.07	1.95	4.43
MD	21.58	3.60	2.72	2.08	4.48
MVD	22.00	3.76	2.84	2.54	4.66

Polyphenol-amino acid ratio is a good indicator of tea taste. The high ratio of polyphenol to amino acid causes a strong and bitter taste. The green tea with low phenol-amino acid ratios has a good taste. The lowest phenol-amino acid ratio of 5.86 was obtained by microwave vacuum drying; while the highest ratio of 7.87 was found in green tea from air hot drying (Figure 4). Results indicated that the green teas produced from microwave drying had a better taste and quality than green teas from hot air drying.

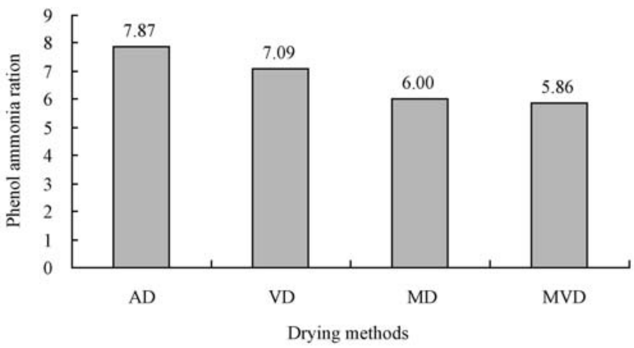
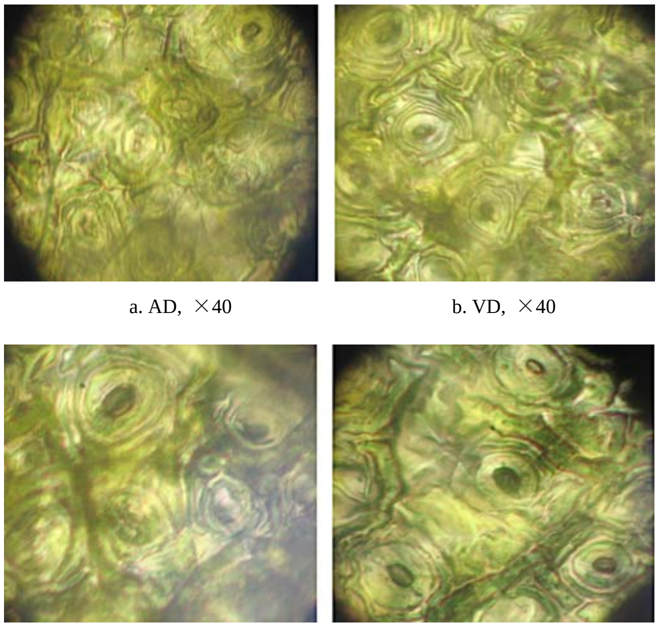


Figure 4 Effects of different drying technologies on tea polyphenols-amino acid ratio

3.5 Comparison of the organizational structure

The rehydration capability and quality of green tea are highly related to the changes of organizational structure during the drying process. The cell was contracted with the loss of water during drying processes. Different drying methods and process parameters resulted in contraction and some degree of damage of the tea cell.

The structures of tea after different drying methods were observed using a microscope with the same magnification (Figure 5). It was observed that tea cells were contracted very closely with a bigger number of cells per unit area by hot air drying. Cell deformation was noticed from tea with hot air drying, while the cell structures were similar and destruction was less observed from tea with vacuum drying. The cell shapes and distance between cells from hot air drying with vacuum were found similar to microwave drying with/without vacuum. The cell sizes were bigger by microwave drying than those by hot air drying with/without vacuum. The large cell sizes were expected to be related to the puffing role of microwave. The structure of cells was uniform and better maintained by microwave drying with/without vacuum. The less damaged cell structure from microwave drying with/without vacuum corresponded to the high rehydration capacity of green tea, high availability of nutrients, and good color of green tea.



a. AD, ×40 b. VD, ×40

c. MD, ×40 b. MVD, ×40

Figure 5 Micrographs of samples dried by different drying methods

3.6 Comparison of sensory quality

The score of sensory evaluation is a combination of tea color, shape, aroma, and taste. The highest score of sensory evaluation was calculated for green tea by microwave vacuum drying with a score of 93.15, followed by microwave drying, vacuum drying, and hot air drying, with the values of 90.95, 89.55, and 87.70, respectively. The drying methods and process conditions, such as drying temperature and time were found to be the main factors to affect the sensory score of green tea. Higher scores obtained from microwave drying suggested a favorable way to maintain the good quality of green tea. The highest sensory score by microwave drying corresponded to the short drying time by microwave and unique tea characteristics resulted from microwave drying. The tea quality can be assured by using microwave vacuum drying due to microwave internal heating and short heating time to reach desired moisture content with less damaged cell structure and more retained nutrients.

4 Conclusions

The quality of green tea was investigated by comparing four different drying methods. The best rehydration capacity of green tea was found from microwave vacuum drying which produced green tea and reached desired moisture content with the shortest drying time. The longest drying time was used by hot air drying method. Brighter and greener teas were obtained from microwave vacuum conditions. Results indicated that using microwave drying not only retained more nutrients but also produced green teas with less astringent taste with the lowest phenol-amino acid ratio among four different drying methods. The structure of cells was uniform and better maintained by microwave drying with/without vacuum. The tea quality can be assured by using microwave vacuum drying with less damaged cell structure and more retained nutrients, which corresponded to the highest score of sensory evaluation of green tea. It was concluded that microwave vacuum drying technology is suitable for green tea drying and production.

Acknowledgements

This work was supported by the Young Scientists and Innovation Foundation of Fujian Province (Grant No. 2007F3052) and Program of the New Century Excellent Talents of Fujian Province (Grant No. XSJRC2007-23).

[References]

[1] Baisier, W. M., Labuza, T. P. 1990. Maillard browning kinetics in a liquid model system. Journal of Agriculture and Food Chemistry, 40: 707–713.

[2] Cai, Y. 2005. Progress in the drying technology of tea. Fujian Tea, (3): 22–23.

[3] Cammarn S. R., Lange T. J., Beckett G. D. 1990. Continuous fluidized-bed roasting. Chemical Engineering Progress, 40–46.

[4] China Standard. 2009. Methodology of sensory evaluation of tea. GB/T23776-2009. China Standard Method Press.

[5] Chua, K. J., Chou, S. K., Ho, J. C. 2002. Heating pump drying: Recent developments and future trends. Drying Technology, 20(8): 1579–1610.

[6] Driscoll, R. H., Madamba, P. S. 1994. Modeling the browning kinetics of garlic. Food Australia, 46: 66–71.

[7] Fu, Z. 2005. The fault in sensory evaluation of tea and a proposal for improving. China Tea Processing, (1): 16–17.

[8] Gong, S. 2001. Methods of sensory evaluation and techniques for the quality green tea. China Tea Processing, (1): 44–46.

[9] Jing, L. 2007. Study on the microwave drying characteristics and drying technology optimization of lotus-seed. [MS thesis]. Fujian Agriculture and Forestry University.

[10] Kloticker, K., Schmidt, L., Steimle, F. A. 2002. Drying heat pump using carbon dioxide as working fluid. Drying Technology, 20(8): 1659–1671.

[11] Krokida, M. K., Maroulis, Z. B. 1999. Effect of microwave drying on some quality properties of dehydrated products. Drying Technology, 17(3): 449–466.

[12] Li, Y., Xu, S. 2004. Study on the Technology of Drying Garlic. Food and Fermentation Industries, 30(6): 54–58.

[13] Lin, T. M., Durance, T. D., Scaman, C. H. 1998. Characteriztion of vacuum microwave air and freeze dried carrot slices. Food Research Internationa, l 31(2): 111–117.

[14] Lin, T. M., Timothy, D., Christine, H. 1999. Physical and sensory properties of vacuum microwave dehydrated shrimp. Journal of Aquatic Food Product Technology, 8(4): 41–53.

[15] Lou, L. 2002. Applications of microwave technology in the tea processing. Fujian Tea, (1): 23–25.

[16] Moss, J. R., Otten, L. 1989. A relationship between color development and moisture content during roasting of peanut. Canadian Institute of Food Science and Technology Journal, 22: 34–39.

[17] Mujumdar, A. S. 2006. Handbook of industrial drying. New York: CRC Press, 622–623p.

[18] Rapusas, R. S., Driscoll, R. H. 1995. Kinetics of non-enzymatic browning in onion slices during isothermal heating. Journal of Food Engineering, 24: 417–429.

[19] Saguy, I., Karel, M. 1980. Modeling of quality deterioration during food processing and storage. Food Technology, 37: 78–85.

[20] Somkiat, P., Paveena, P., Somchart, S. 2004. Effective diffusivity and kinetics of urease inactivation and color change during processing of soybeans with superheated-steam fluidized bed. Drying Technology, 22(9): 2095–2118.

[21] Warmbier, H. C., Schnickels, R. A., Labuza, T. P. 1975. Nonenzymatic browning kinetics in an intermediate moisture model system: effect of glucose to lysine ratio. Journal Food Science, 41: 981–983.

[22] Xiao, H. 2006. The equipment development trend of

mechanized green tea processing. China Tea, (3): 40–41.

[23] Xie, Y., Song, L., Yang, X. 2006. Application of heat pump drying technology and its developmental trend. Journal of Agricultural Mechanization Research, (4): 12–16.

[24] Xu, Y., Zhang, M., Mujumdar, A. S. 2004. Studies on hot air and microwave vacuum drying of wild cabbage. Drying Technology, 22(9): 2201–2209.

[25] Zhang, M. 1996. Processing storage and rehydration theory of special kind dehydrated vegetables. Beijing: Science Publisher.