

# Effect of intermittent microwave drying on nutritional quality and drying characteristics of persimmon slices

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## Research Article

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# Abstract

In recent years, there has been an increasing interest in dried fruits, despite the fact that many of their nutritional components are easily lost during the drying process. The novelty of this paper was to evaluate the effect of intermittent microwave drying (IMD) on the nutritional quality and drying characteristics of persimmon slices. Persimmon slices were treated with IMD at the microwave power levels of 280, 350, 420, 490, and 560 W, and the drying characteristics and nutritional components such as soluble sugar, soluble protein, and other nutrients were determined and analyzed. The results showed that the drying process of persimmon slices could be divided into three stages; increasing speed, constant speed, and decreasing speed. Meanwhile, the higher the microwave power, the shorter the drying time and the higher the drying rate. The critical point of moisture content in the drying process was between 80.28%~157.56% on a dry basis moisture rate. With the increase of microwave power, the contents of soluble sugar, soluble tannin, vitamin C, and ash increased gradually, but had no obvious effect on the content of insoluble tannin, while the contents of soluble protein and vitamin E decreased gradually. In this study, the comprehensive scoring method was used for dried persimmon slices. The optimal microwave power for IMD persimmon slices was determined to be 490 W, which could effectively improve the drying rate and nutritional value. Therefore, it is concluded that IMD is a potential method for obtaining high-quality dried persimmon slices.

## Introduction

Persimmon (*Diospyros kaki* Linn. *f.*) is a widely cultivated fruit tree species in China, and has been cultivated for more than 3000 years (Qin et al., 2020). According to the data of the Ministry of Agriculture and Rural Affairs of the People's Republic of China, Guangxi was the region with the largest persimmon output in China in 2018, with an output of 998000 tons, accounting for 31.75% of the total persimmon output. Among them, Gongcheng persimmon has the characteristics of large fruit size, high yield stability, crisp and tender taste, and so on, which makes it one of the main varieties in Guangxi. In addition, Gongcheng persimmons are rich in nutritional elements and valuable substances that make persimmon conducive to human health (Deng et al., 2019), and they are known as the "holy fruit".

Gongcheng persimmons are mainly eaten fresh. However, since fresh persimmons contain up to 80% water (Pan et al., 2021), and are prone to softening and rotting after harvesting, they cause great waste (Qin et al., 2020). Drying is the most common processing technology in fruits and vegetables and can be used to extend the shelf life of Gongcheng persimmon by reducing the moisture content of the material and limiting microbial and chemical reactions during its storage. Microwave drying is an effective method for the dehydration and drying of agricultural products (Huang et al., 2020). It has a unique heating mode that has the advantages of fast drying speed, environmental protection, easy operation, and time and energy-saving (Li, 2015). However, it also has disadvantages, one of which is uneven heating that can easily lead to material overheating and quality degradation. Intermittent drying can redistribute water by limiting temperature rise, thereby improving energy efficiency, improving product quality and reducing product carbonization (Kumar et al., 2014). Therefore, IMD can maximize the use of

microwave energy, maintain the quality of dried products and reduce thermal damage. It has been widely used in the drying of fruits (Polat et al., 2019; Tepe & Tepe, 2020), vegetables (Zhang et al., 2015; Aysel et al., 2020), meat (He et al., 2019), and other agricultural products. However, there are few studies on the drying characteristics and nutritional quality of Gongcheng persimmon slices by IMD. Theoretically, IMD is represented to apply an effective process to speed up the drying speed and obtain high-quality Gongcheng persimmon products.

Some researchers found that during IMD of apples, the effective water diffusion coefficient and drying rate increased with the increase of microwave power, and the higher the microwave power, the shorter the drying time (Tepe & Tepe, 2020). Some scholars, using IMD of water chestnut flour, found that drying in a lower power range resulted in better quality products as a very high microwave power makes materials coke easily, thereby affecting product quality (Tang et al., 2018). Gongcheng persimmon is rich in water, protein, and other polar molecules, and the microwave field can make the polar molecules, and therefore the material, heat up due to the trend action of energy consumption. When the microwave power is high and the heat production of the material is excessive, it can lead to reactions such as enzyme inactivation, protein denaturation and changes in biofilm permeability (Li, 2015). Hence, the choice of microwave power is very important to the drying speed and quality of materials in the IMD process. The purpose of this study, therefore, was to investigate the effects of microwave power on the drying characteristics and nutritional quality of dried Gongcheng persimmon slices.

## Materials And Methods

### Materials and drying processes

Gongcheng persimmons were purchased from Taixing supermarket in Hezhou, Guangxi, China. Persimmons of the same size and maturity were selected for the experiment. Vitamin E determination kits and protein quantitative determination kits were purchased from Nanjing Jiancheng Bioengineering Institute (Nanjing, China) and (+)-Catechin standard and the other chemicals used were bought from Shanghai Yuanye Bio-Technology Co., Ltd (Shanghai, China).

The fresh persimmons were cleaned, peeled, cored, and cut into 2.0 cm thick slices. Then, IMD was carried out under the conditions of 280, 350, 420, 490, and 560 W, with the intermittent ratio set to 2 (Pan, 2019). The mass of persimmon slices under the intermittent time was measured and recorded until the dry basis moisture rate was lower than 35% (Yang et al., 2015).

### Drying characteristics

In this study, two parameters of drying characteristics, dry basis moisture rate and drying rate, were measured.

First, the dry basis moisture rate in the drying process of Gongcheng persimmon slices was calculated according to equation (1) (Huang et al., 2020):

$$X_t = \frac{G_t - G}{G} \times 100 \quad (1)$$

where  $X_t$ ,  $G_t$  and  $G$  represent the dry basis moisture rate (%), wet material quality(g), and dry material quality(g), respectively.

The drying rate in the drying process of Gongcheng persimmon slices was calculated according to equation (2) (Tepe & Tepe, 2020):

$$DR = \frac{X_1 - X_2}{\Delta t} \quad (2)$$

where  $DR$ ,  $X_1$ ,  $X_2$ , and  $t$  express the drying rate[g/(g\*min)], dry basis moisture content at time  $t_1$  (g/g), dry basis moisture content at  $t_2$ (g/g), and drying time(min), respectively.

### **Soluble sugar**

The soluble sugar content was determined by 3,5-Dinitrosalicylic acid colorimetry. Moreover, 1 ml of water-soluble total sugar solution, 4 ml of 3,5-Dinitrosalicylic acid colorimetry and 1 ml of distilled water were sucked into the test tube and mixed well. After boiling water bath for 5 min, the absorbance value was measured at 540 nm.

### **Soluble protein**

A protein quantitative determination kit (Coomassie brilliant blue method) was used to determine the soluble protein content. The samples (1 g) were mixed with 9 ml normal saline, mechanically homogenized in an ice water bath, and centrifuged at 2500 rpm for 10 min. After centrifugation, 1 ml supernatant and 9 ml normal saline were diluted into 1% homogenate. Then, 0.05 ml of homogenate was mixed with 3 ml Coomassie brilliant blue color developing solution. After mixing, it was allowed to stand for 10 min, and the absorbance value was measured at 595 nm.

### **Soluble tannin**

The content of soluble tannin was determined using the Folin-Ciocalteu method (Tessmer et al., 2014). 1.0 ml of the extracted solution was sucked into the test tube, with 6.0 ml of distilled water and 0.5 ml of 1% of Folin-phenol reagent, and mixed well. After standing for 3 min, 1 ml saturated  $\text{Na}_2\text{CO}_3$  solution and 1.5 ml distilled water were then added and shaken together. The absorbance value was measured at 725 nm after standing for 1 h under dark conditions.

### **Insoluble tannin**

The content of insoluble tannin was analyzed with the vanillin-sulfuric acid method (Yang et al., 2010). 1.0 ml of the extracted solution, 2.5 ml of 2% vanillin aldehyde-methanol solution, and 2.5 ml of 5 mol/L sulfuric acid-methanol solution were sucked into the test tube and shaken well. Then, the test tube was

placed into a constant temperature water bath for color reaction at 30 °C for 30 min. After extraction, the absorbance value was measured at 500 nm.

### Vitamin C

The vitamin C content was determined by 2,6-dichlorophenol indophenol titration (Qiu et al., 2018). After the sample was crushed, 2,6-dichloroindophenol was used to titrate the acid leaching solution of the sample until the solution was pink and did not fade for 15 s. Oxalic acid solution was then used for the blank test. The calculation formula was as follows:

$$X = \frac{(V-V_0) \times T \times A}{m} \times 100 \quad (3)$$

where X, V, V<sub>0</sub>, T, A, and m denote the vitamin C content (mg/100g), volume of dye solution consumed during titration of sample solution (ml), volume of dye solution consumed when titrating blank (ml), 2,6-dichloroindophenol titrimetry (mg/ml), dilution multiple, and sample mass (g), respectively.

### Vitamin E

The vitamin E content was measured by a vitamin E determination kit. The 10% tissue homogenate was prepared by adding homogenate medium to the sample, homogenized in an ice water bath, centrifuged (2500 rpm, 10 min), before vitamin E was extracted with n-heptane. The extraction solution was subjected to color reaction, and the absorbance value was measured at 533 nm.

### Ash

The ash content was determined using the burning method (Zhong et al, 2018). The samples were fully charred to smokeless in an electric furnace (DK-98-II, Tianjin Tester Instrument Co. Ltd., China) and then burned (550 °C, 4 h) in a muffle furnace (F0111C/211C/311C/411C/511C/611C/711C/811C, Chongqing Yamato Technology Co. Ltd., China) until the ashing was complete, and weighed after cooling.

### Comprehensive scoring

Considering the 8 indexes of drying time, soluble sugar, soluble protein, soluble tannin, insoluble tannin, vitamin C, vitamin E, and ash content, the process parameters of persimmon fruit slices were optimized by the comprehensive scoring method. The sum of all indicators in the same test was taken as the total score of the test (Li & Hu, 2008). The calculation formula is shown in Equation (4):

$$Y = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (4)$$

where Y, X<sub>i</sub>, X<sub>min</sub> and X<sub>max</sub> represent the index membership degree, indicator value, minimum indicator value, and maximum indicator value, respectively.

The comprehensive score can be obtained by adding the membership degree of each index.

## Data analysis

Spss19.0 software (SPSS Inc., Chicago, IL, USA) and Duncan multiple comparison method were used for one-way ANOVA. Figures were drawn by origin 9.1 software (OriginLab Corporation, MA, USA). The average values of three parallel determinations were used.

# Results And Discussion

## Effect of microwave power on the drying characteristics of persimmon slices

As shown in Fig.1, the drying curve of persimmon slices was continuous and smooth, showing an exponential downward trend. In addition, the drying time of persimmon slices was shortened with the increase of microwave power. When the dry basis moisture rate of persimmon slices was less than or equal to 35%, the microwave power was 280, 350, 420, 490, and 560 W, and the drying time was 54, 42, 33, 30, and 24 min, respectively. It was reported that a researcher once peeled and pitted Gongcheng persimmons, divided them into 4-6 pieces, and backed them in a high-medium-low interval with varying temperature. The drying process lasted for 84 h until the persimmon moisture rate was close to 30% (Lin, 2019). In addition, some scholars conducted hot air drying after peeling Mopan persimmon until the moisture rate was below 35%, which took about 92 h (Yang et al., 2015). These studies support the fact that the moisture content of dried persimmon products meets the requirements of China's national standard (Yang et al., 2015). Moreover, IMD can greatly shorten the drying time of persimmon to 24~54 min because the water molecules in persimmon slices are polar molecules. Under the action of the microwave, the polar molecules in persimmon slices move at a high frequency, which increases the temperature of persimmon slices and generates a lot of heat, so that the water in persimmon slices evaporates rapidly.

Fig. 2 presents the three stages of the drying process of persimmon slices under different microwave powers; acceleration, constant speed, and deceleration. Similar results were reported in the study of IMD of camellia oleifera seeds and ginkgo fruits (Zhang et al., 2013; Huang et al., 2020). Microwave power has a great influence on the drying rate of persimmon slices. As the microwave power increased, the microwave energy absorbed by persimmon slices increased, and the drying rate increased rapidly. Moreover, the higher drying rate also resulted in a shorter drying time. Under microwave power of 280, 350, 420, 490, and 560 W, the maximum drying rates were 0.11, 0.14, 0.18, 0.21, and 0.23 g/(g\*min), respectively. When the dry base moisture content of persimmon was less than 35%, the drying rates were 0.05, 0.05, 0.07, 0.08, and 0.10 g/(g\*min). As observed in the experiment, the drying rate decreased with the decrease in dry base moisture content under different microwave power. This was due to the loss of water in the material and the weakening of microwave energy absorption and utilization, resulting in a decrease in the drying rate. When microwave power was 280 W and 350 W, the drying rate increased slowly in the speed-up stage, and the drying rate fluctuated obviously in the constant speed stage. Therefore, it was speculated that the intermittent stage might have alleviated the continuous rise of

temperature and made the overall water distribution of persimmon slices more uniform. On a dry basis moisture rate, the moisture critical points of 280 W and 350 W were 157.56% and 144.14%, respectively. The drying rate then began to decrease slowly in the speed reduction stage and the dried persimmon slices became golden. When the microwave power was 420 W and 490 W, the drying rate fluctuation in the constant speed stage was not obvious. With the increase of microwave power, the drying temperature of persimmon slices also increased, so the continuous increase of mitigation temperature in the intermittent stage was slow. The critical points of water content at 420 W and 490 W were 114.01% and 80.28% on a dry basis moisture rate, respectively. The drying rate decreased, the drying time was slightly longer, and the color of persimmon slices was dark yellow. Dramatically, the microwave power of 490 W had a low moisture critical point, which was conducive to improving the quality of the dried products (Duan, 2018). When the microwave power was 560 W, after the peak value was quickly reached in the speed-up stage, there was a short constant speed stage. The critical point of water content was 106.53% on a dry basis moisture rate. After the drying rate decreased, the drying time was significantly shortened, and the persimmon slices were yellowish-brown and dark.

### **Effect of microwave power on the soluble sugar content of persimmon slices**

Soluble sugar is the main component of fruit taste, so it has a vital impact on fruit flavor quality (Lv et al., 2009). As shown in Fig. 3, soluble sugar content increased with the increase of microwave power from 34.68% at 280 W to 41.32% at 560 W. This may be due to the consumption of soluble sugar by tissue respiration. Moreover, the lower the microwave power and longer the drying time, the greater the consumption of soluble sugar (Y. Q. Zhang et al., 1998). Therefore, the higher the microwave power, the higher the consumption of soluble sugar. It could also be that high microwave power leads to a higher drying temperature and increased soluble sugar content. Several researchers reported that a high temperature has caused cell membrane damage, decreased water holding capacity of cells, and promoted the degradation of polysaccharides and other macromolecules, resulting in the increase of soluble sugar content (Pei et al., 2014).

### **Effect of microwave power on the soluble protein content of persimmon slices**

As can be seen from Fig. 4, with the increase of microwave power, soluble protein content presents a clear downward trend from 8.445 g/L at 280 W to 3.566 g/L at 560 W. Some studies have shown that soluble protein decomposes easily during drying and heating, and microwave radiation can cause changes in the structure and some physical and chemical properties of soluble protein (Cheng et al., 2018). With the increase of microwave power, the thermal effect and polarization effect of microwaves exacerbated the destruction of the soluble protein structure, resulting in the decrease of soluble protein content. Moreover, some studies have shown that soluble protein and tannin can be stable complexes by hydrogen-bonded and hydrophobic (Lv et al., 2009). Under the condition of high microwave power, tannin content was higher, so the reaction consumed more soluble protein and the soluble protein content decreased.

### **Effect of microwave power on the tannin content of persimmon slices**

Tannin, with astringency, is the main component of persimmon and its products (Lv et al., 2009). According to the different solubility of persimmon tannins in alcohol, it can be divided into soluble and insoluble tannins (Wang et al., 2019). As shown in Fig. 5, with the increase of microwave power, soluble tannin content showed an upward trend, while insoluble tannin content increased slightly. The soluble tannin content increased from 2.26 mgGAE/g at 280 W to 3.67 mgGAE/g at 560 W. Increasing microwave power can accelerate the increase of soluble tannin content and make persimmon slices produce astringency. The increase in soluble tannin content might be caused by the release of phenolic compounds due to the damage of cell tissue caused by microwave drying (Chen, 2019). It may also be that the moisture content decreased rapidly when heated under high microwave power, resulting in the decrease of the activity of the enzyme promoting the combination of acetaldehyde and soluble tannin (Chung et al., 2015). Therefore, the content of soluble tannin showed an upward trend. Simultaneously, it was also noticed that insoluble tannin content increased slightly with the increase of microwave power, but that the change was not obvious. The insoluble tannin content at 560 W was the highest, which was 0.50 mg(+)-catechin/g. Therefore, it was speculated that some soluble tannins could be combined with pectin to form tannin pectin gel, and also to form insoluble tannins with cell debris (Chen et al., 2019).

### **Effect of microwave power on the contents of vitamin C and vitamin E in persimmon slices**

Vitamins play an important role in maintaining normal physiological functions of the human body. Vitamin C and vitamin E have antioxidant effects, which can enhance immunity and delay aging (Karatas & Kanişlı, 2007). Fig. 6 shows the relationship between different microwave power levels and the vitamin C and vitamin E contents of persimmon slices. Vitamin C is unstable during heat treatment (Nalawade et al., 2018). However, in this experiment, the content of vitamin C increased with the increase of microwave power, from 24.3 mg/100g at 280 W to 33.9 mg/100g at 560 W, which is consistent with the results of previous studies (Pan, 2019; Li et al., 2021). This is due to the drying at high temperature for a short time, which is more beneficial to the preservation of vitamin C. With the increase of microwave power, the drying temperature increases, the drying time is significantly shortened, and the content of vitamin C in high-temperature rapid drying is higher than that in low-temperature slow drying (Zeng et al., 2014). Some studies have shown that the higher the intensity of microwave radiation, the faster the degradation of vitamin E (Zhang et al., 2000), which is similar to the results of this study where vitamin E content decreased from 8.7943 ug/g at 280 W to 4.7537 ug/g at 560 W. The effect of the microwave adds to the degradation of the molecular structure of vitamin E (Lin, 2012). Meanwhile, the thermal effect of the microwave could make the degradation reaction of saturated fatty acids and the oxidation reaction of unsaturated fatty acids in persimmon slices occur simultaneously, increasing the content of free radicals and peroxides. The hydroxyl group on the benzene ring in the vitamin E molecule then reacted with it to form an ester, which lost its antioxidant function (Zhang et al., 1998), and finally resulted in a decrease of vitamin E content.

### **Effect of microwave power on the ash content of persimmon slices**

Ash content is the sum of all kinds of mineral elements and oxides contained in persimmon. As the microwave power increased, ash content increased slightly, from 1.23% at 280 W to 1.42 % at 560 W, as shown in Fig. 7. It has been reported that after freeze-drying, vacuum oven drying, and oven drying of Turkish persimmons, some scholars obtained dry products with very close ash content and no significant change, which were 1.86%, 1.88%, and 1.88%, respectively (Karaman et al., 2014). The ash content of dried persimmon products obtained in this study is lower than that of dried persimmon products in Turkey, which may have been caused by the use of different varieties and drying methods. Previous results also showed that the ash content increased with the increase of microwave power (Fang et al., 2011). This may be that under the treatment of high microwave power and high drying temperature, the organic matter in the persimmon slice is decomposed, a large amount of organic carbon, nitrogen, oxygen, and other elements are lost, while inorganic components such as oxide, carbonate, and silicate remain in the persimmon slice structure, increasing ash content (Yang, 2018).

### Results analysis of comprehensive scoring

**Table 1** Comprehensive scoring results under different microwave power

Microwave power(W)	280	350	420	490	560
Overall score value	1.07	1.68	2.32	3.06	3.00

As can be seen from Table 1, the comprehensive score was highest when the microwave power was 490 W. The drying time, soluble sugar, soluble protein, soluble tannin, insoluble tannin, vitamin C, vitamin E, and ash content were 30 min, 40.17%, 6.193 g/L, 2.96 mgGAE/g, 0.39 mg(+)-Catechin/g, 30.4 mg/100g, 7.5342 ug/g, and 1.4 %, respectively. Some scholars have studied the effect of hot air drying temperature on the quality of persimmon products. The optimal drying temperature was 55 °C, and the drying time, final moisture content, and total sugar content were 92h, 33.71%, and 4.83%, respectively (Yang et al., 2015). The effects of solar drying temperature and slice thickness on the vitamin C of dried persimmon products have also been studied in Pakistan. When the drying temperature was 45 °C and the slice thickness was 1.5cm, the maximum content of vitamin C was 2.08 mg/100g, the drying time was 18h and the moisture content was less than 10% (Hanif et al., 2015). Compared with hot air and solar drying, IMD can significantly shorten the drying time, improve the drying efficiency and improve the nutritional quality of dried persimmon.

## Conclusions

In this study, IMD technology was used to evaluate the drying characteristics and nutritional quality of persimmon slices. Persimmon slices were dried at various microwave power levels. The IMD process of persimmon slices is a typical drying process that can be divided into three stages; acceleration, constant speed, and deceleration. Increasing microwave power improved the drying rate and shortened the drying

time. The contents of soluble sugar, soluble tannin, vitamin C, and ash increased with the increase of microwave power, while the contents of soluble protein and vitamin E decreased with the increase of microwave power. Moreover, the content of insoluble tannin was not affected by microwave power. When the microwave power was 490 W, the moisture critical point was the lowest, and the comprehensive score was the highest. In general, IMD, therefore, was shown to produce high-quality dry products with excellent flavor and should be considered as a potential drying method, and IMD at 490 W was the most suitable microwave power. It provides a theoretical reference for the persimmon drying industry in the future.

## Declarations

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### Conflict of interest

The authors declare that there is no potential conflict of interest.

### Data availability

The datasets used or analyzed in this study can be obtained from the corresponding authors upon reasonable request.

### Author contributions

Yanting Qin designed and performed the experiments, and wrote the manuscript. Zhenhua

Duan designed the experiment, revised the manuscript, and helped with data analysis. Siyun

Zhou and Zhenzhen Wei made suggestions and helped revise the manuscript. All authors reviewed the manuscript.

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## Figures

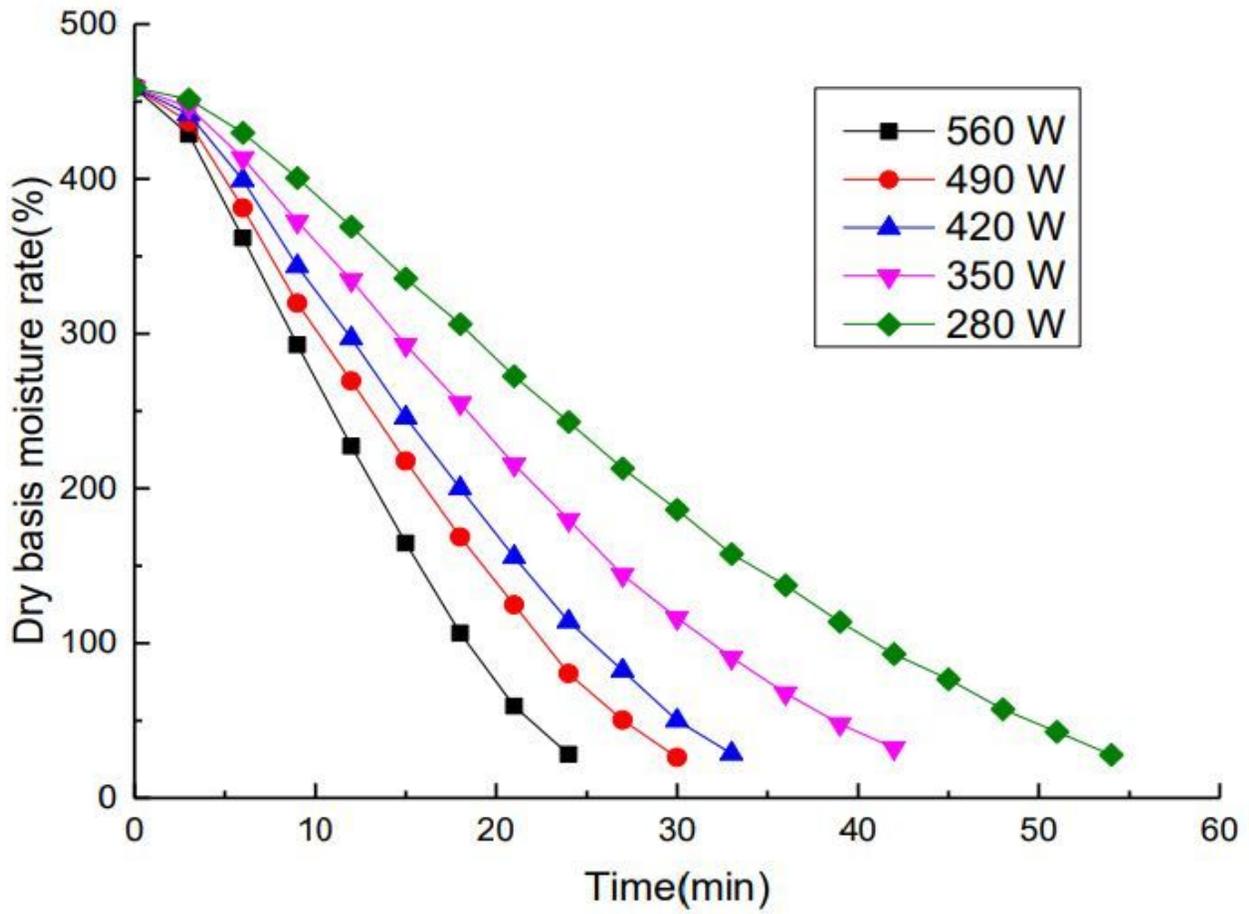


Figure 1

Drying curve of persimmon slices at different microwave power.

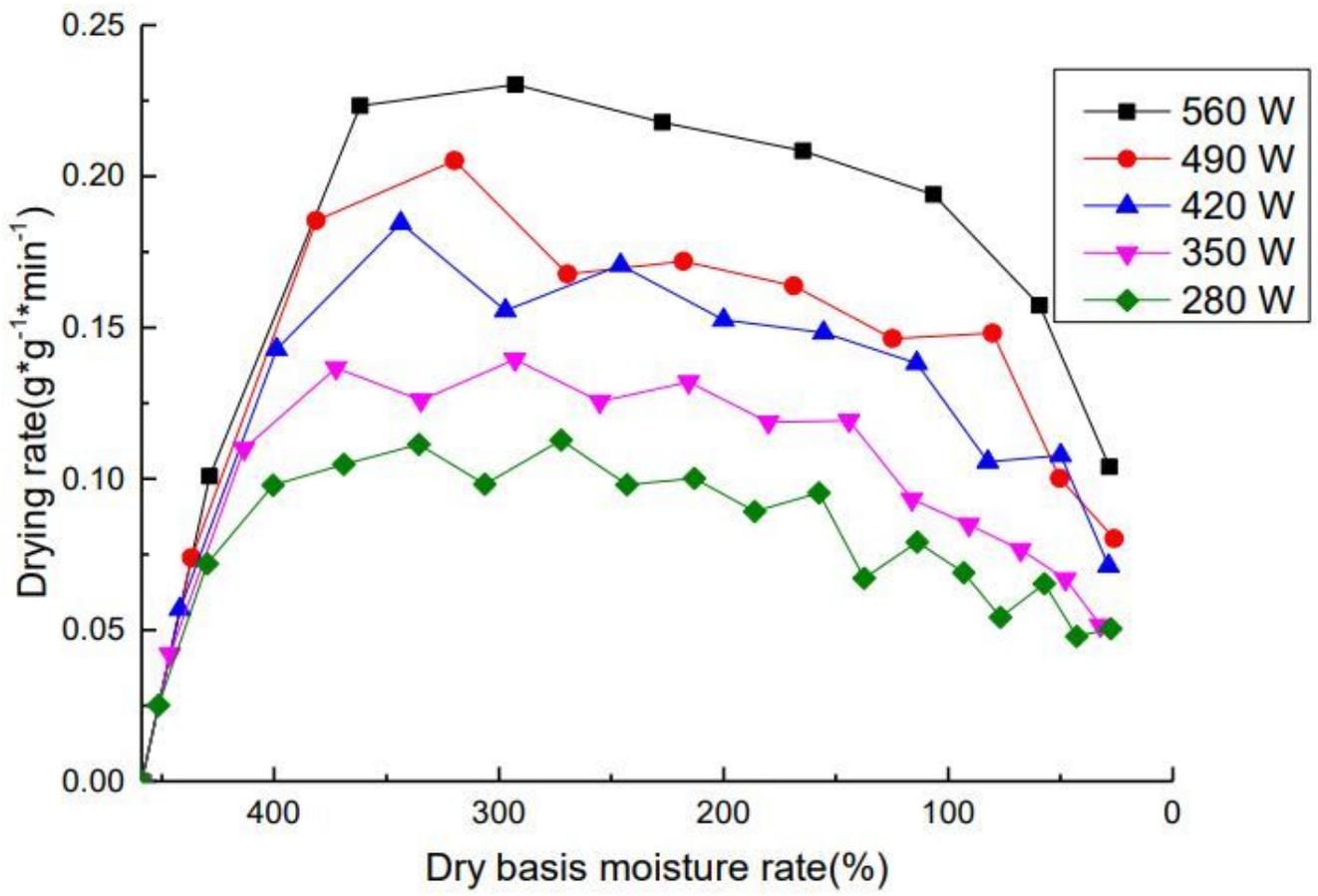
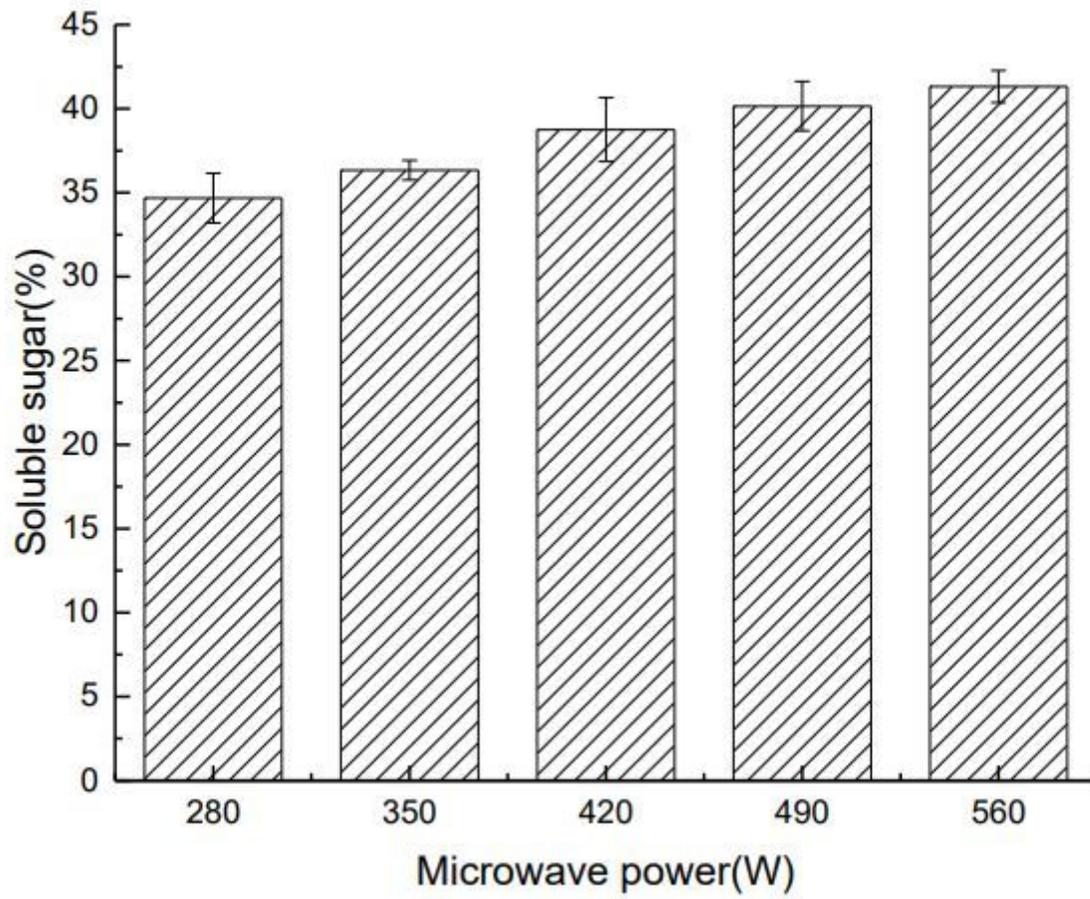


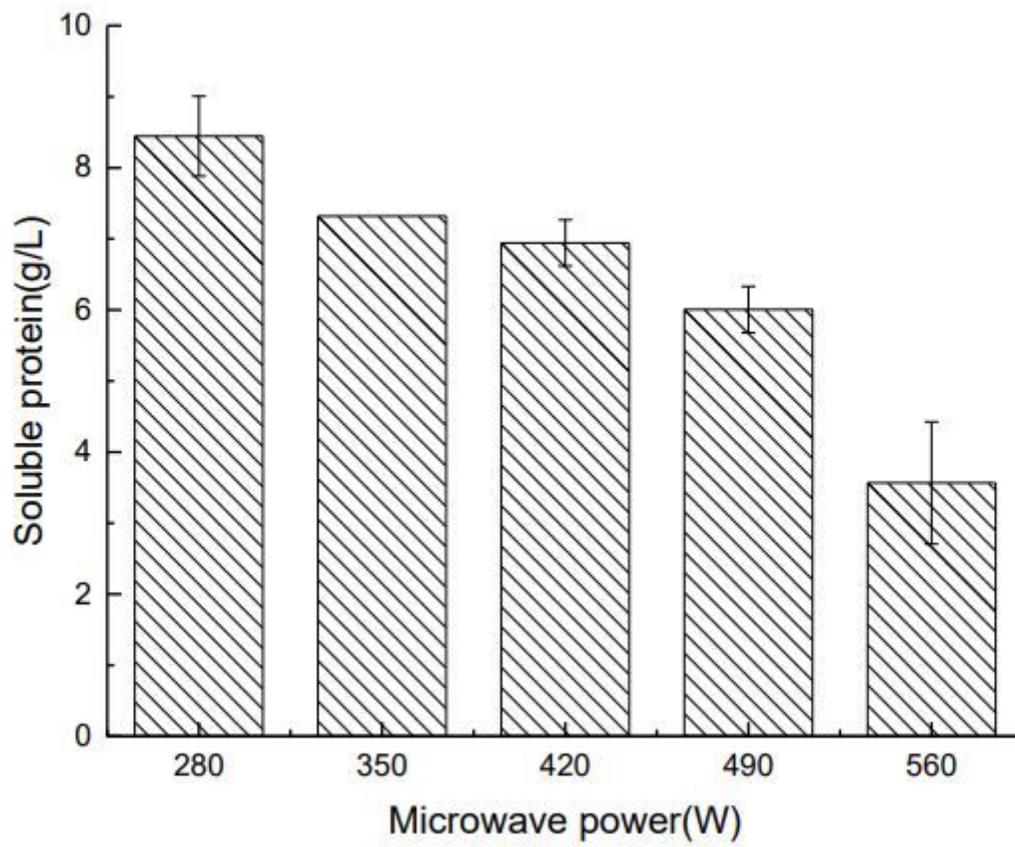
Figure 2

Drying rate curve of persimmon slices at different microwave power.



**Figure 3**

Effect of microwave power on soluble sugar.



**Figure 4**

Effect of microwave power on soluble protein.

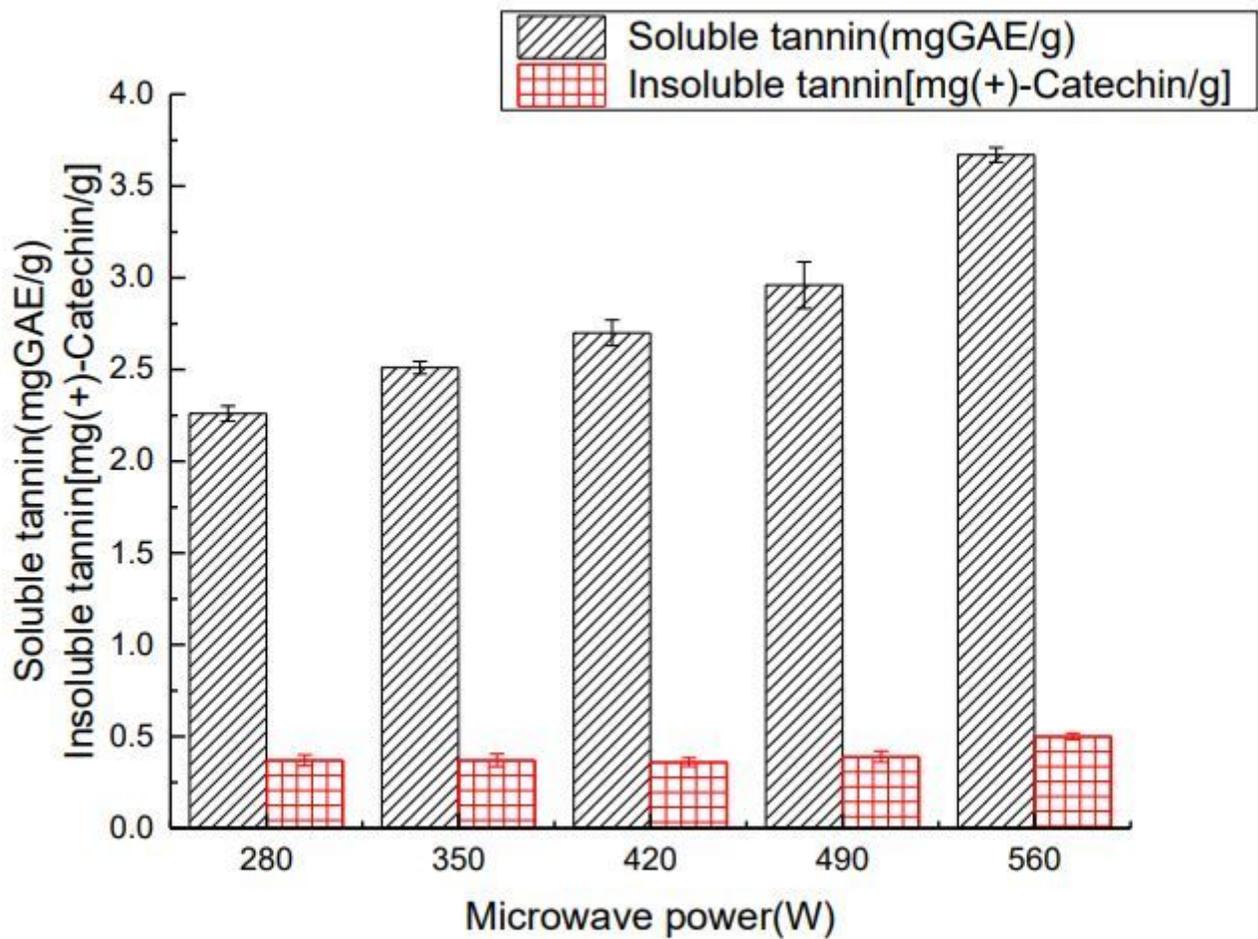


Figure 5

Effect of microwave power on tannin.

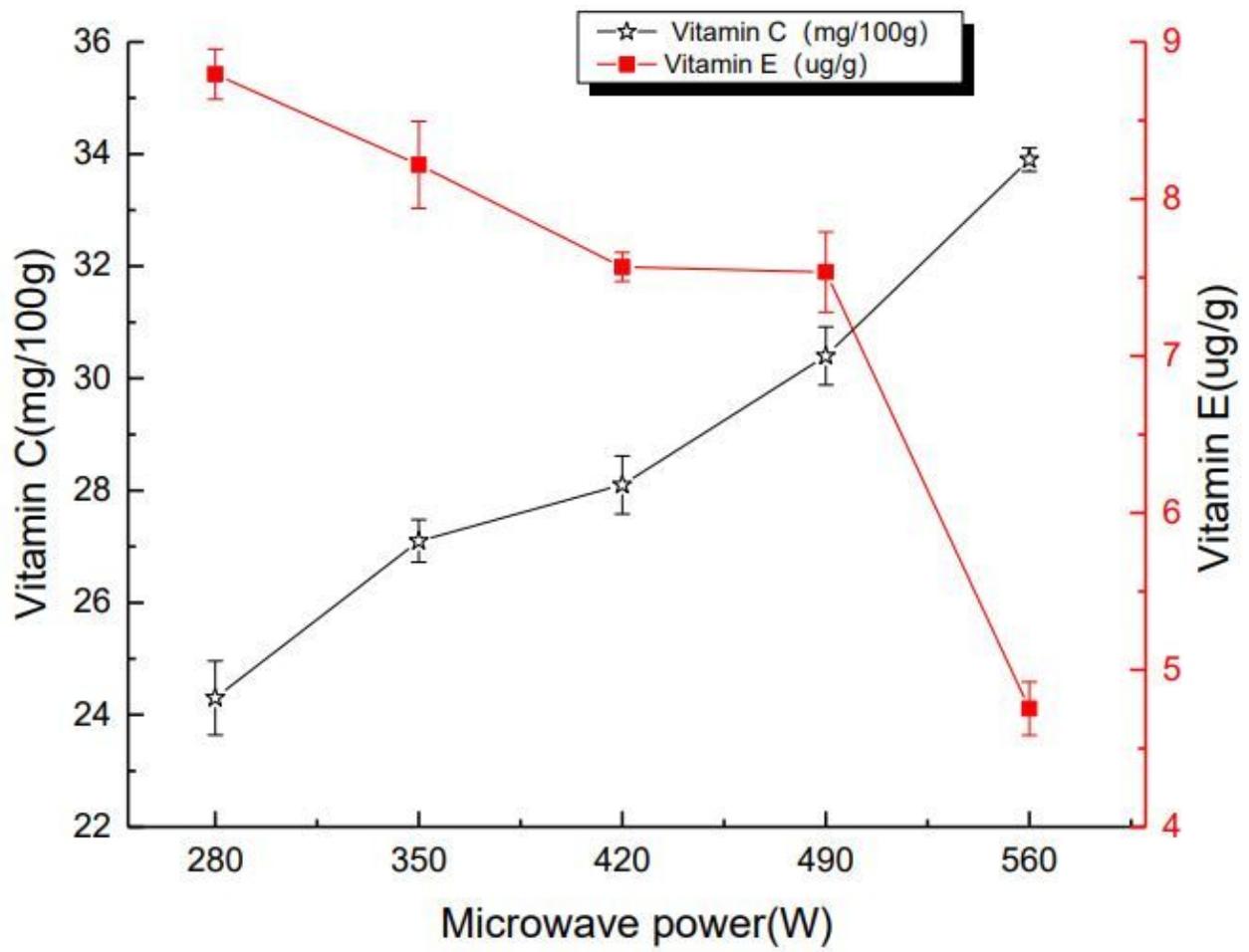
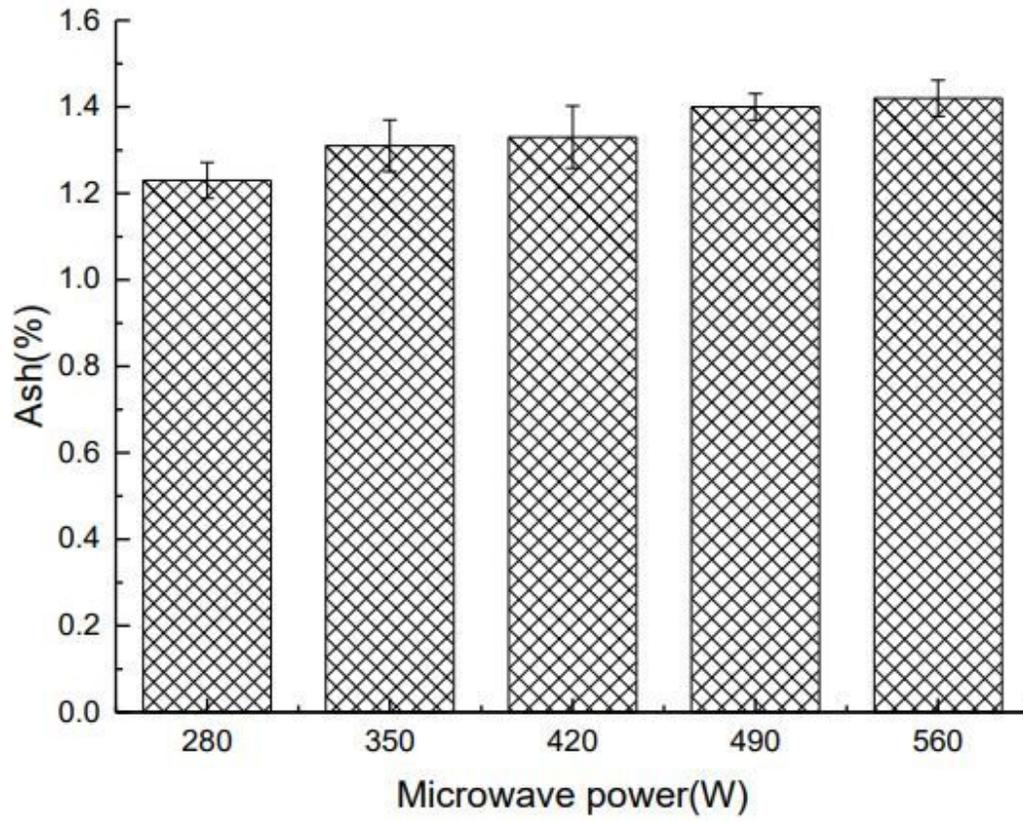


Figure 6

Effect of microwave power on vitamin C and vitamin E.



**Figure 7**

Effect of microwave power on ash content.