Drying characteristics and its effects on quality of jujube treated by combined microwave-hot-air drying

Zizyphuo jujube Miller is a mature fruit of jujube tree of the genus Rhamnoides, which is rich in nutrients [1]. Jujube has a high water content and a short harvest period. Every year, the rainy weather in the late mature stage of the jujube causes a large number of fruits to crack. After harvesting, the mold rot is intensified due to the inability to dry in time, causing great economic losses to the jujube industry. One of the bottlenecks in the development of jujube industry. More than 95% of China's red dates are made into dried dates for storage, processing and consumption. The dry jujube is mostly made of 3-stage hot air drying [2], but it has the problems of long drying time, high energy consumption and poor quality.

In recent years, many new drying technologies have been applied to the drying of red dates [3], in which microwave drying is fast, clean and has received extensive attention [4-7]. The appearance quality of jujube is the first choice for consumers to purchase. The temperature of the outer surface of microwave dried red jujube rises rapidly, the internal temperature is high, and the browning of the fruit is serious [8]. Combining hot air and microwave, it has advantages in improving drying rate, reducing energy consumption and improving product quality [9-15], so it is more and more valued and applied in agricultural product processing. Silva F A et al. studied the drying process of macadamia nuts by microwave-assisted hot air drying method and found that it can effectively shorten the drying time and improve the quality of dried macadamia nuts [16]. Zhang Guofan and other methods used microwave oven + hot air + microwave vacuum to dry the scallop column, the drying time is shortened by more than 50% than the simple hot air drying, the shrinkage rate and the rehydration rate are improved compared with the microwave vacuum drying alone, and the crush resistance is obviously better than the hot air. Dry [17]. Shuzheng and other dried jujubes with hot air and microwave combination are superior to hot air drying products [18]. However, it has not been reported that the red dates are dried by a combination of microwave, high temperature hot air and low temperature hot air.

In this study, microwave-hot air combined technology was applied to study the drying characteristics of jujube, and the total vitamin C content, total flavonoid content, browning coefficient A420 and rehydration ratio of jujube under different drying methods were compared to determine the best combination of joint drying. Dry production provides technical basis and reference.

1 Materials and methods

1.1 Test materials

Jujube was collected from Baojiashan Village, Shuangmiaohe Township, Qingyi County, Shaanxi Province (dry basis moisture content 144%). The fruit is fully mature. After transporting back to the laboratory, the fruit surface is selected to be red, and the size (short diameter is about 4.5×10- 2m, long diameter of about 8.9 × 10-2m), the shape of the same fruit at (0 ± 1) °C, relative humidity 85% ~ 90% cold storage.

1.2 Test equipment

DHG-9070A electric heating constant temperature air drying oven (Shanghai Jinghong

Experimental Equipment Co., Ltd.); PJ21C-B1 microwave oven (Guangdong Midea Microwave Manufacturing Co., Ltd.); ST-TM902C digital display thermometer (Wuqiang County Jingchuang instrument) Factory); JYL-A02 Jiuyang Food Machine (Jiuyang Co., Ltd.); ALC-210.3 Electronic Analytical Balance (Sedolis Aikele Company); HH-S6 Double Row Six-hole Electric Hot Water Bath (Beijing Kewei) Ltd.; KDC-40 low-speed centrifuge (Keida Innovation Co., Ltd. Zhongjia Branch); KQ-600DB CNC ultrasonic cleaner (Kunshan Ultrasonic Instrument Co., Ltd.); UV-mini1240 UV-Vis spectrophotometer (Japan Shimadzu Corporation).

1.3 Methods

1.3.1 Test method

Remove the preserved red dates from the cold storage and clean them with tap water. Then use absorbent paper to absorb the surface water. Take 300 g of red dates and place a small layer of bamboo in a dry equipment. Hot air drying measured the mass and temperature change of the sample every 1 h; according to the pre-test results, the microwave was dried at 119 W for 12 min, and the jujube was stored in the microwave drying equipment for 4 min. The mass change of the jujube during the batch process was small and negligible. Repeat this and measure the mass and temperature changes of the sample every 16 minutes. The drying time of jujube is determined by the actual energy consumption drying time.

Table 1 Experimental conditions of six drying methods Table 1 Experimental conditions of six different drying methods Download original table

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1.3.2 Determination of indicators

1) Calculation of dry basis moisture content Mt

Where Mt is the dry basis moisture content of the sample dried to t, %; mt is the mass of the sample dried to time t, kg; mg is the mass after the sample is dried, kg.

2) Calculation of drying rate Dr

Where Dr is the sample drying rate, kg / (kg · h); Mt + ?t is the dry basis moisture content of the sample t + ?t, kg / kg; ?t is the dry interval, h.

3) Determination of total vitamin C and total flavonoids

Take 18 g (4 dried dates). After adding the jujube to the core, add 60 m L20 g/L of oxalic acid solution, pour into a mincer and make a homogenate. Take 1.5 g of homogenate and pour into a 100 m L volumetric flask. Dilute to the mark with 10 g/L oxalic acid solution and mix. The above solution was filtered, and the filtrate was reserved. The vitamin C content was determined according to the 2,4-dinitrophenylhydrazine colorimetric method in GB/T 5009.86-2003.

Take 18 g (4 dried dates), dry the jujube, and then grind it in a mortar. Accurately weigh 2 g of the sample into a stoppered flask, add 80 ml of 80% ethanol solution, and place it in a ultrasonic ultrasonic wave. After 40 min, filter, transfer to a 100 m L volumetric flask, and make up to 80% ethanol to obtain the test solution. The total flavonoid content was determined by Na NO2-Al

(NO3) 3 colorimetric method [19-20].

4) Browning coefficient A420
The sample was thoroughly ground, weighed 5 g, made up to 50 m L with water, allowed to stand for 2 h, then centrifuged at 3 800 r/min for 10 min in a centrifuge, and the sample was taken 5 m L, then 95% was added. The ethanol was 5 m L and centrifuged at 3 800 r/min for 10 min. The absorbance (A420) was measured at 420 nm, and the browning degree was directly expressed by the absorbance [21].

5) Determination of rehydration ratio
Take about 20 g of dried red jujube, record the mass as m dry, put it into hot water of 90 (±5) °C, take it out after 15 min of rehydration, place it on stainless steel wire mesh and drain for 8~10 min, and weigh it. , the record is m complex. Rehydration rate (R complex) can be calculated as follows

6) Calculation of unit energy consumption dehumidification
Calculated by the mass of water removed by unit energy consumption [22], the calculation formula is as follows

Where N is the unit of energy dehumidification, g / (k W · h); W is the rated input power, k W; T is the total drying time, h; G is the mass of moisture removal, g.

7) Determination of jujube temperature
The jujube temperature was measured every 1 h during the drying process. Surface temperature measurement: Take the red dates to the edge of the drying box, and quickly place the TP-10 probe of the probe type digital thermometer on the surface of the jujube. The surface temperature needs to be measured for 5~8 s for the first time, and the repeated measurement is 2 times for 1 time. It can be completed within ~2 s, and the average value is measured. The internal temperature of the thermometer is measured by piercing the original probe of the thermometer into the surface of the red jujube at 4~6 mm, and the reading is repeated 6 times.

2 Results and analysis
2.1 Effects of different drying methods on the drying characteristics of jujube
2.1.1 Changes in dry soil moisture content in six drying modes
Figure 1 shows the relationship between the drying time and the moisture content of jujube dry basis in six different drying modes. It can be seen from the figure that when the red dates are dried to the same water content (?40%), microwave intermittent drying has the shortest drying time, and the time taken is about 3.4 h; the time required for segmental hot air drying is the longest (28 h); Under the combined drying conditions of 4 kinds of microwave + high temperature hot air + low temperature hot air, the time required is simple microwave drying and hot air drying, and the drying time of combined drying method is shortened by more than 11% than the segmental hot air drying, wherein the VI combination In the combined drying mode, the total drying time is the shortest (17.8 h), only 63.57% of the segmented hot air drying time.

It can be seen from Fig. 1 that the moisture content changes rapidly during the whole process of microwave intermittent drying. Microwave heating is caused by the internal frictional heat of the

molecules obtained by the rotation of dipoles such as water molecules with the direction of the electric field. Temperature gradient The same direction as the water gradient, the driving force of heat and mass transfer inside the material is increased, and the drying efficiency of the red jujube is improved, but the long-term drying causes loss of easily oxidized components [23]. The water content change during the segmental hot air drying process is the smallest, and the heat and mass transfer direction is opposite in the drying process. The internal water diffusion rate of the material is smaller than the surface water vaporization amount [24]. The combination of microwave and hot air has obvious advantages in shortening the drying time.

Figure 1 Drying curves of six drying methods Fig.1 Drying curves of jujube products treated by six different drying methods
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Note: I is segmented hot air drying; II is microwave intermittent drying; III is microwave-hot air combined drying, microwave phase is repeated 6 times; IV is microwave-hot air combined drying, microwave phase is repeated 7 times; V is microwave-hot air combined drying Repeated 8 times in the microwave phase; VI is combined with microwave-hot air drying, and repeated 9 times in the microwave phase, the same below.

2.1.2 Change of drying rate in segmented hot air and microwave intermittent drying mode
Figure 2 is a graph showing the relationship between the drying rate and the dry basis moisture content in the first and second drying modes. Overall, the drying rate in the first 3 h of the segmental hot air drying process has been rising, undergoing a short accelerated drying phase, and then entering the two stages of constant speed drying and slow drying. The higher the temperature of the hot air, the faster the convective mass transfer on the surface of the material, and the moisture on the surface of the material is taken away in time to accelerate the drying rate. However, in the late drying stage (Table 2), the moisture content is reduced, and the evaporation surface is continuously transferred to the material center, drying. The rate drops.

Fig. 2 Relationship between drying rate and water content of dry jujube in two ways. Fig.2 Curves of drying rate vs moisture content of jujube treated by drying methodsI, II
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At the beginning of drying, jujube has a high water content, a strong absorption capacity for microwaves, an increased drying rate, and then rapidly enters a constant-speed drying stage [25]. The microwave drying material is easy to discharge, and the drying rate of microwave drying is high. However, the waxy layer on the surface of red jujube is relatively thick, and the moisture absorption of microwave energy vaporizes, which is difficult to evaporate from the

surface and accumulate inside the material, resulting in overheating of red jujube to produce "steaming" phenomenon. , affecting the appearance quality of the product. In the later stage of microwave drying (Table 2), due to the expansion of microwave, many channels have formed inside the jujube, and internal moisture can quickly evaporate through these channels, and the drying rate is slightly increased.

2.1.3 Temperature change of jujube under segmental hot air and microwave intermittent drying
Fig. 3a is a graph showing the change of moisture content, temperature and drying time of jujube dry base in the first drying mode. During the hot air drying process, the heat is conducted from the outside to the inside of the material. The surface temperature of the dried material is greater than the internal temperature, but the waxy layer of the red jujube skin inhibits the evaporation of the inner layer of water, and the heat is concentrated, and the internal temperature is higher than the surface temperature. The surface temperature and internal temperature are consistent with changes in drying temperature and are relatively stable at different stages.

Fig. 3b is a graph showing the change of moisture content, temperature and drying time of jujube dry base in the second drying mode. Microwave can heat the heated material inside and outside at the same time. However, in practical applications, due to the influence of the flowing air around the material, the external surface is easy to dissipate heat, so that the surface temperature of the material is often lower than the internal temperature.

Fig.3 Relationship between moisture content, temperature and drying time of jujube dryness in the first and second drying modes Fig.3 Curves of moisture content and temperature of jujube vs drying time by two drying methodsI, II
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At the beginning of drying, the material absorbs energy, the surface and internal temperature show an upward trend, and the drying rate also rises rapidly. Due to the uneven microwave radiation inside the material, the internal temperature of the jujube rises unevenly [26], and the local temperature can reach 80~. 90°C,