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Experimental Study on Hot-air Drying Process Parameters Optimization of Chinese Jujubes

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Abstract: In this study, the drying characteristics of jujubes conducted in a convective dryer were investigated under different air temperatures, air velocities, specific surface areas and densities of arrangement which conducted in a convective dryer. Furthermore, an orthogonal experiment was developed under different air temperatures, air velocities, specific surface areas and densities of arrangement. Such a reduction on drying rate was observed by the drying process. Also the total sugar of jujube was found to increase, according to the degree of influence, the order was air temperature > air velocity>specific surface area >density of arrangement; for decreasing of vitamin C, the order was air temperature>air velocity>specific surface area>density of arrangement; and for improving the organoleptic attribute which was air temperature>density of arrangement >air velocity>specific surface area. Through orthogonal optimization analysis, the optimum processing parameters were obtained under 55°C (drying temperature), 0.5 m sec^{-1} (air velocity), 2.5 cm^{-1} (specific surface area), 12.0 kg m^{-2} (density of arrangement). This research can provide theoretical and technical basis for drying conduction of jujubes and also an important reference value for optimizing processing technology.

Key words: Jujube, hot-air drying, orthogonal test, process

INTRODUCTION

Jujube, also called red jujube, big jujube, China jujube, dried jujube and so on, is the fruit of Rhamnaceae Ziziphus plants has abundant nutritional value and powerful health care function. Jujube is rich in a variety of body essential amino acids, carbohydrates, various vitamins as well as minerals has "the king of vitamin" reputation in fruits. China is the largest producer of jujube in the world with a planting area of 1.33 million hectares, annual production of about 2.5 billion kg (Yang *et al*., 2009). Fresh jujubes with high water content about 80%, short storage period, lose as high as 20-30% every year, the loss will be higher without drying in time which causes serious economical loss and a drop in the jujube's quality. Therefore, drying plays one of the most important roles in improving the commodity rate of jujubes.

In recent years, the research on jujube drying characteristics has made many achievements, by comparing hot air drying and microwave drying, the result showed that the best temperature of drying is 35°C (Li *et al*., 2008). By analyzing dried jujube quality after various methods with a raised temperature, the result showed that the quality of dried jujube is best at 60°C the highest drying temperature is lower than 70°C (Chen *et al*., 1999; Mu and Chen, 2001).

In this study, the drying characteristics of jujubes and the influence of the quality were investigated under different air temperatures, air velocities, specific surface areas and densities of arrangement. This research can provide a theoretical and technical basis for drying conduction of jujubes and also an important reference value for optimizing processing technology.

MATERIALS AND METHEDS

Materials: Bioer jujubes used in the experiments were produced in Tarim, Xinjiang and were chosen as drying materials in September, 2012. The samples in the same species with full maturity and uniform size were stored in a refrigerator at 4°C before starting the experiments. The initial moisture content was about 77.61 wet basis (w.b.).

Testing equipment: The test instruments mainly include a thin layer drying test-bed, precision air dry oven (DHG-9125A), anemometer (LUTRON, AM-4201, Taiwan), ratio surface area analyzer (3H-2000A) and digital electronic balance (OHAUS, CP3102, USA). The thin layer drying test-bed is developed by College of Biological and Agricultural Engineering, Jilin University. The test bed is composed of air blower, diffuser, heater, materials tray(18.5cm¡Á18.5cm), drying chamber, the temperature and humidity control unit and transmission.

Experimental procedure: Take the stored jujubes out of refrigerator, wait until they reach room temperature. Then

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select some undamaged, mold-free, insect-free jujubes as experimental materials that without moldy without insects without damage. By selecting optimal specific surface area, the drying experimental is carried out at different air temperatures, air velocities and densities of arrangement. According to the standards set by General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ, 2009), the drying process was continued until the moisture content of the samples reached below 25% (w.b.).

To investigate the effect of changing the drying factors levels on the quality of dried jujubes, the optimum technology conditions were selected by orthogonal test consisting of three factors air temperatures, air velocities, specific surface areas (the specific surface areas of jujubes per unit volume) and densities of arrangement at three different levels. Adopt $L_9(3^4)$ orthogonal table, as Table 1.

Experimental parameters: Moisture content is shown as moisture content on dry basis during jujubes hot air drying. Plot the drying curve with the time (h) as the abscissa and the moisture content (%) as the ordinate. The moisture content on dry basis(M_t) is expressed as follows (Midilli, 2001; Lou *et al*., 2010):

$$M_t = \frac{G_t - G_0(1 - M_0)}{G_0(1 - M_0)} \quad (1)$$

There, G_t is the mass of jujubes at any time t, the unit is g; G_0 is the initial mass, g; is the initial moisture content on dry basis,%.

Experimental index evaluation:

Physical and chemical indexes inspection: The initial moisture content is determined using a precision air dry oven according to Chinese national standard (Testing method of moisture content in foodstuff, GB/T5009.3–2003). The content of total sugar is determined according to Chinese national standard (General rule for preserved fruits, GB/T10782-2006); the higher content is, the less the loss during drying and the better the quality of jujubes. The vitamin C content was determined according to the 2,6-dichlorindophenol titration method; the higher the content is, the better the quality.

Sensory index: It depends on the sensory score that comes from the judgment of the assessing team of twelve people for jujubes. The code of points is shown as Table 2.

RESULTS AND DISCUSSIONS

Drying characteristics: The dry basis moisture content versus time curves for density of arrangement 14.0 kg m^{-2} and specific surface area 2.3 cm^{-1} under air velocity 2.0 m sec^{-1} in drying chamber as influenced by various air temperature (45 55, 65 °C) are shown in Fig. 1. It is shown that the higher the temperature, the shorter the drying time. It indicated that transfer is rapid at high temperature because more heat is generated within the jujube, creating a larger vapor pressure differential between the centre and the surface of the fruits.

The dry basis moisture content moisture versus time curves for density of arrangement 14.0 kg m^{-2} and specific surface area 2.3 cm^{-1} under air temperature 65°C as influenced by different air velocities (0.5 1.0 2.0 m sec^{-1}) are shown in Fig. 2. It is shown that as the velocity increases, the time to achieve certain moisture decreases. The result indicated that more and more heat is moved out of the drying chamber as the air velocity increases, only a fraction of energy acts.

The dry basis moisture content moisture versus time curves for density of arrangement 14.0 kg m^2 under air temperature 65°C and air velocity 0.5 m sec^{-1} as influenced by various specific surface area (2.1' 2.3' 2.5 cm^{-1}) are shown in Fig. 3. It is seen that the drying time is shorter when the specific surface area is bigger. That is because per unit volume of jujubes with bigger surface area will result in a shorter journey for moisture releasing from the internal of the fruit.

Table 1: Factors and levels of orthogonal test

Levels	Factors A/Air temperature (°C)	B/Air velocity(m/s)	C/Specific surface area(1/cm)	D/Density of arrangement (kg m^{-2})
1	45	0.5	2.3	12
2	55	1	2.4	14
3	65	2	2.5	16

Table 2: Sensory index scoring rules

Index	Evaluation criterion	Full mark
Color	Peel for rosy, no browning, luster	30
Appearance	The shape full, big and uniform, no mildew, no hard skin	20
Flavor	Pulp thick, sweet flavor, no bitter focal taste	20
Smell	Have date aroma	15
Form of organization	Fleshy closely and uniform distribution	15

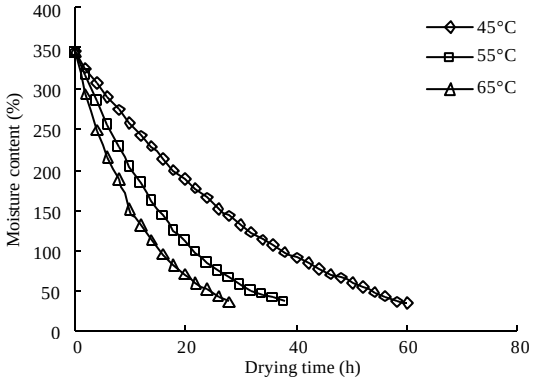

Fig. 1: Drying curves of moisture content with time at different temperatures for jujubes

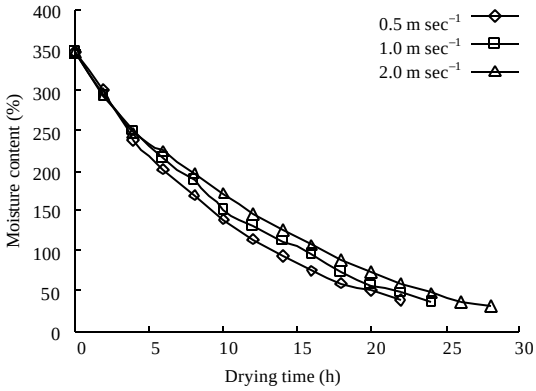

Fig. 2: Drying curves of moisture content with time at different air velocities for jujubes

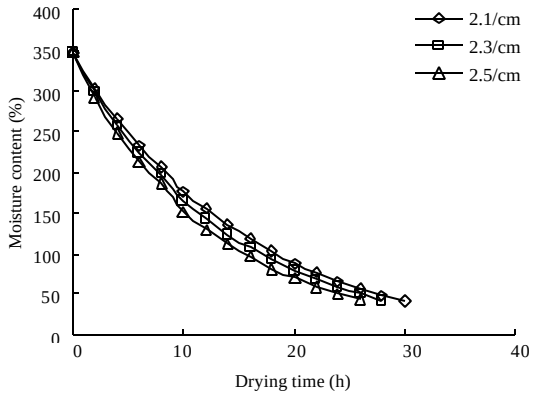

Fig. 3: Drying curves of moisture content with time at different specific surface areas for jujubes

The moisture versus time curves for specific surface area 2.1 cm^{-1} under air temperature 65°C and air velocity 0.5 m sec^{-1} as influenced by different density of arrangement (12.0' 14.0' 16.0 kg m^{-2}) are shown in Fig. 4. It is shown that the drying time increased with smaller density of arrangement in drying chamber, because there is a larger contact area between jujubes and hot air which is beneficial for the heat transfer and mass transfer.

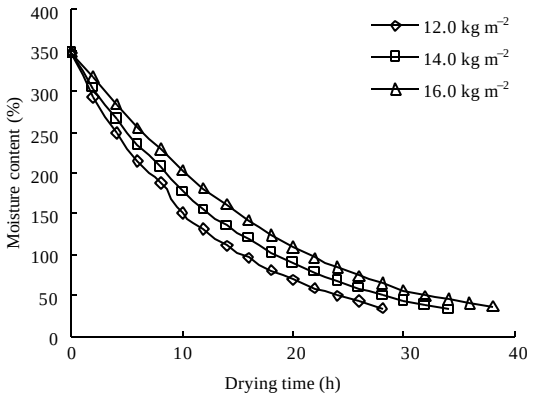

Fig. 4: Drying curves of moisture content with time at different densities of arrangement for jujubes

Drying quality: Though observing the jujubes after drying at different temperatures it is seen that most of them appear red or deep red, taste sweet and have fruity aromas of dried jujubes while part of them appear dark red even black with strong bitter taste. The main reason is that the action of heat extremely encourages VC aerobic decomposition those metabolites react with amino acids to produce red pigment and yellow pigment which cause fruits to brown; at the same time, melanoidins are reaction products of the maillard reaction of sugars and amino acids which deepen jujube color.

Through the observing of the jujubes after drying at air velocity it is seen that high velocity causes peel to harden some cracks on the peel. It's possible that air velocity is so high that the transfer of surface moisture moves faster than internal moisture. If surface moisture is transferred to a certain level, there will be a membrane formed on the surface of the jujube which will stop internal moisture moving. If internal moisture still moves to surface it will vaporize and rush out of surface which will cause the surface of jujubes to crack.

Though observing the jujubes after drying at different temperatures it is seen that the palate is sweeter at the bigger specific surface area; one possible reason is that jujubes with bigger surface area of per unit volume have higher drying speed and shorter drying time which decreases the loss of carbohydrate during drying.

Table 3: Design and Results of orthogonal experiment

	Factor				Test index		
Test No.	Atemperature (°C)	BAir velocity (m s^{-1})	C Specific surface area (cm^{-1})	DDensity of arrangement (kg m^{-2})	The content of the total sugar (g kg^{-1})	The content of VC (mg kg^{-1})	Sensory index point
1	1(45)	1(0.5)	1(2.1)	1(12.0)	722.812	2261	95.33
2	1(45)	2(1.0)	2(2.3)	2(14.0)	642.692	2256	94.75
3	1(45)	3(2.0)	3(2.5)	3(16.0)	592.311	2183	92.52
4	2(55)	1(0.5)	2(2.3)	3(16.0)	732.827	2352	94.85
5	2(55)	2(1.0)	3(2.5)	1(12.0)	672.274	2311	96.67
6	2(55)	3(2.0)	1(2.1)	2(14.0)	688.392	2224	93.25
7	3(65)	1(0.5)	3(2.5)	2(14.0)	576.371	2116	83.53
8	3(65)	2(1.0)	1(2.1)	3(16.0)	489.380	1925	79.33
9	3(65)	3(2.0)	2(2.3)	1(12.0)	556.407	2047	81.67

Table 4: Analysis of range for orthogonal experiment

	Content of the total sugar				Content of VC				Sensory index			
	A	B	C	D	A	B	C	D	A	B	C	D
K_1	1957.8	2032.0	1900.6	1951.5	6700.0	6729.0	6410.0	6619.0	282.6	273.7	267.9	273.7
K_2	2093.5	1804.3	1931.9	1907.5	6887.0	6492.0	6655.0	6596.0	284.8	270.8	271.3	271.5
K_3	1622.2	1837.1	1841.0	1814.5	6088.0	6454.0	6610.0	6460.0	244.5	267.4	272.7	266.7
k_1	652.6	677.3	633.5	650.5	2233.3	2243.0	2136.7	2206.3	94.2	91.2	89.3	91.2
k_2	697.8	601.4	644.0	635.8	2295.7	2164.0	2218.3	2198.7	94.9	90.3	90.4	90.5
k_3	540.7	612.4	613.7	604.8	2029.3	2151.3	2203.3	2153.3	81.5	89.1	90.9	88.9
R	157.1	75.9	30.3	45.7	204.0	91.7	66.7	53.0	13.4	2.1	1.6	2.3
Excellent level The order of major-secondary factors	A_2 A	B_1 B	C_2 D	D_1 C	A_2 A	B_1 B	C_3 C	D_1 D	A_2 A	B_1 D	C_3 B	D_1 C

Jujubes with bigger density of arrangement taste sourer than the smaller which maybe because the greater weight of jujubes per unit area, the slower the drying speed moisture is seldom discharged immediately also part of jujubes ferment during drying.

Orthogonal experiment: Orthogonal experiment design and results are shown in Table 3. The results of extreme difference analysis of orthogonal experiments are shown in Table 4; the primary factors of influence on the total sugar are air temperature, air velocity, density of arrangement and specific surface area. The result indicates: when the major elements air temperature is at 55°C it has the highest sugar count. The possible reason is that at low air temperatures, the drying rate small, drying time long, the action time of jujubes affected by respiratory metabolism and other function enzyme is longer it consumes part of sugar; when the air temperature is high, the sugar is easily reacts with the amino acid and other substance, greatly reducing the sugar count. According to the results of analysis of range, the optimal combination is $A_2B_1C_2D_1$, that is air temperature 55°C, air velocity 0.5 m sec^{-1}, specific surface area 2.3 cm^{-1} and density of arrangement 12.0 kg m^{-2}. The combination $A_2B_1C_2D_1$ is beyond the nine groups of experiments it is proved by the experiment that the total sugar content is 746.33 g kg^{-1} which is superior to the others.

Though Table 4 analysis of range it shows that from step-down sequence, the factors of the effect on VC are as follows: Air temperature>air velocity>specific surface area>density of arrangement. The air temperature has remarkable influence other factors have smaller effects. This is because VC is a heat-sensitive material oxidized easily if heated. The processing cycle is long when the temperature is lower; when the temperature is higher, VC is extremely easy to be oxidized. There is a large amount of VC wasted due to double adverse effects of heat and oxidation. By means of orthogonal experiment, the optimal combination of parameters is $A_2B_1C_3D_1$: Drying temperature 55°C, air velocity 0.5 m sec^{-1}, specific surface area 2.5 cm^{-1} and density of arrangement 12.0 kg m^{-2}. The combination $A_2B_1C_3D_1$ is beyond the nine groups of experiments it is proved by the experiment that VC content is 2496.82 mg kg^{-1} which is superior to the others.

The analysis of range show that from step-down sequence, the factors of the effect on sensory index are as follows: Air temperature>density of arrangement>air velocity>specific surface area. Air temperature is still a major factor of all, other factors matter less. The possible reason is high temperature promotes the rate of enzymatic reactions which decreases the quality of jujubes, causes jujube's peel to harden, blackens the color and leads to bitter flavor. The optimal combination $A_2B_1C_3D_1$ is given by analysis, the score of sensory index is 97.37 which is the highest of the nine groups of experiments.

Therefore it is clear that air temperature is the most important factor, then the air velocity. We can see the optimal combination of the total sugar is $A_2B_1C_2D_1$, the

optimal combination of VC and sensory index are both $A_2B_1C_2D_1$. Considering the influence of specific surface area on VC content and sensory index there is little difference between specific surface area C_2 (2.3 cm^{-1}) and C_3 (2.5 cm^{-1}) for the content of the total sugar, the optimum technical conditions have been determined they are as follows: Drying temperature 55°C, air velocity 0.5 m sec^{-1}, specific surface area 2.5/cm, density of arrangement 12.0 kg m^{-2}.

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CONCLUSION

Air temperature, air velocity, specific surface area and density of arrangement all have some impact on the drying characteristic. Air temperature is the most significant factor to the characteristic. As air temperature and specific surface area increase, air velocity and density of arrangement decrease the drying rate increases.

Air temperature, air velocity, specific surface area and density of arrangement are the factors which influence the quality of jujubes among them temperature is the most significant factor and the optimum temperature is 55°C. Decreasing wind speed helps to improve the quality. As specific surface area increases and density of arrangement decreases, the quality of jujubes increases.

By the orthogonal experiment, we have obtained that the effect order of three factors for the total sugar is as follows: Air temperature, air velocity, density of arrangement and specific surface area; for the content of VC is air temperature, air velocity, specific surface area and density of arrangement; and for sensory index is air temperature, density of arrangement, air velocity and specific surface area. The optimal combination of parameters is $A_2B_1C_3D_1$: drying temperature 55°C, air velocity 0.5 m sec^{-1}, specific surface area 2.5 cm^{-1}, density of arrangement 12.0 kg m^{-2}.

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