

Analysis of quality changes and hot air drying characteristics of Xinjiang jujube (*Zizyphus jujuba* cv. Junzao) by hang on trees drying

Chao Xu

Tarim University

Xiaokang Yi (✉ yxk@taru.edu.cn)

Tarim University

Can Hu

Tarim University

Qiaonan Yang

Fujian Agriculture and Forestry University

Jie Li

Tarim University

Yi Yang

Tarim University

Jie Zhang

Tarim University

Research Article

Keywords: Jujube, Hang on trees drying, Picking stage, Quality changes, Drying kinetics

Posted Date: March 10th, 2023

DOI: <https://doi.org/10.21203/rs.3.rs-2651017/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Analysis of quality changes and hot air drying characteristics of Xinjiang jujube (*Zizyphus jujuba* cv. Junzao) by hang on trees drying

Chao Xu ¹, Xiaokang Yi *, Can Hu ¹, Qiaonan Yang ², Jie Li¹, Yi Yang ¹, Jie Zhang ¹

1. College of Mechanical and Electrochemical Engineering, Tarim University, Arar 843300, China;

2.College of Mechanical and Electrical Engineering, Fujian Agriculture and Forestry University, Fuzhou 350000, China;

Abstract: The purpose of this study was to explore the changes in quality indicators and hot air drying characteristics of jujube during the natural hang on trees drying stage, and to determine the optimal picking period for Xinjiang jujube suitable to drying and processing, samples were collected six times in a 7-day cycle, respectively denoted as S1-S6, research the effects of different picking stages on the nutrient content, color, hot air drying kinetics and drying quality of Xinjiang jujube during hang on trees drying. The results showed that the water content of jujube gradually decreased; the percentage of soluble solids, total and reducing sugars increased, but the total mass of those in a single jujube decreased, and the percentage of ascorbic acid and total mass decreased during the natural drying process. The hot air drying time is different at different picking stages. The highest ascorbic acid content after hot air drying is 87.14 mg/100 g for jujube at stage S4. with a decreasing trend in cracking rate after drying from S1 to S6 and an increasing trend in rehydration. Used AHP to evaluate the quality comprehensively, found that jujube picked at S4 were more suitable for drying and processing.

Keywords: Jujube; Hang on trees drying; Picking stage; Quality changes; Drying kinetics

1 Introduction

As the birthplace of jujube, China's annual jujube production accounts for more than 95% of the world's annual production.^[1] Xinjiang, due to its unique geographical and climatic conditions, is the largest jujube

*Corresponding author.

Email address:yxk@taru.edu.cn

4 producer in China, with an annual production of nearly 4 million tons.^[2], accounting for more than 45% of
5 China's total production.^[3], and mainly are Junzao and grey jujube, the combined output of the two accounts
6 for over 90% of the annual production of jujube in Xinjiang^[4]. The jujube fruit is large, nutritious, sweet and
7 sour, rich in sugars, organic acids, ascorbic acid, phenols and other nutrients, and is a tonic among fruits^[5].
8 The high water content of fresh dates makes them susceptible to alcoholisation. Fresh jujube often lose up to
9 15-30% of their value after harvesting.^[6] Therefore, 95% of jujube are dried and sold worldwide.^[7] Drying
10 technology for jujube is now relatively mature, Common drying methods include hot air drying^[8],
11 microwave drying^[9], vacuum freeze drying^[10], infrared drying^[11], As hot air drying has the advantages of
12 simple structure, easy operation, low energy consumption and high efficiency^[12], it has become the main
13 drying method for jujube drying in Xinjiang, China. Xinjiang jujube are not picked immediately after they
14 are fully ripe, but are first dried by solar radiation, natural wind and other environmental factors to reduce the
15 free water and combined water inside the jujube as much as possible, this process that lasts approximately 40
16 days and is known as the natural hang on trees drying. The method of determining the natural hang on trees
17 drying depends mainly on farmers' experience and market demand, and does not take into account the impact
18 of the natural hanging process on the quality of jujube, which is yet to be confirmed.

19 Many scholars have investigated the changes in fruit quality with growth stage^[13]. Gou Xi et al.2014^[14]
20 investigated the changes in cyclic adenosine phosphate, soluble sugar and mineral element content of
21 Lingwu jujube at different maturity levels. Zhang Kekun et al. 2016^[15] found that there were significant
22 differences in quality characteristics of grapes at different stages of hang on trees storage. Deng et al. 2019^[16]
23 studied the physicochemical properties and drying kinetics of apricot fruit at different maturity levels and
24 found that the drying rate decreased after a certain stage of maturity. Liu Qinyuan et al. 2020^[17] found that
25 the aroma and color of the finished product differed when using peach at different maturity levels for wine
26 making. Wang H et al.^[18] studied the effects of postharvest ripening on the physicochemical properties,
27 microstructure, cell wall polysaccharide content and nanostructure of kiwifruit. Tang Ni et al.2022^[19] found
28 that the crude fat and 17 amino acids content of different varieties of avocado reached peak levels. The
29 optimal harvesting period for each variety of avocado was determined by measuring the change curve of the
30 content of the components. Diop Alioune et al.2022^[20] found during experiments on mango drying that as
31 the ripeness of mangoes continued to increase, the browning condition of the product became more

pronounced, i.e. ripeness had a significant effect on the color of dried mangoes. In conclusion, the physical and chemical properties and processing characteristics of the fruit differ significantly at different stages of harvesting, but no studies have been reported on the quality changes during the hang on trees drying period of jujube.

In order to investigate the effect of different picking stages on the physicochemical and drying characteristics of jujube, this paper investigates the natural hang on trees drying stage of jujube after maturity, and determines the content of total and reducing sugars, soluble solids, titratable acids and ascorbic acid, and analyses their changes. The drying characteristics of jujube at different picking stages, as well as the nutrient retention rate, color and cracking rate after drying, were analysed using hot air drying to provide a theoretical reference for determining the optimal picking period suitable for drying and processing during the natural hang on trees drying of jujube.

2 Materials and methods

2.1 Test materials

The jujube used in the experiment were harvested from farm No. 8, 10th regiment, Alar City, Xinjiang Uygur Autonomous Region (81° 12' 15.53" E, 40° 38' 16.21" N, 1023m above sea level). On 30 jujube trees of uniform growth conditions and 10 years old, branches with the same orientation and fruit maturity were selected. The jujubes on the branches were marked (according to Xinjiang Special Forestry and Fruit Industry Export Marketing ^[21]). The first picking was carried out on 16 September 2022 and with an interval of 7 days for each sample. Six batches of samples, denoted as S1-S6, were collected. The samples were wiped clean with alcohol, then sealed and stored in a refrigerator at a constant temperature of 4 °C to prevent loss of moisture and nutrients. Due to the long sampling period and to lower errors, batches of experiments were conducted the next day. The surface conditions of jujubes at different picking stages are shown in Table 1.

The experimental site was selected from the key Laboratory of Modern Agricultural Engineering, Tarim University, Alar, Xinjiang Uygur Autonomous Region, and the experimental period was from 16 September to 30 October .

Table 1. Sensory characteristics of jujubes at different picking stages

Picking stage	Picking Date	Surface condition
S1	16 September	Reddening of the surface over 75%, bright color and full and firm of fruit
S2	24 September	Over 95% of the surface reddened, bright color and full and firm of fruit
S3	1 October	surface all red, brighter in color, surface ruffled
S4	8 October	Surface all red, duller in color, with increased surface ruffling
S5	16 October	Surface all red, dull, with distinctive surface folds
S6	23 October	Surface all red, dull, with distinctive surface folds

57

58 2.2 Measurement methods for each indicator

59 2.2.1 Determination of moisture content and average mass

60 (1) Moisture content of jujubes at different picking stages

61 Ten jujubes were selected, the total weight was measured and put into an electric digital display blast
62 dryer (model: GZX-9140 MBE; range: 50-200°C; produced by Buxun Medical Biological Co., Ltd.,
63 Shanghai, China) at 105°C for drying, and weighed every two hours, and when the change in weight was less
64 than 0.1g between the two times, samples was considered to be absolutely dry, and the initial wet basis
65 moisture content M of the jujubes at the corresponding picking stage was calculated by the difference in
66 mass, as shown in equation (1).

$$67 \quad M = \frac{G_{nw} - G_{nd}}{G_{nw}} \cdot 100\%$$

68 (1)

69 Male in equation (1), M is the moisture content of jujubes at different picking stages, %. G_{nw} is the
70 weight of jujubes before hot air drying, g. G_{nd} is the mass of jujubes after hot air drying, g.

71 (2) Average weight of jujubes at different picking stages

72 Ten jujubes were selected and weighed using electronic balances (model: CP3102; range: 0-3200g;
73 accuracy: 0.01g; manufactured by Ohaus Instruments Ltd., Jiangsu, China) and the average value was obtained
74 as the average mass of the corresponding batch of jujubes.

75 2.2.2 Determination of total and reducing sugars

76 The total sugar content was determined according to the method in GB/T 10782-2021 "General rules for
77 the quality of preserves"^[22]. The reducing sugar content was determined according to the direct titration
78 method in GB5009.7-2016 "Determination of reducing sugars in foodstuffs"^[23].

79 2.2.3 Determination of titratable acids

80 Ten jujubes were selected and a total of 15 g of flesh samples were randomly weighed from different
81 parts of the jujubes, crushed and the filtrate was taken and determined by neutralisation titration with sodium
82 hydroxide^[24]. The main acid in the jujube was malic acid.^[25]

83 2.2.4 Determination of soluble solids

84 Ten jujubes were selected and a total of 5 g of samples were randomly weighed in different parts of
85 different jujubes, pounded and the filtrate was taken and dropped in the test area of a hand-held refractometer
86 (Model: LH-Y28, manufactured by Lu Heng Biotechnology Co., Ltd., Hangzhou, China) for measurement
87 and reading at 22 °C. The results were expressed as mass fraction, %.

88 2.2.5 Determination of ascorbic acid content

89 The ascorbic acid content was determined using the 2,6-dichloroindophenol titration method in GB
90 5009.86-2016^[26].

91 2.3 Determination of color

92 The color variation between picked and dried jujubes from S1 to S6 was determined using a
93 spectrophotometer (model: YS6003, Sanenshi Technology Co., Ltd., Shenzhen, China), based on the
94 CIELAB color chart system. The brightness L*, green-red value a* and blue-yellow value b* were
95 determined. The color difference values between the different picking stages and the hot air dried jujubes
96 were also analysed and calculated as follows ^[27]

$$97 \Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

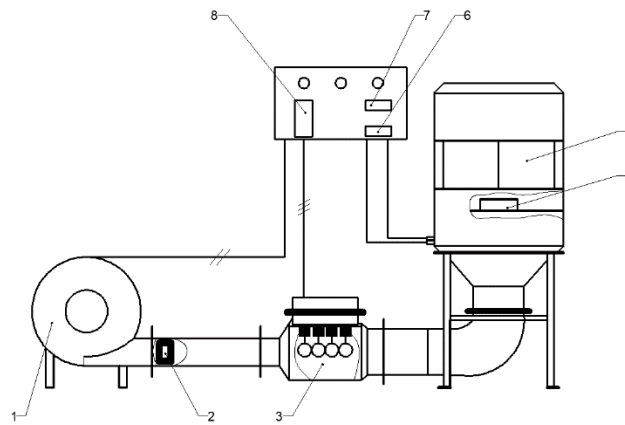
98 (2)

In equation (2), ΔE is the color difference value; ΔL^* , Δa^* and Δb^* are the difference in color parameters between fruit picked at stages S2-S6 and S1, respectively.

2.4 Drying of jujubes

2.4.1 Drying equipment

Twenty jujubes of approximately the same size, shape and hardness were selected from each batch, removed from the refrigerator, brought to room temperature, wiped dry and the total weight of the fruit recorded as the initial drying mass. The drying conditions were set at 65°C, 1.5 m/s wind speed and 40% relative humidity using a hot air thin layer drying test apparatus (homemade by the Key Laboratory of Modern Agricultural Engineering, Tarim University)^[28]. Figure 1 shows schematic diagram of the hot air thin layer drying test rig.



1. Fan 2. Spoiler 3. Electric heating unit 4. Material tray 5. Drying chamber 6. Drying chamber temperature control unit 7. Drying chamber humidity control unit 8. Air speed adjustment unit

Figure 1. Schematic diagram of the hot air thin layer drying test rig

Turn on the dryer, start the heating and air supply device, after running for 15min the material bin preheats to the set parameters and reaches a constant, then the jujubes are placed into the drying chamber trays in equal spacing order, the weight sensor inside the material bin is automatically weighed and recorded every hour, the quality of the trays is monitored in real time to determine their real time moisture content, until the moisture content of the dry base of the jujubes reaches below 33.3%, the drying test is complete. Once cooled and surface cracks have been observed using a stereo microscope, the jujubes are bagged, sealed using a vacuum machine and stored at room temperature pending testing.

2.4.2 Drying parameters

(1) Moisture content of dry base

The moisture content of dates varies continuously with drying time. The dry basis moisture content of jujubes at time t is given by M_t expressed by the following equation:

$$M_t = \frac{G_t - G_0(1 - M_0)}{G_0(1 - M_0)} \quad (3)$$

In equation (3), the G_t is the mass of all jujubes in the material tray at time t , g. G_0 is the mass of all jujubes in the material tray at the initial moment, g. M_0 is the initial wet base moisture content of the jujubes, %.

(2) Drying rate

The drying rate of any stage (Drying rate) is expressed as a function of the moisture content of the dry base at the beginning and end of the stage versus time, as follows^[29] :

$$DR = \frac{M_{t_2} - M_{t_1}}{t_2 - t_1}$$

(4)

In equation (4), the M_{t_1} is the dry basis moisture content at the beginning of the stage. M_{t_2} is the dry basis moisture content at the end of the stage. t_1 is the moment of the start of the phase; and t_2 is the moment of the end of the stage.

(3) Effective diffusion coefficient of moisture

The effective diffusion coefficient of moisture during hot air drying of steamed dates can be calculated according to Fick's second law equation^[30]:

$$MR = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \exp \left(- \frac{n^2 \pi^2 D_{\text{eff}}}{r_e^2} t \right)$$

(5)

In equation (5), MR is the moisture content ratio; D_{eff} is the effective diffusion coefficient of moisture, m^2/s ; r_e is the volume equivalent radius, m; t is the drying time, s.

Taking the logarithm of both sides of the above equation at the same time gives:

$$\ln MR = \ln \frac{6}{\pi^2} - \frac{\pi^2 D_{\text{eff}}}{r_e^2} t \quad (6)$$

The slope method was used for the calculation of the effective diffusion coefficient of moisture, and the slope expression from equation (6) is:

$$k = - \frac{\pi^2 D_{\text{eff}}}{r_e^2} \quad (7)$$

2.4.3 Observation of superficial surface cracks

The high rate of heat mass transfer during hot air drying of jujube makes the process of heat expansion and water loss and shrinkage faster, which can easily lead to cracks, causing nutrient loss, microbial enrichment and infiltration and other conditions, reducing the drying quality. Twenty jujubes without initial cracks were selected from each batch for drying. The surface of the jujubes was observed using a stereomicroscope (Model: TD-2KH, Sanmang Teda Optical Instruments Co., Ltd., Shenzhen, China) and the cracking rate of jujubes at different picking stages after hot air drying was calculated with reference to the hazelnut drying cracking statistics method ^[31].

$$P = \frac{N_d}{N_w} \quad (8)$$

In equation (8), P is the rate of cracked fruits, and N_d is the number of stepped jujubes with cracks after hot air drying, and N_w is the total number of dried jujubes.

2.4.4 Determination of the rehydration ratio

The rehydration is an important indicator of the quality of the dried jujubes. Random selection five dried jujubes was weighed and placed in a constant temperature water bath at 50° C for 40min and then removed, dried on absorbent paper and left to dry for 20 minutes on before being weighed again. The formula for calculating the rehydration of jujubes is as follows ^[32]:

$$R = \frac{M_w}{M_d} \quad (9)$$

167 In equation (9), R is the rehydration ratio and M_d is the initial mass, and M_w is the mass after
168 rehydration.

169 2.5 Integrated evaluation methods

170 The evaluation indicators of jujubes after hot air drying need to be normalised. The positive indicators
171 are ascorbic acid content and rehydration ratio after hot air drying; the negative indicators are drying time,
172 cracking rate and color difference. The normalisation formula y_i , as shown in equation (10):

$$173 \quad y_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (10)$$

$$174 \quad y_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \quad (11)$$

175 In equation (10) and equation (11). y_i are the normalised values of the indicators, the x_i are the actual
176 values of the indicators, the x_{max} and x_{min} are the maximum and minimum values of the indicators
177 respectively.

178 Combined score for the drying quality of jujubes at different picking stages of hang on trees drying y. The
179 formula is as follows:

$$180 \quad y = y_1 l_1 + y_2 l_2 + y_3 l_3 + y_4 l_4 + y_5 l_5 \quad (12)$$

181 In equation (12). y_1, y_2, y_3, y_4 and y_5 are the normalised results for ascorbic acid content, rehydration
182 ratio, drying time, cracking rate and color difference, respectively l_1, l_2, l_3, l_4 and l_5 are the corresponding
183 weights, respectively.

184 2.6 Data processing

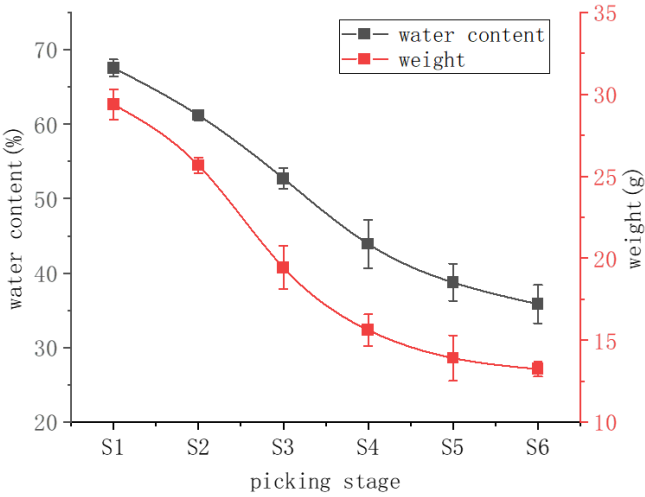
185 Three parallel experiments were carried out for the determination of drying parameters, composition
186 content, color and rehydration. Origin 2018 software was used for plotting, Excel 2015 and SPSS 25.0 were
187 used for data statistics and analysis, mean values were used for plotting and data analysis, and the level of
188 significance of differences was 0.05.

189 3 Results and analysis

190 3.1 Moisture content and mass change Analysis

191 The quality, moisture content and nutrient content of ascorbic acid and soluble solids of jujube change
192 during natural hang on trees drying. As shown in Figure 2, the wet basis moisture content and mean mass of
193 jujubes picked at different stages of the hang on trees drying period ranged from 35.84% to 67.55% and 13.32-
194 29.38 g, respectively. The jujubes were in a water-depleted and dry state during the hang on trees drying period,
195 with significant differences ($P<0.05$) between the moisture content and mean mass of jujubes picked at S1-S4,
196 and the most significant reduction in water content was observed in S2-S4, with 8.47% and 8.80% reduction
197 respectively, was the main stage of water loss during hang on trees drying, compared to S1-S2, where the
198 variation in water content and quality of jujubes was smaller, probably because the branches were still
199 supplying water and other materials to the fruit. After the rapid loss of water from the surface of the jujube
200 during the drying process, natural environmental factors were not sufficient for the internal water of the jujube
201 to rapidly migrate to the surface and diffuse into the air^[33].

202



203

204 Figure 2. Graph of water content and mass change

205 3.2 Analysis of changes in nutrient content

206 As the moisture content and average mass of the batches of jujubes continued to decrease, the total
 207 weight of material within a single fruit of jujubes was used to express the changes in the indicators during the
 208 natural drying of the jujubes.

209 As shown in Table 2 and Figure 3, the range of variation of total and reducing sugars was 28.13%-
 210 56.22% and 16.73%-38.02%, while the range of soluble solids was 32.41%-63.89%. As the drying process
 211 progressed, the percentage content of both was on an increasing trend, and the total content within a single
 212 fruit first increased and then decreased, reaching a peak at the S2 stage, where the percentage content of total
 213 sugars and total content within a single fruit both increased the most from S1 to S2. It is believed that jujube
 214 is still in the “reddening stage” of the initial hang on trees drying process, starch changes into soluble sugar.

215 The percentage ascorbic acid content varied from 377.25 mg/100g to 111.61 mg/100g, with the same
 216 trend as the total content, and a clear downward trend throughout the S1-S6 stage. Similar to existing
 217 studies^[34]. It is suggested that the continuous loss of ascorbic acid during ripening and drying is related to the
 218 fact that it is highly susceptible to oxidation.

219 The total titratable acid content in single fruit increased slightly from S1 to S2, similar to the findings of
 220 Gou Xi^[14] et al. who investigated the stabilisation of titratable acid content in Lingwu jujube after
 221 maturation, while the total content continued to decrease from S2 to S6, i.e. there was some loss of titratable
 222 acid during the hang on trees drying process.

223

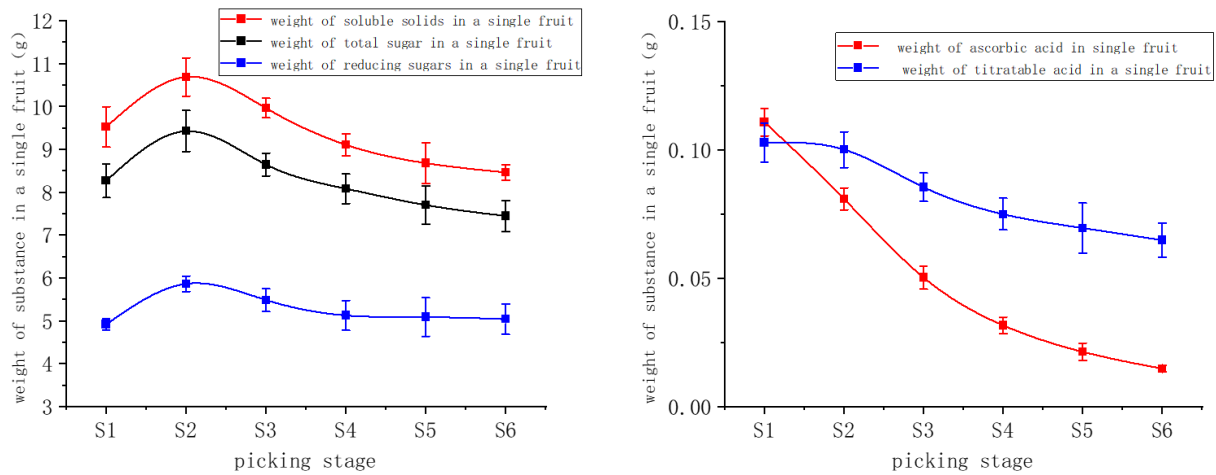
224 Table 2. Variation in the content of jujube components at various stages of hang on trees drying

Picking stage	Soluble solids %	Ascorbic acid mg/100g	Total sugar %	Reducing sugar %	Titratable acid %
S1	32.41 ± 1.84e	377.25 ± 6.58a	28.13 ± 1.77d	16.73 ± 1.12d	0.35 ± 0.07b
S2	41.64 ± 2.77d	315.21 ± 10.81b	36.71 ± 2.54c	22.84 ± 1.59c	0.39 ± 0.02ab
S3	51.26 ± 0.45c	258.76 ± 5.32c	44.48 ± 0.85bc	28.22 ± 0.04bc	0.44 ± 0.05ab
S4	58.28 ± 1.21b	202.65 ± 8.04d	51.73 ± 2.01ab	32.81 ± 0.84ab	0.48 ± 0.01a
S5	62.37 ± 1.36a	153.43 ± 9.36e	55.34 ± 1.65a	36.56 ± 1.01a	0.50 ± 0.02a
S6	63.89 ± 2.15a	111.61 ± 4.94f	56.22 ± 3.63a	38.02 ± 0.45a	0.47 ± 0.11ab

225

226 Note: Letters in the table indicate significant differences, $p < 0.05$, same below.

227



228

229 Figure 3. Variation in the total content of individual jujube fruits at each stage of hang on trees drying

230 3.3 Color analysis

231 The appearance and color of the fruit is the primary determinant of consumer purchase ^[35] and the color
232 change during the natural hang on trees drying stage is shown in the Table 3.

233

234 Table 3. Changes in color of jujubes at various stages of hang on trees drying

Picking stage	Brightness L*	Red and green values a*	Blue and yellow values b*	Color difference value ΔE
S1	51.26 $\pm$ 5.64a	12.75 $\pm$ 3.91b	35.54 $\pm$ 2.15a	-
S2	39.82 $\pm$ 1.29b	20.13 $\pm$ 2.58a	22.12 $\pm$ 0.55b	16.00 $\pm$ 1.21c
S3	34.58 $\pm$ 0.88c	22.21 $\pm$ 1.54a	16.35 $\pm$ 1.72c	25.09 $\pm$ 2.54b
S4	31.48 $\pm$ 0.97d	21.92 $\pm$ 2.21a	14.03 $\pm$ 0.36d	30.62 $\pm$ 2.25a
S5	31.51 $\pm$ 1.04d	22.45 $\pm$ 2.53a	14.01 $\pm$ 1.13d	30.78 $\pm$ 2.49a
S6	29.53 $\pm$ 1.26d	23.28 $\pm$ 0.74a	13.65 $\pm$ 1.11d	32.59 $\pm$ 0.77a

235

236 From Table 3, it can be obtained that the brightness L* of jujubes in the natural hang on trees drying
237 process significantly decreased ($P < 0.05$) in S1-S4 stage, S1-S2 stage decreased the most, from 51.26 to

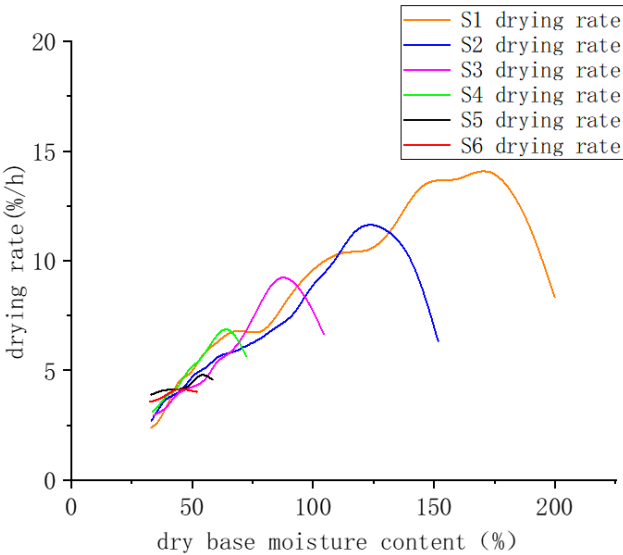
39.82 , due to S1 stage fruit epidermis still exist part of green, and green compared to red brightness value is higher, S2-S4 stage brightness decreased from 39.82 to 31.48, due to rapid water loss between this stage, with the loss of water from the epidermal cells, the reflection of light decreased and the fruit changed from a luminous maroon to a dull dark red, no significant change in brightness between S4-S6 stage ($P<0.05$), the surface state of the jujube gradually stabilised after S4 stage; the red-green value a^* was significantly lower in S1 stage than in S2-S6 stage, consistent with S1 stage, the red-green value a^* did not change significantly after S2, and it is believed that the main changes in the fruit coloring substances occurred mainly during the "red-change" stage; the blue-yellow value b^* tended to decrease significantly during S1-S4 and did not change significantly after S4-S6 ($P<0.05$), which is consistent with the trend of brightness L^* . The chromatic aberration value of the S2-S4 stages increases and stabilizes in the S4-S6 stage that the chromatic aberration value of each stage of S1-S4 is significant, and the difference in the S4-S6 stage is not significant ($P<0.05$), so although the color difference can indicate the different maturity of jujubes in the growth process^[36], it cannot be used as a criterion for the natural hang on trees drying process.

3.4 Drying characteristics

3.4.1 Influence of picking stage on the kinetics of hot air drying of jujubes

The hot air drying rate curves for the different picking stages are shown as Figure 4. The drying time required for each batch of jujubes from S1-S6 was 22h, 19h, 14h, 10h, 7h and 6h respectively, i.e. the overall drying time for hot air drying decreased as the jujubes of hang on trees drying naturally, and the drying rate of the samples from S1-S4 showed a trend of increasing first and then decreasing, i.e. the jujubes were in the preheating and heating up stage at the beginning of the drying period, and the drying rate increased first; at the later stage, the internal moisture diffusion control decreased. The drying curves of the samples in S5-S6 were more similar to uniform drying, indicating that the reduction of the initial moisture content accelerated the preheating and heating process of the jujubes. During hot air drying, it was easier to disperse moisture from the surface of the jujube than to migrate moisture from the interior of the jujube to the surface, but the drying rate at the S5-S6 stage near the completion of drying was higher compared to the S1-S4 stage. Combined with the shrinkage characteristics of the moisture-containing porous media during drying, it is believed that the high initial moisture content of the jujube is more destructive to the tissue structure during

265 hot air drying due to the long drying time and fast mass transfer rate, which makes the shrinkage of jujubes
 266 with low initial moisture content is not obvious due to the slower heat mass transfer and better preservation
 267 of the pore structure of the flesh and higher efficiency of water passage during natural hang on trees drying.



268
 269 Figure 4. Hot air drying rate curves for different stages of hang on trees drying

270 3.4.2 Effect of picking stage on the effective diffusion coefficient of water in jujubes

271 The effective diffusion coefficient of moisture indicates how quickly the moisture inside the material
 272 migrates to the surface during the drying process, which is influenced by changes in material structure,
 273 moisture content and drying temperature. The results are shown in Table 4. From S1 to S6, the effective
 274 moisture diffusion coefficient varied from $9.3621 \times 10^{-10} \text{ m}^2/\text{s}$ to $10.7400 \times 10^{-10} \text{ m}^2/\text{s}$, showing an increasing
 275 trend followed by a decreasing trend. It is suggested that jujubes picked too early have a high initial moisture
 276 content and rapid water diffusion during the initial drying stage, but produce severe wrinkling and crusting,
 277 resulting in deformation and destruction of internal water transfer channels and slowing down water
 278 diffusion, while jujubes picked too late have a similarly slow water diffusion process due to their low initial
 279 moisture content and mostly internally bound water. Combining the moisture content and crumbling
 280 deformation, the highest effective water diffusion coefficients were found for jujubes picked at S4 during the
 281 hang on trees drying process.

282 Table 4. Variation in the effective diffusion coefficient of jujube moisture at various stages of hang on trees drying

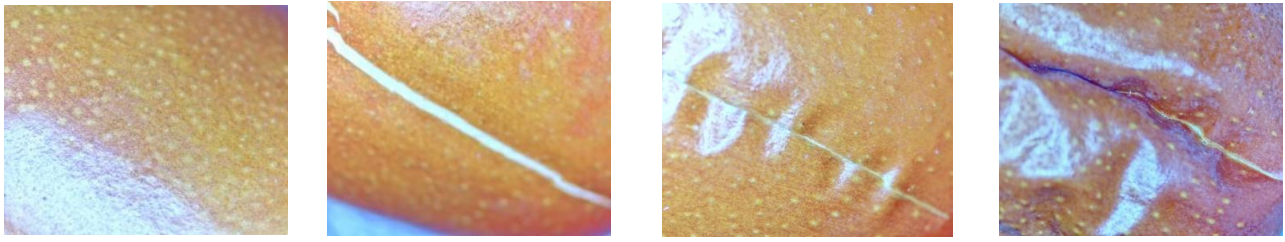
Picking stage	Initial dry basis moisture content	Drying time h	Linear regression fitting formula	Decision factor R^2	Effective diffusion coefficient of moisture $D_{eff}/(\times 10^{-10})m^2 \cdot s^{-1}$
S1	$2.08 \pm 0.17a$	22	$\ln MR = -2.31 \times 10^{-5}t - 0.1355$	0.9855	9.3621
S2	$1.58 \pm 0.17b$	19	$\ln MR = -2.34 \times 10^{-5}t + 0.04423$	0.9863	9.4837
S3	$1.11 \pm 0.06c$	14	$\ln MR = -2.38 \times 10^{-5}t + 0.0018$	0.9849	9.6458
S4	$0.78 \pm 0.11d$	10	$\ln MR = -2.65 \times 10^{-5}t - 0.0056$	0.9880	10.7400
S5	$0.63 \pm 0.06de$	7	$\ln MR = -2.55 \times 10^{-5}t - 0.0174$	0.9991	10.3348
S6	$0.56 \pm 0.06e$	6	$\ln MR = -2.52 \times 10^{-5}t - 0.0147$	0.9994	10.2132

283

284 3.5 Analysis of the drying quality of jujubes at different picking stages

285 3.5.1 Cracking rate of jujube after hot air drying at different stage

286 The generation of drying cracks is related to the drying method and the moisture content, mechanical
287 properties and tissue structure of the material itself^[37], with the postponement of the picking stage, the hot
288 air drying crack rate of jujube continuously decreases, the early stage of hot air drying is the main stage of
289 crack generation, and the higher the initial moisture content, the greater the probability of crack generation in
290 the early stage, as shown in Table 5, the cracking rate of jujube at the end of drying was 16.7%, 13.3%,
291 11.6%, 5.0%, 0% and 0%, respectively, at the initial moisture content of 67.55%, 61.19%, 52.72%, 43.92%,
292 38.76% and 35.84%, respectively. It is believed that when jujube with high moisture content (S1-S3) is dried
293 by hot air, the internal water in jujube is heated and vaporized rapidly, but cannot be completely discharged
294 in time, resulting in internal expansion and cracking of the peel under force (Figure 5.b), this phenomenon
295 mostly occurs in the accelerated drying phase, and due to the strong water locking capacity of the crack site,
296 the mass transfer rate of the cracked area will be significantly higher than the rest of the area (Figure 5.c),
297 resulting in crack diffusion, juice outflow, linear deep shrinkage and other conditions affecting the drying
298 quality (Figure 5.d), therefore, at high moisture content of jujubes, the drying process parameters such as
299 lowering the temperature and increasing the humidity should be controlled to reduce the heat mass transfer
300 rate of the surface of the jujubes in the early drying phase.



a. Surface characteristics of jujubes before drying

b. Initial crack generation

c. Rapid mass transfer in the cracked area

d. Produce deep shrinkage lines

Figure 5. Dynamics of hot air drying cracks in jujubes

Table 5. Changes in the production of cracks in natural drying of jujube at various stages of hot air drying

Picking stage	Drying quantity (pieces)	Number of fruit that cracked	Drying crack rate
S1	60	10	0.167
S2	60	8	0.133
S3	60	7	0.116
S4	60	3	0.050
S5	60	0	0.000
S6	60	0	0.000

3.5.2 Comprehensive evaluation of the picking phase

Unlike heat-tolerant substances such as sugars, ascorbic acid is highly susceptible to oxidation and thermal degradation during high-temperature drying and its preservation is better suited for evaluating the quality of the fruit after drying ^[38]. During high temperature drying, the evaporation of surface water and chemical reactions such as enzymatic browning, non-enzymatic browning and caramelisation reactions can lead to differences in the color of jujubes ^[39]. The rehydration reflects the structural damage of the jujubes after drying ^[40]. This is shown in Table 6. In combination with the drying time and the crack rate, the above five indicators were used to determine the quality of the jujubes after hot air drying.

The weights of ascorbic acid content, rehydration ratio, drying time, crack rate and color difference were set at 0.3, 0.15, 0.3, 0.15 and 0.1, respectively. According to the evaluation data in Table 7, the comprehensive scores of hot-air drying quality at the picking stage of S1-S6 were 0.15, 0.27, 0.58, 0.79, 0.73

315 and 0.59, respectively. Although the color of the jujubes picked in the earlier stages was good and the drying
316 time and crack rate of the jujubes picked in the later stages was lower, the overall quality of the samples
317 picked in the S4-S5 stage was still the best, and the jujubes picked in this stage were more suitable for drying
318 and processing.

319 Table 6. Statistics on the quality of jujubes after drying at various stages

Picking stage	Average mass per fruit after drying g	Color				Ascorbic acid content mg/100g	Rehydration ratio
		Brightness L*	Red and green values a*	Blue and yellow values b*	Color difference value ΔE		
S1	12.67±0.63ab	33.66±2.36a	17.20±2.54b	27.47±2.02a	-	56.59±1.78e	1.21±0.17c
S2	13.25±0.76a	27.05±1.36b	20.61±1.79a	17.37±1.70b	12.54±1.13a	63.04±2.44d	1.25±0.02c
S3	12.21±0.31bc	27.19±2.02b	21.55±2.13a	17.18±1.53b	12.90±1.58a	82.80±1.05b	1.46±0.15b
S4	11.65±0.61bc	30.40±1.57ab	22.86±2.21a	13.82±0.18c	15.13±2.27a	87.14±1.27a	1.63±0.11a
S5	11.32±0.43c	28.95±2.71b	23.49±1.80a	13.58±1.78c	15.95±1.87a	73.65±3.92c	1.65±0.16a
S6	11.29±0.40c	29.59±1.49b	23.44±1.45a	13.31±1.06c	16.00±2.14a	58.03±2.30e	1.61±0.21a

320

321 Table 7. Results of the comprehensive evaluation of the jujubes picking stages

Picking stage	Normalized Ascorbic Acid Content	Normalized value of compound water ratio	Drying time normalized value	Cracking rate normalized value	Color difference normalized values	Overall rating
S1	0.1722	0.0000	0.0000	0.0000	1.0000	0.15
S2	0.4996	0.0909	0.1875	0.2036	0.2163	0.27
S3	0.9901	0.5682	0.5000	0.3054	0.1938	0.58
S4	1.0000	0.9545	0.7500	0.7006	0.0544	0.79
S5	0.4972	1.0000	0.9375	1.0000	0.0031	0.73
S6	0.0000	0.9091	1.0000	1.0000	0.0000	0.59

322

323 4 Conclusions

324 In summary, the natural hang on trees drying stage had a great influence on the nutrients and hot air
325 drying characteristics of jujubes, and the change patterns of each index were different. As the picking stage

was delayed, the percentages of soluble solids, total sugars, and reducing sugars increased, but the total mass in individual fruits increased and then decreased, reaching a peak at the S2 stage. The percent ascorbic acid content and the mass within a single fruit were decreasing, and the trend was obvious, while the percent titratable acid content did not change significantly and the mass within a single fruit was decreasing. The sugar-acid ratio kept increasing and the taste sweetness was better. The brightness of the fruit gradually decreased with picking time, and there was no obvious change after the S4 stage. The hot air drying time required at each stage gradually decreased, and the preservation rate of ascorbic acid kept increasing, and the ascorbic acid content of the jujube fruit was the highest after the S4 stage. The surface cracks of jujube fruits after drying were observed through the body microscope, and the cracking rate of red dates picked at S4-S5 stage was lower, and the trend of change of water rehydration was similar to the trend of crack generation. The changes of the hot air drying characteristics and quality were combined, and the jujubes picked at S4 stage were considered more suitable for subsequent hot air drying processing.

338

Author contributions: resources, Q.Y.; data curation, J.L.; Writing-original draft preparation, C.X.; Writing-review and editing, X.Y.; visualization, Y.Y. and J.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by National Natural Science Foundation of China. grant number 32160427; Graduate Research and Innovation Project of Tarim University, grant number TDGRI202248.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: This work was supported by National Natural Science Foundation of China (Project No. 32160427) and Graduate Research and Innovation Project of Tarim University(Project No. TDGRI202248). The authors are grateful to anonymous reviewers for their comments.

349 **Declarations**

350 Ethics Approval Not applicable.

351 Consent for publication Not applicable.

352 **Consent to Participate** Not applicable.

353 **Conflicts of Interest** The authors declare no conflict of interest.

354 **Reference**

355 [1] Xinjiang Uygur Autonomous Region Bureau of Statistics. Xinjiang Statistical Yearbook [M]. Beijing: China Statistics Press,
356 2020.

357 [2] Xinjiang Production and Construction Corps Statistical Bureau. Statistical Yearbook of Xinjiang Production and
358 Construction Corps [M]. Beijing: China Statistics Press, 2020.

359 [3] Hu, Dingding, Ren, Zongjiao, Li, Huan, Jing, Meng. Xinjiang jujube industry: development trend and pillar status[J].
360 Xinjiang Agricultural Reclamation Science and Technology,2022,45(02):1-3.

361 [4] Bao Yanli, Cheng Hongmei, Zhang Lizhao. Research on the development of red jujube industry in Xinjiang[J]. Rural
362 Economy and Technology,2022,33(01):145-146+152.

363 [5] WANG Jun, ZHANG Baoshan, CHEN Jinping. Study on the nutritional composition and functions of red jujube[J]. Food
364 Research and Development,2003(02):68-72.

365 [6] LIU Liguo, ZHANG Xuejun, SUN Jie, JIN Wei, YAN Jinshan, XIN Qianqian. Experimental study on hot air drying process
366 of red jujube[J]. Agricultural Mechanization Research,2017,39(03):258-263.

367 [7] Ren Songwei,Li Chuanfeng,Li Bo,Ren Yongqiang,Ma Bo. Application of infrared heating technology in the processing of
368 red dates[J]. Food Industry,2020,41(05):250-253.

369 [8] Niu Yubao, Yao Xuedong, Xiao Hongwei, Wang Dongdong, Zheng Xia, Wang Qiang, Zhu Rongguang, Zang Yongzhen,
370 Liu Huan. Effect of RF-assisted hot air drying on the textural properties and microstructure of crispy red jujube slices[J]. Journal of
371 Agricultural Engineering,2022,38(02):296-306. DOI: 10.11975/j.j.issn.1002-6819.2022.02.033.

372 [9] LI Fan, SHAO Pei-lan, HAN Yating, XIE Hui, ZHANG Li-fen. Effect of drying methods on the content of pigment active
373 ingredients and antioxidant activity of red jujube[J]. Food Science and Technology,2019,44(01):120-124. DOI:
374 10.13684/j.cnki.spkj.2019.01.022

375 [10] GUO Wenbo, ZHENG Xia, GUO Jingyu, LI Jiu, CHEN Guogang. Research on processing technology of vacuum freeze-
376 dried red date powder[J]. Food Industry,2016,37(06):95-99. DOI:10.1016/J.ULTSONCH.2022.106219

377 [11] WANG Kunhua, LI Jiami, PENG Fei, LIU Yudi, MA Qi, LI Mei, XU Huaide. Effect of RF treatment on kinetics and
378 quality characteristics of red jujube dried in short and medium wave infrared[J]. Food Science,2020,41(07):117-123.
379 DOI:10.7506/spkx1002-6630-20190403-045.

380 [12] Liu De-Cheng, Zheng Xia, Xiao Hong-Wei, Yao Xuedong, Shan Chun-Hui, Chang An-Tai, Ugly Wei-Xin. Research
381 progress of red jujube drying technology and equipment[J]. Agricultural Mechanization Research,2022,44(01):8-18.
382 DOI:10.13427/j.cnki.njyi.2022.01.002

383 [13] Xu Xingang,Zhao Tianyuan,Ma Jianing,Song Qi,Wei Qiao,Sun Weihong. Application of Two-Stage Variable Temperature
384 Drying in Hot Air-Drying of Paddy Rice[J]. Foods,2022,11(6). <https://doi.org/10.3390/foods11060888>

385 [14] GOU Xi, WANG Min, JI Xiaolong, SHEN Jing, WANG Youke, Duan Xuchang. Study on the edibility and nutritional
386 quality of Lingwu long jujube at different maturity levels[J]. Modern Food Science and Technology,2014,30(11):98-104. DOI:
387 10.13982/j.mfst.1673-9078.2014.11.019

388 [15] ZHANG KK, WANG HEB, WANG XIAODI, SHI Xiangbin, WANG Baoliang, ZHENG Xiaozui, LIU Fengzhi. Changes
389 in fruit quality of 'Italian' grapes during storage in delayed cultivation hanging trees[J]. Journal of Horticulture,2016,43(05):853-866.
390 DOI: 10.16420/j.issn.0513-353x.2015-0702

391 [16] Deng L, Pan Z, Zhang Q, et al. Effects of ripening stage on physicochemical properties, drying kinetics, pectin
392 polysaccharides contents and nanostructure of apricots[J]. Carbohydrate Polymers, 2019, 222: 114980. [https://doi.org](https://doi.org/10.1016/j.carbpol.2019.114980)
393 /10.1016/j.carbpol.2019.114980

394 [17] Liu Qinyuan,Weng Peifang,Wu Zufang. Quality and aroma characteristics of honey peach wines as influenced by different
395 maturity[J]. International Journal of Food Properties,2020,23(1). <https://doi.org/10.1080/10942912.2020.1736094>

396 [18] Wang H, Wang J, Mujumdar A S, et al. Effects of postharvest ripening on physicochemical properties, microstructure, cell
397 wall polysaccharides contents (pectin, hemicellulose, cellulose) and nanostructure of kiwifruit (*Actinidia deliciosa*)[J]. Food
398 Hydrocolloids, 2021, 118: 106808. DOI: 10.1016/j.foodhyd.2021.106808

399 [19] TANG Ni, ZHU Hongtao, LI Yazhi, XIANG Hanzhang, LI Na, WANG Dong, ZHANG Yingjun. Study on the change of
400 nutrient content during the development of avocado fruit[J]. Guangxi Plant:1-14[2022-07-24].
401 DOI:10.11931/guihaia.gxzw202201025.

402 [20] DIOP A, MÉOT J M, LÉCHAUDEL M, et al. Impact of Special Drying Schemes on Color Stability of Mangoes with
403 Different Maturity Degrees[J/OL]. Foods, 2022, 11(5): 656. DOI:10.3390/foods11050656

404 [21] WU Mingqing, LI Chuanfeng, LUO Huaping, YI Xiaokang, SHAKEEL Ahmed Soomro, CHEN Kunjie. Physical
405 characteristics of different grades of Xinjiang steamed jujube and their influence on grading results[J]. Journal of Agricultural
406 Machinery,2018,49(08):324-330. DOI: 10.6041 /j.issn.1000-1298.2018.08.038

407 [22] GB/T 10782-2021, General rules for the quality of candied fruit [S]. General Administration of Quality Supervision,
408 Inspection and Quarantine of the People's Republic of China. Available online: <https://openstd.samr.gov.cn/bzgk/gb/newGbInfo>
409 (accessed on 1 April 2022)

410 [23] GB 5009.7-2016, National standard for food safety Determination of reducing sugars in foods [S]. General Administration
 411 of Quality Supervision, Inspection and Quarantine of the People's Republic of China. Available online:
 412 <http://down.foodmate.net/standard/sort/3/49327.html>

413 [24] GB 12456-2021, National Standard for Food Safety Determination of total acids in foods [S]. General Administration of
 414 Quality Supervision, Inspection and Quarantine of the People's Republic of China. Available online:
 415 <http://down.foodmate.net/standard/sort/3/97830.html>

416 [25] Sun Miao Miao. Research on the quality evaluation system of dried dates[D]. Northwest University of Agriculture and
 417 Forestry Science and Technology, 2016.

418 [26] GB 5009.86-2016, National standard for food safety Determination of ascorbic acid in foods [S]. General Administration
 419 of Quality Supervision, Inspection and Quarantine of the People's Republic of China. Available online:
 420 <https://www.antpedia.com/standard/1489571510-1.html>

421 [27] Xiao H W, Law C L, Sun D W, et al. Color change kinetics of American ginseng (*Panax quinquefolium*) slices during air
 422 impingement drying[J]. *Drying Technology*, 2014, 32(4): 418-427. DOI:10.1080/07373937.2013.834928.

423 [28] WANG Long, HU Can, LI Chuanfeng, HE Xiaowei, YI Xiaokang. Experimental study of hot air drying process and
 424 shrinkage characteristics of red jujube[J]. *Chinese Journal of Agricultural Chemistry*, 2020, 41(01): 79-82. DOI:
 425 10.13733/j.jcam.issn.2095-5553.2020.01.14.

426 [29] LU Jie, SUN Jianfeng, WANG Jie, YUAN Zhourate, LIU Zhanqi. Effect of hot air drying on the quality of Fuping red
 427 dates and its mathematical model construction[J]. *Food Industry Science and Technology*, 2013, 34(01): 97-102. DOI:
 428 10.13386/j.issn1002-0306.2013.01.051.

429 [30] QIAN Jingya, ZHANG Xi, WANG Jun, FANG Xiaoming, ZHANG Weipeng, GAO Zhenjiang, LIU Yanhong, XIAO
 430 Hongwei. Effects of three drying techniques on the drying characteristics and quality of red jujube crisps[J]. *Journal of Agricultural*
 431 *Engineering*, 2016, 32(17): 259-265. DOI: 10.11975/j.issn.1002-6819.2016.17.034.

432 [31] Wang Wenjun, Tang Juming, Zhao Yanyun. Investigation of hot-air assisted continuous radio frequency drying for
 433 improving drying efficiency and reducing shell cracks of inshell hazelnuts: The relationship between cracking level and nut
 434 quality[J]. *Food and Bioprocess Technology*, 2021, 125. DOI: 10.1016/j.fbp.2020.10.013.

435 [32] Wang Nan, Yang Shuaiyao, Zhang Yifu, Jiang Lan, Zheng Xuechao, Jiang Peiyun, Chen Ye. Drying kinetics and quality
 436 characteristics of daylily dried by mid -infrared[J]. *International Journal of Food Engineering*, 2021, 17(12). DOI: 10.1515/ijfe-2021-
 437 0137.

- 438 [33] Guo HuiLing,Chen Ying,Xu Wei,Xu MengTian,Sun Yong,Wang XueCheng,Wang XiaoYa,Luo Jing,Zhang Hua,Xiong
439 YaoKun. Assessment of Drying Kinetics, Textural and Aroma Attributes of *Mentha haplocalyx* Leaves during the Hot Air Thin-
440 Layer Drying Process[J]. *Foods*,2022,11(6). DOI: 10.3390/foods11060784.
- 441 [34] WANG Jiqiang, DENG Lizhen, PUI Yupeng, WANG Dongdong, GAO Zhenjiang, XIAO Hongwei. Effect of maturity on
442 the kinetics of vacuum pulsation drying and product quality of jujube[J]. *Journal of Agricultural Engineering*,2021,37(23):273-279.
443 DOI: 10.11975/j.issn.1002-6819.2021.23.032.
- 444 [35] Souhila Ghidouche,Brigitte Rey,Martin Michel,Nico Galaffu. A Rapid tool for the stability assessment of natural food
445 colours[J]. *Food Chemistry*,2013,139(1-4). DOI: 10.1016/j.foodchem.2012.12.064.
- 446 [36] Zhao JL, Gao H, Li CONGXI, et al. Postharvest physiological studies on pear and date fruits[J]. *Northwest Journal of*
447 *Agriculture*, 2002, 11(1): 61-63.
- 448 [37] Zheng Zhaohui,Ren Liuyang,Wei Shuo,Xie Weijun,Fan Ben,Fu Hanyu,Yang Deyong. Effect of glass transition on drying
449 crack formation of maize kernels[J]. . *Biosystems Engineering*,2022,222. DOI: 10.1016/j.biosystemseng.2022.08.002.
- 450 [38] Jun-Wen Bai,Zhen-Jiang Gao,Hong-Wei Xiao,Xiao-Tuo Wang,Qian Zhang. Polyphenol oxidase inactivation and vitamin C
451 degradation kinetics of F uji apple quarters by high humidity air impingement blanching[J]. *International Journal of Food Science &*
452 *Technology*,2013,48(6). DOI: 10.1111/j.1365-2621.2012.03193.x
- 453 [39] LI Qianying, FU Tong, SUN Yu, LIAN Hongxia, GAO Tengyun. Effect of Merad reaction on silage quality of alfalfa[J].
454 *Journal of Livestock Ecology*,2012,33(03):73-76. DOI: 10.1016/J.JAFR.2022.100409
- 455 [40] Kim SiYeon, Lee ByungMin, Hong SeokYoung, Yeo HyunHo, Jeong SeHo & Lee DongUn. (2023). A Pulsed Electric Field
456 Accelerates the Mass Transfer during the Convective Drying of Carrots: Drying and Rehydration Kinetics, Texture, and Carotenoid
457 Content. *Foods*(3). DOI:10.3390/FOODS12030589

458

