Real-time monitoring system for quality monitoring of jujube slice during drying process

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Abstract: The real-time monitoring and prediction system for quality attributes of jujube slices during the drying process was designed to solve the problem of destructive and inconvenient of the traditional quality detection method and realize quality online monitoring. Firstly, machine vision and automatic weighing were employed to monitor the color and moisture content changes of jujube slices in real-time. Secondly, correlation models between color parameter (a* value) and nutritional quality attributes (vitamin C, reducing sugar) were established to predict vitamin C and reducing sugar content of jujube slices during the drying process. Finally, the upper computer monitoring software was integrated and designed based on LABVIEW virtual instrument, and the real-time monitoring system was tested and validated. Results showed that: the changing trends of color (L*, a*, and b* values) monitored by the system were basically the same as the results detected by the color difference meter, and the average errors of L*, a*, and b* values were 0.93, 0.52, and 0.73, respectively. The average relative error of moisture content between the system monitoring and manual static detection was 0.18%. The average error of vitamin C and reducing sugar content between the system prediction and manual detection were 50 mg/100 g on dry basis and 0.71g/100 g on dry basis, respectively. The current work can provide a useful reference for real-time monitoring of quality attributes of fruits and vegetables during the drying process.

Keywords: jujube slice, quality attributes, real-time, monitoring system, drying process
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1 Introduction

Jujube slices are rich in health promoting nutrients, such as vitamin C, cyclic adenosine monophosphate, organic acid, amino acids, calcium, iron, and other nutrients[1]. The dried jujube slices are favored by consumers for their crisp texture and sweet taste. They can also be consumed in tea, porridge, and soup or used as food ingredients. In addition, the jujube slices are more convenient in packaging, transporting, preserving, fabricating, and further processing[2]. Recently, the market demand for jujube slices is increasing.

Drying is one of the key operations for jujube slices production as drying can directly influence its quality, drying time, and energy consumption. However, the drying process is more like a black box that cannot be fully understood the drying behavior and evolution of quality during the drying process. Due to the lack of real-time quality monitoring and optimization systems for the drying process, the drying parameters are usually set and optimized according to experience and experiments[3]. Moreover, once the drying parameters are set, they will remain unchanged throughout the drying process, which is contrary to the dynamic drying process. So, the development of an online quality monitoring system for the drying process is necessary and tempting for the drying industry[4].

On the drying parameters monitoring system of jujube slices and other fruits or vegetables, Song et al.[5] proposed a fuzzy control method for the microwave dryer, which could control temperature and humidity precisely during Chinese jujube drying, and compared the quality of jujube dried by three different microwave drying methods. Bórquez et al.[6] applied automatic switching temperature controller in microwave vacuum drying system. It was found that the energy efficiency of the dryer improved from 4% to 54%, and the dried strawberry has good color and quality. Sun et al.[7] used Nuclear Magnetic Resonance (NMR) method aided by artificial neural network to monitor the flavor changes of garlic by drying. Tomas-Egea et al.[8] applied

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the infrared thermography to monitor the drying process of hot air and microwave combined drying of potato. Zhang et al.[9] studied the influence of sweeping frequency ultrasonic pretreatment on pulsed vacuum drying characteristics and microstructure of okra based on real-time monitoring. Zhao et al.[10] developed a novel online moisture monitoring method for vacuum drying lithium-ion battery powder. Zhang et al.[11] proposed a real-time temperature and humidity decoupling control method. A modified inhalation hygrometer was employed as a relative humidity measurement unit and an adaptive neuro-fuzzy inference system was used to control the temperature and relative humidity of the drying chamber. It was observed that the relative humidity fluctuation was reduced from ±2.5% to ±0.6%. Ju et al.[3] enhanced the drying rate, energy efficiency, and quality of fruits and vegetables under hot air drying by controlling the relative humidity during the drying process based on the Weibull model and the Bi-Di model. Mohammadzaheri et al.[12] proposed a mixed temperature control system for infrared dryers based on temperature monitoring to address the temperature control of an infrared dryer.

The quality change affects the final quality of jujube slices, and it is difficult to understand the quality change of jujube slices during the drying process. Therefore, the real-time changes of each quality attribute can be comprehensively monitored on the basis of dryer control and the appropriate macro-control methods and strategies can be applied in order to enhance the drying rate and quality of jujube slices.

The quality attributes of jujube slices can be divided into sensory quality attributes and nutritional quality attributes. The common sensory quality attributes mainly contain color, water content, shape, and size, while the common nutritional quality attributes mainly cover sugar, acid, vitamin C content, and so on[13]. Most of the existing jujube detection was to detect the color, moisture content, and size of jujube after drying[14,15]. The real-time monitoring system of jujube quality in the drying process is less studied. In the monitoring of other quality attributes of fruits and vegetables in the drying process, Zhang et al.[16] collected wirelessly the relative dielectric constant of fruits and vegetables during freeze-drying. Moscetti et al.[17] carried out real-time non-destructive monitoring of moisture content and color change of apple block during hot air drying using the near-infrared spectroscopy (NIR) for the intelligent drying system. Sun et al.[18] used the intelligent technology of low field nuclear magnetic resonance (LF-NMR) and back propagation artificial neural network (BP-ANN) to monitor the moisture content of carrots during microwave vacuum drying. Nguyen-Do-Trong et al.[19] used VNIR hyperspectral reflectivity imaging to predict the moisture content, texture, and color of banana slices in the average reflectivity spectrum of each slice extracted from hyperspectral images. The existing research showed that the sensory indexes such as moisture content, color, and size were easy to be detected, and it was easy to realize nondestructive real-time monitoring in the drying process. There was less literature on the real-time monitoring of nutritional attributes because the routine detection of nutritional indicators requires complex physical and chemical analysis methods[20], which is time-consuming and labor-intensive. This brought great difficulties to the real-time monitoring of the nutritional quality attributes in the drying process.

A real-time monitoring system for the quality attribute of jujube slices' drying process was developed and designed based on LABVIEW virtual instrument. The real-time prediction of nutritional quality attributes (Vitamin C, reducing sugar) of jujube slices was further realized on the basis of realizing the control of drying parameters of dryer and real-time monitoring of sensory quality attributes (color, moisture content) of jujube slices. The results can be used as a reference for the real-time monitoring of the changes in quality attributes in the drying process of jujube slices and other fruits and vegetables.

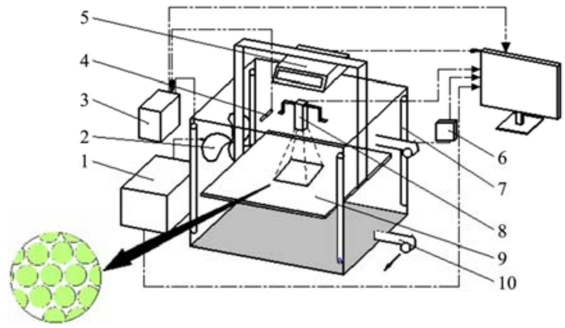
2 Materials and methods

2.1 Jujube slice samples

Fresh winter jujube was purchased in Shihezi Comprehensive Wholesale Market. The selection maturity is the same, the shape is regular (longitudinal diameter (30±2) mm, transverse diameter (26±2) mm), and the surface integrity of Hotan winter jujube without mechanical damage was put into the freezer with temperature and relative humidity of (4±1)°C and (96±2)%, respectively for 24 h, and the slices (thickness (7±1) mm) were cleaned and wiped as experimental material (The average moisture content of wet base determined by oven method after slicing was (80.0±1.0)%.).

2.2 Experimental equipment

The real-time monitoring system of quality attributes of jujube slice drying process is composed of hardware system and software system, as shown in Figure 1. The hardware system is based on the hot air and infrared combined drying equipment in the Key Laboratory of Agricultural Equipment in Northwest China of Shihezi University, China[21]. It is composed of temperature monitoring module, wind speed monitoring module, humidity monitoring module, color monitoring module, and moisture content monitoring module, including Dema frequency converter (DMA000D7543A), Omron temperature controller (E5CC), C51 single chip microcomputer, solenoid valve, Charge Coupled Device (CCD) industrial camera and lens, electronic balance, upper computer, etc. The software system was established by the virtual instrument LABVIEW2016.



1. Dema frequency converter 2. Fan 3. Omron temperature controller 4. PT100 temperature sensor 5. Electronic balance 6. Single chip microcomputer 7. Infrared heating tube 8.CCD industrial camera and lens 9. Plates 10. Solenoid valve

Figure 1 Structure of real-time monitoring system for quality indexes of jujube slice during drying process

Other experimental equipment includes the electronic balance (BSM220.4) produced by Shanghai Zhuojing Electronic Technology Co., Ltd., China, and the color meter (SMY-2000SF, Beijing Shengyang Science and Technology Co., Ltd., China).

2.3 Real-time monitoring of drying parameters

The hardware structure of temperature monitoring module, wind speed monitoring module, and humidity monitoring module is shown in Figure 2.

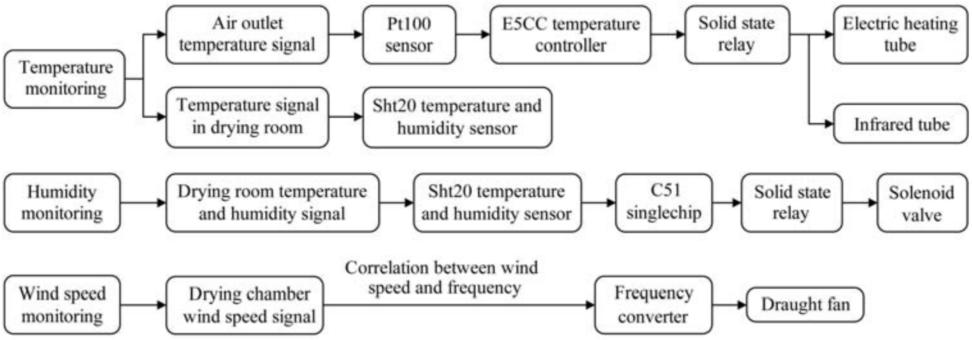
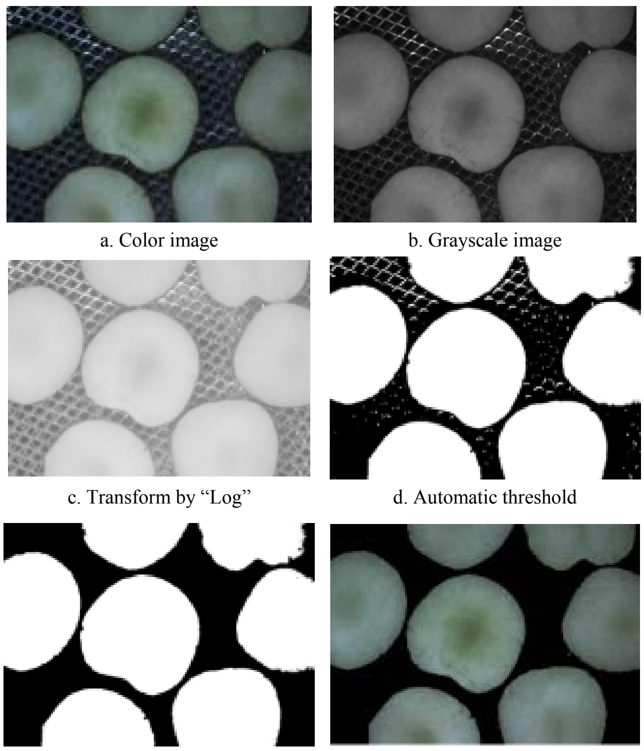


Figure 2 Hardware structure of temperature, relative humidity, and wind speed monitoring

2.4 Real-time color monitoring

Machine vision has been widely used in the classification of agricultural products, color selection, disease identification, scar detection, and so on[22-24], to replace the very time-consuming and laborious process of manual selection and screening, realize the automation of production process. Human eye cannot recognize the color changing of the slow changing jujube during the drying process, but the machine vision technology can instead of the human eye identify, judge, and obtain the target information. The real-time monitoring of jujube color was carried out according to the process of image acquisition, image storage, image processing, and color extraction. In the drying process, the image was collected to the local path by the camera in real-time, and then the five pictures in the path are read into a group of graying, image enhancement, threshold segmentation, morphological operation, color extraction after image restoration to obtain RGB color images of the characteristic area of jujube. The RGB values of all the divided images were processed and converted from CIERGB to CIELAB. Finally, the current average L^*, a^*, b^* values were obtained. The acquisition and analysis period can be set. The image processing process is shown in Figure 3.

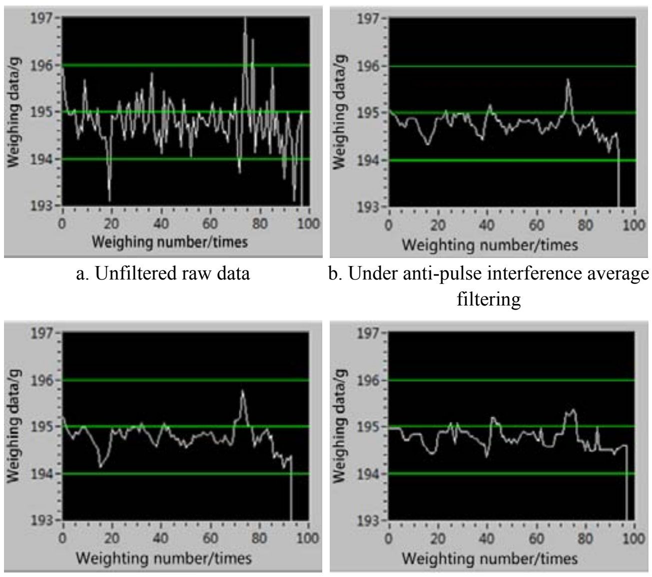


a. Color image
b. Grayscale image
c. Transform by "Log"
d. Automatic threshold
e. Morphological processing effect diagram
f. Recovered image

Figure 3 Image processing process of jujube slices in the drying process

2.5 Real-time monitoring of moisture content

The moisture content was manually measured by taking out the material samples before and after drying and then calculated by the moisture content equation. This method is time-consuming and laborious, and it is difficult to control the drying result. The automatic weighing method was applied in the system to monitor the moisture content of materials in real-time during the drying process. Mechanical vibration was produced in the process of system quality acquisition, which affects the accuracy of data acquisition, so the data filtering algorithm was carried out after 100 fluctuating data collected continuously by electronic balance. It was found that the anti-pulse interference average filtering method and the moving average filtering method have large amplitude and poor stability by comparing the three filtering algorithms. Finally, the median filtering method was used to filter the data, as shown in Figure 4.



a. Unfiltered raw data
b. Under anti-pulse interference average filtering
c. Under moving average filtering
d. Under median filtering

Figure 4 Processing results of three filtering methods

The median filtering method can be expressed as Equations (1) and (2)[25].

$$\left. X_i - \frac{\sum_{i=1}^{n} X_i}{n} \right| \leq \frac{\sum_{i=1}^{n} X_i}{n} \times \xi \tag{1}$$

$$\overline{Y} = \sum_{i=1}^{n} Y_i \tag{2}$$

where, X_i represents the original array of filtering; ξ represents the amplitude coefficient, and 1.0% is selected in this study; Y_i represents the sub-array obtained after deleting the data with large error.

After filtering, the current moisture content of jujube slices was obtained by Equation (3)[26]:

$$w_1 = \frac{M_t - M_0 \times (1 - w_0)}{M_t} \tag{3}$$

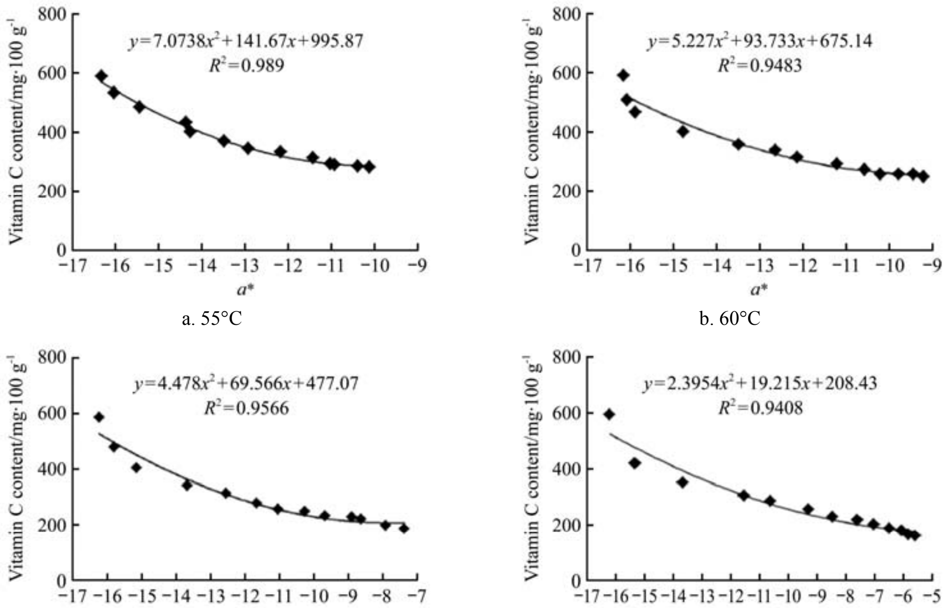
where, M_t indicates the quality of jujube slices at t time of drying; M_0 represents the total initial value mass of dried winter jujube slices, and both M_t and M_0 are measured by balance; w_0 indicates that the wet content of fresh jujube slices can be determined by oven method (the wet content of winter jujube slices determined by oven method is 85%); w_1 indicates the wet base moisture content of jujube slices during drying.

2.6 Real-time prediction of nutrition quality attributes

Nutrition indicators change kinetics is essential for better optimization and control of the drying process[4,27]. However, the detection of nutrient degradation kinetics during thermal processing is very difficult[28]. With the development of computer vision technology, it is relatively easier to monitor the color kinetics change during the food thermal process. In addition, it has been found that color change kinetics during the drying process has a strong relationship with its nutrients, particularly thermal sensitive nutrients such as vitamin C contents, and natural pigment[29]. So it is possible to realize online nutrient quality index prediction through the established relationship between color changes and vitamin C during the drying process.

A theoretical analysis was made on the changes of sensory quality attribute and nutritional quality attribute of jujube slices during drying, and explored the relationship between the quality indexes of jujube slices under different drying temperatures. Then, the correlation between vitamin C was modeled, reducing sugar content and color change kinetics during the drying process of jujube slices. As shown in Figure 5, the correlation coefficients between the change of a^* and the change of vitamin C content were 0.989, 0.9483, 0.9566, and 0.9408, with drying temperatures of 55°C, 60°C, 65°C, and 70°C, respectively. The correlation coefficients between the change of a^* and the content of dry basis reducing sugar were 0.9993, 0.9999, 0.997, and 0.9986, respectively, as shown in Figure 6. The correlation between a^* and dry basis total acid content was not obvious, and the correlation between water content and vitamin C content, reducing sugar content and total acid content was not obvious.

The relevant relation model was applied to the real-time monitoring system software of the quality index of the dry process of the jujube slice in the development of the LABVIEW virtual instrument, the nutrition quality prediction program is shown in Figure 7, according to the current temperature, different prediction models were selected. The range of temperature was set as 57.5°C -52.5°C for the 55°C prediction model, 57.5°C-62.5°C for the 60°C prediction model, 62.5°C-67.5°C for the 65°C prediction model, and 67.5°C-72.5°C for the 70°C prediction model due to the fluctuation of the temperature. In order that the nutrient quality vitamin C content and the reducing sugar content of the current jujube slice can be predicted by real-time monitoring of the color data in the drying process.

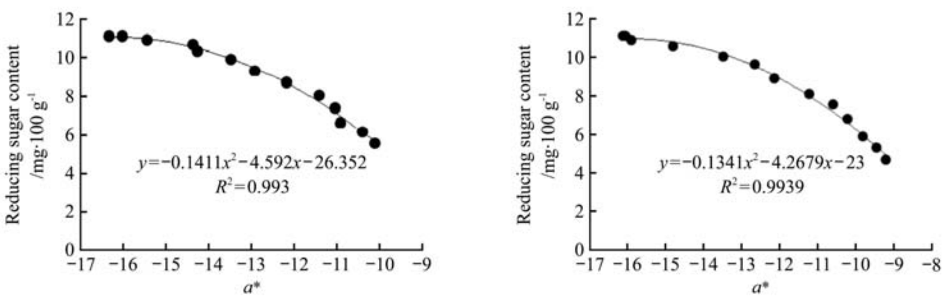


a. 55°C b. 60°C

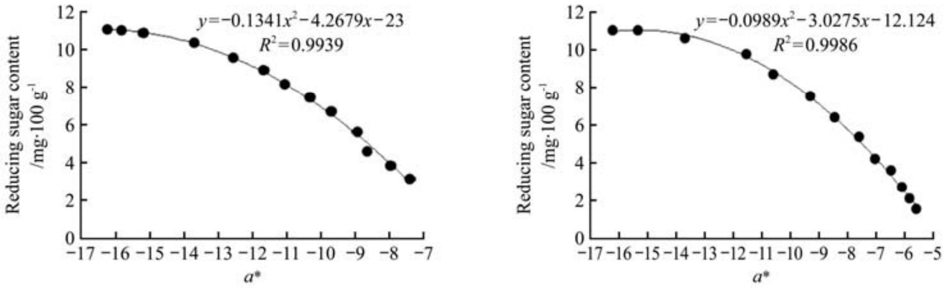
c. 65°C d. 70°C

Note: a^* is a chroma parameter of colors. The same as below.

Figure 5 Correlation between a^* and dry basis vitamin C content in jujube slices at different drying temperature

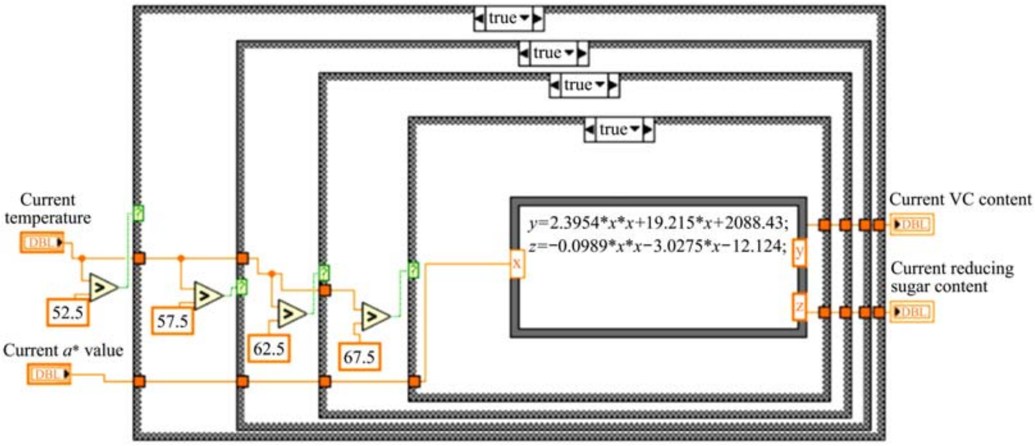


a. 55°C b. 60°C



c. 65°C d. 70°C

Figure 6 Correlation between *a** and dry basis reducing sugar content of jujube slices at different drying temperatures



Note: VC: Vitamin C.

Figure 7 Nutrition quality prediction program

2.7 Software system design

The upper computer software designed by LABVIEW virtual instrument is shown in Figure 8. The drying can be started after setting the drying temperature, wind speed, and maximum humidity, and the parameters such as moisture content and color collection cycle can also be set, as shown in Figure 8a. After drying, the color and moisture content of jujube slices were monitored in real-time, as shown in Figure 8b, and the vitamin C content and reducing sugar content of jujube slices were predicted in real-time during drying.

a. Preferences b. Quality monitoring

Figure 8 Real-time monitoring system for drying process of jujube slices

2.8 Contrast test

The comparative experiment was performed under the same drying conditions with a wind speed of 4 m/s and a drying temperature of 65°C. During the drying process, the dried samples at drying times of 0.5 h, 1.0 h,1.5 h, and 6.0 h, as well as the final drying time, the sensory quality attributes (color, moisture content), and nutritional quality attributes (reducing sugar, vitamin C content) of jujube slices were detected manually. *L**, *a**, and *b** were determined using a color meter (SMY-2000SF, Beijing Shengyang Science and Technology Co., Ltd., China). The weight of the samples was detected using an electronic balance (BSM220.4, Shanghai Zhuojing Electronic Technology Co., Ltd., China) with an accuracy of ±0.001 g. The vitamin C and the reducing sugar content were determined according to the direct titration method[30,31], respectively. All the vitamin C and reducing sugar contents were expressed in mg and (g/100 g) on dry basis, respectively.

3 Results and discussion

3.1 Real-time color detection results

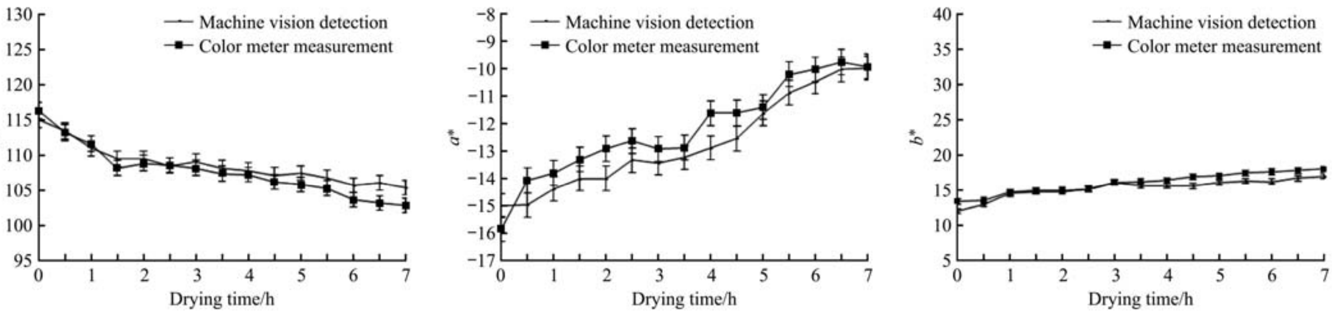
In this study, CIE-LAB color parameters *L**, *a**, and *b** were used to represent the color kinetics change of the jujube slices during the drying process.

As shown in Figure 9a, the brightness value *L** of the two methods decreased. During the drying process, *L** value of materials is often reduced[32]. The range of *L** of jujube slices detected by the machine vision in real-time was 105-115, while the range of *L** detected using a color meter was 102-116. The average error between the machine vision and the color meter detected data was 0.93. Due to the different light sources of the two detection methods, the brightness value error is obvious, which is the same as the result of Aghilinategh et al.[33]. In the early stage of drying, the change of $L*$ detected by the color meter is relatively fast, while the change of $L*$ detected in real-time is slow, and the real-time detection and static detection tended to be consistent in the middle and late drying stage. The color change of dry materials is a complex phenomenon, and its dynamics depend on the moisture content of products[34]. At the early stage of drying, the moisture content decreased rapidly and $L*$ value also decreased rapidly, which was similar to the results of color experiment of Cao et al.[35].

As shown in Figure 9b, the changing trend of the two detection methods $a*$ increased. The real-time detection of $a*$ was in the range of −10 to −15, while the change range of $a*$ detected by the color meter was in the range of −9 to −16, and the average error was 0.52. In the early stage of drying, the change of $a*$ detected by color meter was relatively fast, while that of real-time detection $a*$ was slow. In the early stage of drying, higher moisture content will lead to the formation of brown pigment[36]. In the late drying period, long-term drying and higher temperature promoted the Browning reaction of materials, and the value of $a*$ continued to increase. Similar results were obtained in the drying experiment of apple slices conducted by Nadian et al.[37] And the real-time detection and static detection tended to be consistent in the middle and late drying stages.

As shown in Figure 9c, the $b*$ of the two detection methods shows a slowly increasing trend, and the range of $b*$ detected by the color meter was in the range of 12-17, while the change range of $b*$ detected by color meter was about 13-18. Aghilinategh et al.[33] drying apple slices experiment also found an increase in $b*$ value during drying. It's because Browning also increases the $b*$ value during drying[38]. The average error between the machine vision and the color meter detected data was 0.73. The changing trend of $b*$ value detected by color real-time detection is basically consistent with that detected by the color meter.

The results show that the different light sources in the drying process will have a great influence on the color detection, and the changing trends of $L*$, $a*$, and $b*$ values of the two detection methods are similar.



a. L^* value b. a^* value c. b^* value

Figure 9 Comparison of color kinetics change of jujube slices between machine vision detection and color meter measurement

3.2 Real-time monitoring results of moisture content

The error analysis of the automatic weighing system is shown in Table 1. It was found that the maximum, minimum, and average errors were 1.80 g, 0.59 g, and 1.12 g, respectively. In the case of moisture content, the maximum, minimum, and the average relative error of jujube slices during the drying process were 0.71%, 0.04%, and 0.18%, respectively. The moisture content monitoring accuracy of Cheng et al.[39] in the grain drying experiment was 0.5%. Similar results were obtained in the dried carrot moisture content monitoring system in Sun et al.'s[18]

Table 1 Error analysis table of automatic weighing result

Drying time/h	Measured quality/g		Error of material quality		Error of moisture content	
	Static weighing	Automatic weighing	Absolute error	Relative error	Absolute error	Relative error
0.5	480.59	481.36	0.77	0.16%	0.03%	0.04%
1.0	402.67	401.53	1.14	0.28%	0.06%	0.08%
1.5	330.65	332.45	1.80	0.54%	0.15%	0.20%
2.0	285.94	286.59	0.65	0.23%	0.07%	0.10%
2.5	245.23	243.86	1.37	0.56%	0.21%	0.33%
3.0	226.48	225.54	0.94	0.42%	0.17%	0.27%
3.5	214.76	216.23	1.47	0.68%	0.28%	0.49%
4.0	206.53	205.12	1.41	0.68%	0.30%	0.53%
4.5	199.81	198.54	1.27	0.64%	0.29%	0.52%
5.0	196.47	195.86	0.61	0.31%	0.14%	0.26%
5.5	196.03	194.57	1.46	0.74%	0.34%	0.64%
6.0	195.89	196.48	0.59	0.30%	0.14%	0.26%
6.5	195.46	194.23	1.23	0.63%	0.29%	0.54%
7.0	195.22	196.86	1.64	0.84%	0.38%	0.71%

3.3 Real-time prediction results of nutritional quality

Maillard reaction and caramel reaction may probably occur in the drying process of jujube slices[40]. The accumulation of substances produced by these two reactions will lead to the decrease of green value and red value of jujube slices and by thus lead to darker[41]. Gong et al.[42], Zhang et al.[43] and other scholars have explored the correlation between color change of the material and the content of the nutrients content. It was found that there was a linear or non-linear relationship between the color change of the material and the change of the nutrient contents.

The real-time quality index real-time monitoring system of the jujube slice brings the color $a*$ value detected in real-time. Then take the color $a*$ value to the correlation model between color $a*$ value and dry basis vitamin C content and dry basis reducing sugar content in jujube slices. The prediction of the content of the vitamin C and the content of the reducing sugar in the drying process is carried out, in a drying environment that determines the drying parameters (the drying temperature is 65°C and the drying wind speed is 4 m/s.). The vitamin C content of jujube slices in the drying process was detected manually every 0.5 h. From Figure 10, it was found that both the actual value of manual detected and the real-time prediction value showed a downward trend the actual value of manual detection was mostly lower than the real-time prediction value. The maximum and the average error between the online predicted value and the actual manual measured value was 100 mg/100g and 50 mg/100g. In Chen et al.[44] vitamin C detection experiment, it was found that the amount of vitamin C in dried jujube slices was 34%-70% compared with fresh samples. The results are similar to those of the two methods in this paper. However, manual detection of vitamin C content in jujube slices requires a certain preparation time for pretreatment, and it is normal that the result of manual detection is lower than the predicted result.

Similarly, the artificial detection of reducing sugar content of jujube slices during the drying process was carried out every 0.5 h. In the case of reducing sugar content of jujube slices during the drying process, it was observed that both the actual manual detection and the real-time prediction value showed a downward trend, as shown in Figure 11. In addition, the actual manual detected value of reducing sugar content in jujube slices at the later drying stage was lower than the real-time prediction value. The maximum and the average errors were 1.90 g/100 g and 0.71 g/100 g, respectively. The part of the error between the online predicted value and the actual determined is probably due to the interrupting of the drying process when carrying out manual chemical detection as it changes the drying environment of the jujube slices by taking the samples out of the drying chamber during the drying process.

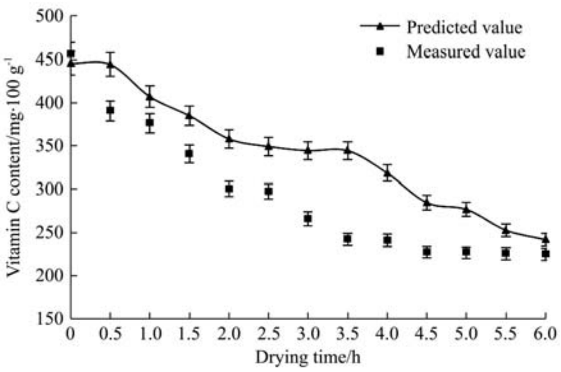


Figure 10 Comparison between predicted and measured dry basis Vitamin C content

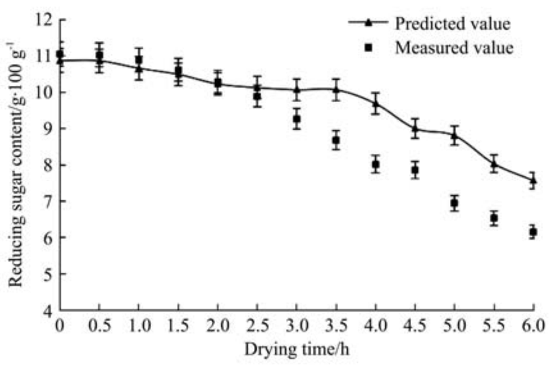


Figure 11 Comparison of the predicted value of dry basis reducing sugar content with the measured value

3.4 Discussion

The comparative test showed that the system can basically complete the real-time monitoring of the drying process of jujube slices. Several commonly used quality indexes of jujube slices in drying process were monitored and predicted using this system. The changes in morphology, shrinkage, aromatic smell, calcium, iron, and other quality indexes in the drying process of jujube slices were also monitored and predicted in real-time by adding other quality indexes in the follow-up study and the energy consumption is also considerable[10]. However, it should be noted that the correlation model between color a^* and nutrient content of jujube slices directly affects the prediction of nutritional indexes of jujube slices. The prediction model should be further optimized to improve the accuracy of the system in predicting nutritional quality indexes. Or some other methods also can be used for real-time monitoring such as hyperspectral imaging technology and microwave spectroscopy[45,46].

4 Conclusions

A real-time monitoring system of quality indexes of jujube slices drying process was established and studied. The system can control the drying parameter temperature, humidity, and wind speed during the drying process, and can monitor and predict the quality indexes of jujube slices in real-time. The current work indicates that machine vision could be used to collect process and extract the color change kinetics of jujube slices during its drying process so as to realize the color real-time monitoring. The vitamin C content and reducing sugar content of jujube slices on dry basis were predicted by color a^* value by establishing a correlation model, and this method will be applied to the non-destructive testing of the internal nutritional quality of future dry materials.

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