Construction method of quantitative evaluation model for the maturity of Korla fragrant pear

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Abstract: The maturity variation laws of Korla fragrant pears were explored for a quantitative evaluation of harvest maturity to solve the reasonable matching between harvest maturity of Korla fragrant pears and market quality demands. Korla fragrant pears from different harvesting periods were chosen as the research objects. Some quality indexes were chosen as the evaluation indexes per industry standards, including hardness, soluble solid content (SSC), single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, pericarp color parameters (L^*, a^*, and b^*), and titratable acid. Variation data of these quality indexes with accumulated temperature were collected. Scores of several quality indexes were gained through principal component analysis. A mathematical model of scores and accumulated temperatures was constructed. On this basis, a quantitative maturity model of Korla fragrant pears was constructed. Results demonstrate that SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^* are significantly and positively correlated with the accumulated temperature. Meanwhile, hardness and titratable acid showed significant negative correlations with the accumulated temperature. Relations between scores of principal components and accumulated temperature conform to the Sigmoidal model. The constructed quantitative maturity model of Korla fragrant pears can quantify the maturity of pears. Research conclusions can provide insight into the harvest periods, evaluate Korla fragrant pears' maturity, and lay a theoretical foundation for quantitative research on fruit maturity.

Keywords: Korla fragrant pear, quantitative evaluation, maturity, principal component analysis, accumulated temperature
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1 Introduction

The Korla fragrant pear is a characteristic fruit in Xinjiang and is famous in China and foreign countries for its bright colors, thin pericarp, exquisite pulp, and refreshing taste[1]. Harvest is an important link in the production process of Korla fragrant pears. Korla fragrant pears for different purposes have different quality requirements for different purposes. Further, there are specific requirements for the harvest maturity of Korla fragrant pears to achieve a specific quality. At present, practitioners' judgment on the maturity of Korla fragrant pears was mostly defined based on planting experience or visual estimation, such as eight-point ripeness and nine-point ripeness. Harvesting Korla fragrant pears based on traditional experiences influence the follow-up production and marketing process. Consequently, some Korla fragrant pears with rich nutrients, good taste, and small size may experience price discrimination. Further, some immature or overripe Korla fragrant pears cannot meet the requirement for the best production processing and fresh storage, thus influencing the nutrition and commodity value of pears. The scientific quantitative maturity evaluation method of Korla fragrant pears based on the maturity laws can overcome the disadvantages of traditional methods and provide guidance for harvesting Korla fragrant pears. Hence, establishing a scientific maturity evaluation method and combining maturity quantization for harvest and processing can effectively promote reasonable docking between the harvest maturity of Korla fragrant pears and quality demands in target markets. Consequently, harvest maturity can match practical production and processing demands after the harvest. This has important theoretical guidance and practical values to extend the industrial processing chain and increase the industrial economic benefits of Korla fragrant pears.

With respect to maturity quantization, Lan et al.[2] chose fruit hardness, soluble solids content, chlorophyll content, and vitamin C content of Korla fragrant pear as the maturity evaluation indexes. The researchers further gained maturity evaluation equations corresponding to different physical and chemical indexes.

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Chełpiński et al.[3] tested the maturity of sweet cherries during the harvest via L^*, a^*, and b^*. The researchers gained the optimal numerical ranges of these three parameters corresponding to the best harvest maturity. Some scholars have conducted quantitative maturity analyses of apricot[4], banana[5,6], peach[7], papaya[8], and berries[9] based on quality indexes. The maturity evaluation method based on the single characteristic index can reflect maturity characterized by a single index and applicable to specific conditions. Fruit maturity involves several quality indexes[10]. Several quality indexes can be chosen for a comprehensive quantitative evaluation of fruit maturity according to relevant industry and national standards. Common information that reflects maturity can be extracted from multiple quality indexes through the data processing method to achieve quantitative maturity evaluation. For example, Zhao et al.[10] studied the internal quality indexes of watermelon with maturity by principal component analysis. The researchers gained two characterization factors to evaluate the quality of a small-sized watermelon "Jingxiu" and guide the harvest time.

At present, quality indexes are mainly evaluated via harvest time. However, one cannot use the uniform and fixed harvest time to gain dynamic changing quality indexes due to the uncertainty of annual climate conditions and individual subjective judgment differences. Japan has evaluated rice maturity by accumulated temperature and achieved good effects[2], indicating that guiding the harvest time of crops based on accumulated temperature possessed promising application prospects. At present, no study has conducted a comprehensive analysis based on multiple quality index test data concerning accumulated temperatures and industry standards. No study has constructed a quantitative maturity evaluation model of Korla fragrant pears either.

Concerning the Agricultural Industrial Standards of the People's Republic of China NT/T 585–2002[11], this study selected quantitative quality indexes of maturity for Korla fragrant pears to process via principal component analysis (PCA). On this basis, common factors that characterize the maturity of Korla fragrant pears could be gained. Moreover, a quantitative maturity evaluation model of Korla fragrant pears was constructed. Further, the quantitative maturity requirements for harvest and processing were unified. This study was expected to provide reference to quantitative studies on fruit maturity.

2 Materials and methods

2.1 Test samples

Korla fragrant pears were harvested from the 13-year-old trees in the Pear Garden of Tarim University, Alaer City, Xinjiang Uygur Autonomous Region, China (Longitude: 80°30′E-81°58′E, latitude: 40°22′N-40°57′N, altitudes: 900-950 m). This is a high-quality Korla fragrant pear production area in South Xinjiang. The sample Korla fragrant pears had no mechanical injuries, pest diseases, distortions, or spots throughout the test period. They also had uniform colors. All samples were picked wearing gloves and then used to test various quality indexes immediately after the harvest.

2.2 Instruments and apparatus

The following instruments were used: a portable sugar measurement refractometer (B32T type), Vernier caliper (0.02 mm, Guiling Measurement and Cutting Tools Plant, China), fruit hardness meter (GY1 type), high-quality computer colorimeter (SC10, Shenzhen Sanenshi Scientific Technology Co., Ltd., China), electronic balance (JEC30002, Hangzhou Hengyi Instrument Technology Co., Ltd., China), digital display electric-heated thermostatic water bath (HH-S6, Jintan Medical Instrument Plant, China) and high-speed refrigerated centrifuge (Sorvall ST8, Shanghai Lingyi Biotechnology Co., Ltd., China).

2.3 Methodology

2.3.1 Test of accumulated temperature

Accumulated temperature is an essential index of crop growth and development[12]. It is the sum of the daily average air temperature in a continuous period when the daily average air temperature was equal to or greater than 10°C in a year[13,14]. The accumulated temperature was calculated as the mean of the highest and lowest air temperature in one day[15]. In this study, the accumulated temperature started from the blossom period of Korla fragrant pears to their complete maturity falling from trees. The daily average air temperature in this period was recorded and accumulated. The test was implemented in 2019 and 2020. In 2019, Korla fragrant pears began to blossom on April 13. Following industry standards NY881-2004[16], Korla fragrant pears were harvested from August 25 to October 5 in 2019. These Korla fragrant pears were harvested once every day. In 2020, Korla fragrant pears began to blossom on April 15, and they were harvested from August 23 to October 3. These Korla fragrant pears were also harvested once every day. Meteorological data were collected from the Meteorological Observatory of Alaer City, Xinjiang, China.

2.3.2 Single-fruit weight test

The single-fruit weight of Korla fragrant pears was tested via an electronic balance. A total of ten Korla fragrant pears were selected and weighted in an electronic balance one by one. Data were recorded after the numerical value of the electronic balance stabilized. Each Korla fragrant pear was measured three times and the mean was collected (unit: g).

2.3.3 Fruit longitudinal diameter and fruit equatorial diameter test

The fruit longitudinal diameter and fruit equatorial diameter were measured via a Vernier caliper. The fruit longitudinal diameter was measured as the distance from the stalk end of the Korla fragrant pear to the bottom point. The fruit equatorial diameter was measured as the diameter distance at the trunk of the Korla fragrant pears. In each test, ten Korla fragrant pears were selected, and each was measured three times. The mean results were collected (unit: mm).

2.3.4 Pericarp color (L^*, a^*, and b^*) test

A total of ten Korla fragrant pears were collected, washed with clean water, and dried. The color differences at the equator's four diagonal points were tested randomly with a high-quality computer colorimeter (SC10 type) to evaluate the pericarp colors, expressed by L^*, a^*, and b^*. The pericarp color was tested four times. L^* is brightness and a higher value indicated that the sample surface was brighter; a^* is the red-green difference, and its positive value indicated red and its negative value indicated green. A higher absolute of a^* indicates a darker red or green; b^* is the yellow-blue difference. A positive value indicated yellow, and a negative value indicated blue. A higher absolute of b^* indicates a darker yellow or blue[17].

2.3.5 Hardness test

Fruit hardness was tested with a fruit hardness meter. In each test, ten Korla fragrant pears were examined at the equator's four diagonal measuring points. The hardness meter's head was pressed perpendicular to the peeled Korla fragrant pears until reaching the scale line (10 mm). The pointer's read was used as the Korla fragrant pears' hardness value[18]. The reset button was rotated after each measurement to make the pointer return to the initial scale line. Test data were recorded, and the mean of the test (unit: kg/cm^2) results was collected.

2.3.6 Soluble solid content test

Soluble solid content (SSC) was tested with the B32T portable sugar test refractometer. Before the test, the B32T portable sugar test refractometer was calibrated to make the visual dark-bright border line overlap with the zero on the scale. Ten Korla fragrant pears were tested, during which four points around the equator were selected uniformly. A scalpel collected pulp with pericarp at these four points. They were squeezed manually to drop juice on the center of the refractometer's mirror for observation. The scale on the dark-bright borderline in the view was read as the SSC[19,20]. In each measurement, the refractometer was calibrated with distilled water. The mean test results were used as the SSC (unit: %) of Korla fragrant pears.

2.3.7 Titratable acid content test

The titratable acid was tested with the NaOH solution titration method. Ten Korla fragrant pears were chosen. Next, 1 g of pulp was collected from each pear and ground in a mortar by adding distilled water. The grinding fluid was heated for 30 min in a water bath under 80°C. Following this, it was centrifuged for 10 min at a rotation speed of 4000 r/min. The supernate was transferred into a 25 mL volumetric flask. Distilled water was added to residues continuously for centrifuging in a water bath[21]. This process was repeated twice before it dissolved into the constant volume by a volumetric flask. Later, 20 mL extracting solution was collected for three organic acid titrations, and the mean (unit: %) was collected.

3 Results and analysis

3.1 Variations of quality indexes with accumulated temperature

Hardness, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, b^*, and titratable acid were selected as maturity evaluation indexes with references to the Agricultural Industrial Standards of China NT/T 585-2002[11]. The variation laws of the selected quality indexes with accumulated temperature were explored.

Hardness is one of the most important indexes to measure for evaluating the maturity of Korla fragrant pears[22]. Figure 1a shows that with increased accumulated temperature, the hardness of Korla fragrant pears decreased from 8.15 to 4.23 kg/cm^2. Such reduction changed slowly in the beginning and then accelerated until reaching a stable fluctuation after maturity. The hardness reduction of pulp is a significant changing characteristic of fruit development and maturity, helping the fruit to reach an ideal edible state. Before fruit maturity, pectin substances are insoluble and exist as protopectin, which is a major component. At this developmental stage, pulps have a hard texture and complete cell structures. When the maturity of Korla fragrant pears increases, protopectin changes from an insoluble state to a soluble state, and cell division disappears gradually. Consequently, the turgor is lost, and cell wall fiber is dissolved gradually. Subsequently, cell structures are destroyed, and the pulp hardness declines quickly[23].

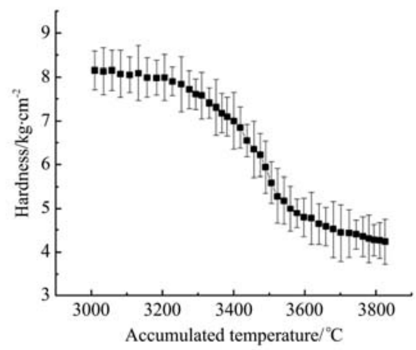
SSC is a major index of fruit quality[24]. Figure 1b shows that SSC increased from 11.51% at the beginning of harvest to 15.41%, in the maturity period with increased accumulated temperature. Such reduction changed slowly in the beginning and then accelerated until reaching a stable fluctuation after maturity. Since starch accumulation takes the dominant role in the early maturity period of Korla fragrant pears, the starch content changed slowly. When the starch accumulated a specific amount, starch accumulation begins to stop and transform into sugar, manifested by the diagram's fast variation. When sugar accumulated to certain content, starch gradually stopped transforming into sugar. Accordingly, the variation rate fluctuated stably in the diagram[25].

The single-fruit weight, fruit longitudinal diameter, and fruit equatorial diameter are appearance quality indexes for commodity fruits[26,27]. Figures 1c-1e show that when accumulated temperature increased, single-fruit weight increased from 102.08 g in the early harvest period to 140.48 g in the late maturity period. Meanwhile, the fruit longitudinal diameter increased from 47.21 mm to 70.27 mm, and the fruit equatorial diameter increased from 38.64 mm to 52.71 mm. The single-fruit weight, fruit longitudinal diameter, and fruit equatorial diameter all increased gradually. During the whole maturity period, Korla fragrant pears accumulate water, starch, and nutrient substances gradually increasing all cell tissues. Macroscopically, this was manifested by the gradual growth of the Korla fragrant pear's single-fruit weight, fruit longitudinal diameter, and fruit equatorial diameter.

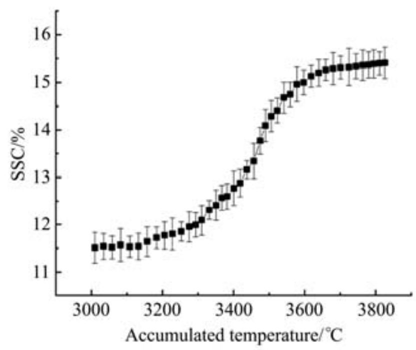
Pericarp color is often viewed as an important index for the maturity of Korla fragrant pears, and it importantly influences the commodity value of fruits[28]. Figures 1f-1h show that the values of L^*, a^*, and b^* achieved uniform growths with increased accumulated temperature. Specifically, L^* increased from 59.22 in the early harvest period to 66.31 in the late maturity period. Meanwhile, a^* increased from –9.74 to –4.72, and b^* increased from 43.21 to 47.86. Variations of pericarp color were related to the chlorophyll content in the pericarp. The chlorophyll content in the pericarp mainly determined the pericarp color of Korla fragrant pears. Chlorophyll decreased gradually in the maturity process of the Korla fragrant pears[29]. Hence, the numerical values of L^*, a^*, and b^* increased gradually. Korla fragrant pears became bright and gold-yellow.

Taste and sweetness are factors that influence the fresh eating of Korla fragrant pears. Therefore, the acid content in fruit is an important index to measure the quality characteristics of Korla fragrant pears[25]. Titratable acid is a major numerical index to measure the acid content in fruits. Figure 1i shows that titratable acid decreased from 0.129% in the early harvest period to 0.071% in the late harvest period. Therefore, the Korla fragrant pears had a relatively high acidic value in the early maturity period and they tasted relatively acidic. Increased accumulated temperature, led to decreased titratable acid content, indicating that the acid taste decreased, whereas the sweet taste increased gradually. This was because some titratable acids were catalyzed into sugar by biochemical enzymes in fruits. Then, the fruits began to expand, and the water's dilution increased[25].

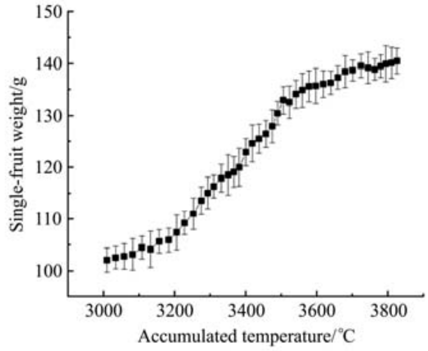
In summation, it can be seen that the quality indexes of Korla fragrant pears show different trends with the variation of accumulated temperature during the ripening process. The soluble solids content, single fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^* of Korla fragrant pears showed an increasing trend with the accumulation of accumulated temperature; hardness and titratable acid showed a decreasing trend with the accumulation of accumulated temperature. A multicollinearity problem threatened results since many quality indexes were selected. To avoid this problem, correlations between nine quality indexes and accumulated temperature were analyzed. The quality indexes strongly correlated with accumulated temperature were chosen in PCA.



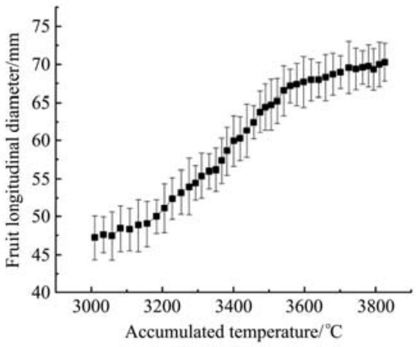
a. Variation laws of hardness with accumulated temperature



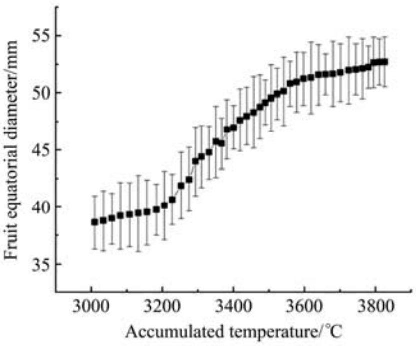
b. Variations of SSC with accumulated temperature



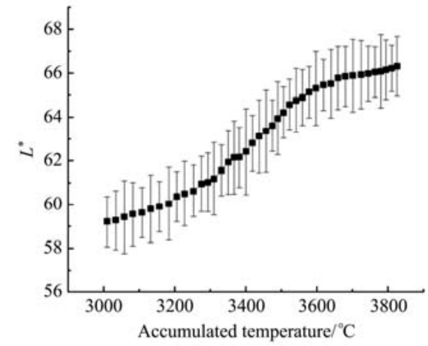
c. Variation laws of single-fruit weight with accumulated temperature



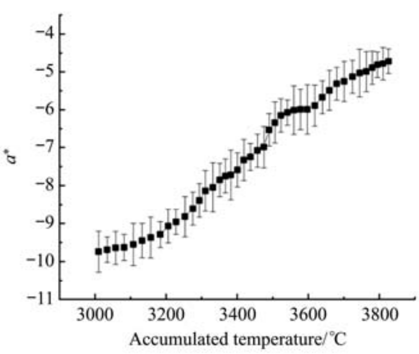
d. Variations of fruit longitudinal diameter with accumulated temperature



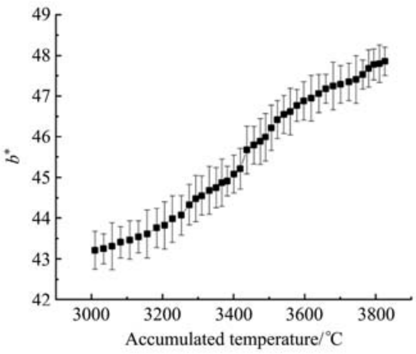
e. Variations of fruit equatorial diameter with accumulated temperature



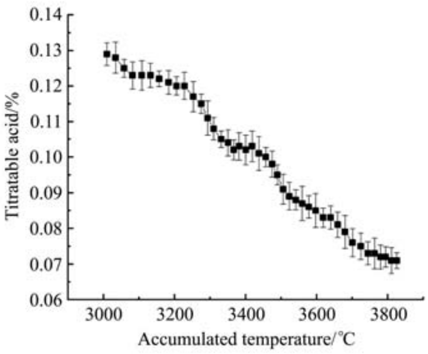
f. Variations of L^* with accumulated temperature



g. Variations of a^* with accumulated temperature



h. Variations of b^* with accumulated temperature



i. Variation laws of titratable acid with accumulated temperature

Note: SSC means the soluble solid content; L^* is brightness and a higher value indicated that the sample surface was brighter; a^* is the red-green difference, and its positive value indicated red and negative value indicated green; b^* is the yellow-blue difference. The same as below.

Figure 1 Variations of hardness, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, b^*, and titratable acid with accumulated temperature

3.2 Correlation analysis between quality indexes and accumulated temperature

SPSS 26 software was used for correlation analysis between quality indexes and accumulated temperature. Table 1 shows that hardness and titratable acid showed significantly negative correlations with accumulated temperature. In contrast, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^* showed significant positive relations with accumulated temperature. There were significant correlations among quality indexes. The hardness had a significantly positive correlation with titratable acid. However, it had significant negative correlations with SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^*. In a word, hardness, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^*, and titratable acid had significant correlations with accumulated temperature. Hence, these quality indexes were chosen as quantitative evaluation indexes to evaluate the maturity of Korla fragrant pears.

3.3 Variable correlation test

The variable correlation test was the premise to judge whether the original variable applies to PCA. First, correlations of quality indexes were judged by the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) and Bartlett sphericity tests. The KMO test evaluated the simple correlation coefficients and partial correlation coefficients among variables. The coefficients ranged between 0 and 1. If simple correlation coefficients and partial correlation coefficient approached 1, the correlations among variables were stronger. The factor analysis could be performed when the KMO numerical value was higher than 0.5. According to the determinant of the correlation coefficient matrix, the Bartlett sphericity test found that the original variables were strongly correlated when the approximate Chi-square value was high, and the corresponding significance was smaller than 0.05. These original variables could be used in

PCA[30]. In this study, the statistics of KMO were 0.908, higher than 0.5. Bartlett sphericity test's significance is smaller than 0.05, indicating that the original variables were correlated and could be used in PCA. The purpose of using PCA was to convert multiple indicators into a few comprehensive indicators, where each principal component can reflect most of the information of the original variable, and the information contained does not repeat each other[31].

Table 1 Statistics on correlations between quality indexes and accumulated temperature

Project	Accumulated temperature/°C	Hardness /kg·cm^{-2}	SSC/%	Single-fruit weight/g	Fruit longitudinal diameter/mm	Fruit equatorial diameter/mm	*L**	*a**	*b**	Titratable acid/%
Accumulated temperature	1	−0.967**	0.963**	0.981**	0.980**	0.973**	0.985**	0.992**	0.991**	−0.993**
Hardness	−0.967**	1	−0.998**	−0.975**	−0.975**	−0.959**	−0.989**	−0.985**	−0.990**	0.979**
SSC	0.963**	−0.998**	1	0.978**	0.979**	0.962**	0.991**	0.983**	0.988**	−0.976**
Single-fruit weight	0.981**	−0.975**	0.978**	1	0.998**	0.996**	0.995**	0.993**	0.991**	−0.985**
Fruit longitudinal diameter	0.980**	−0.975**	0.979**	0.998**	1	0.994**	0.995**	0.991**	0.991**	−0.982**
Fruit equatorial diameter	0.973**	−0.959**	0.962**	0.996**	0.994**	1	0.987**	0.985**	0.981**	−0.978**
*L**	0.985**	−0.989**	0.991**	0.995**	0.995**	0.987**	1	0.996**	0.997**	−0.990**
*a**	0.992**	−0.985**	0.983**	0.993**	0.991**	0.985**	0.996**	1	0.998**	−0.996**
*b**	0.991**	−0.990**	0.988**	0.991**	0.991**	0.981**	0.997**	0.998**	1	−0.993**
Titratable acid	−0.993**	0.979**	−0.976**	−0.985**	−0.982**	−0.978**	−0.990**	−0.996**	−0.993**	1

Notes: ** indicates significant correlations on the 0.01 level (double tails). "+" or "no mark" indicates a positive correlation between variables; "−" indicates a negative correlation between variables. SSC means the soluble solid content; *L** is brightness and a higher value indicated that the sample surface was brighter; *a** is the red-green difference, and its positive value indicated red and negative value indicated green; *b** is the yellow-blue difference. The same as below.

3.4 Communality

PCA extracted the communality of multiple quality index data (i.e., the communality among different factors). Communality indicates the degree of original information in various variables expressed by the common factor. Table 2 shows that the communality of all quality indexes was higher than 0.950. This proved that the extracted common factor could strongly explain the variables, indicating that this communality extraction is effective.

Table 2 Statistics on the proportion of communality in quality indexes

Quality indexes	Proportion of communality in variables
Hardness	0.978
SSC	0.980
Single-fruit weight	0.992
Fruit longitudinal diameter	0.991
Fruit equatorial diameter	0.977
L^*	0.999
a^*	0.996
b^*	0.996
Titratable acid	0.985

Notes: PCA was used as the extraction method.

3.5 Eigenvalue of correlation matrix and interpreted total variance

The proportion of communality of the various quality indexes in variables was relatively high. Subsequently, statistics on the eigenvalue distribution of principal components could be performed on the quality indexes of Korla fragrant pears (Table 3). One principal component was extracted by using an eigenvalue higher than 1 as the standard, and its numerical value was 8.893. The cumulative contribution rate of the first principal component was 98.813%. Since the first principal component covered all variables' initial information on the premise of no loss of variables, it was used to represent the original nine quality indexes in the analysis and evaluation.

3.6 Construction of a factor load matrix

The factor loads of the load matrix were analyzed (Table 4) to acquire the information size of various indexes. These factor loads mainly reflect the relative size and directional influence of the quality indexes of Korla fragrant pears on the principal component loads. The higher loads indicate the higher content of index information. The load was determined by the comprehensive information about hardness, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, b^*, and titratable acid. Therefore, the quality indexes significantly contributed to the scores of the principal components, and the contribution rate was higher than 0.950. These quality indexes were applicable to construct the evaluation index equation.

Table 3 Statistics on eigenvalue distribution of principal component analysis

Component	Total	Percentage of initial eigenvalue variance	Cumulative value/%	Total	Percentage of variance of the extracted load square sum	Cumulative value/%
1	8.893	98.813	98.813	8.893	98.813	98.813
2	0.069	0.764	99.577			
3	0.026	0.294	99.870			
4	0.005	0.052	99.923			
5	0.003	0.028	99.951			
6	0.002	0.021	99.972			
7	0.001	0.012	99.984			
8	0.001	0.010	99.994			
9	0.001	0.006	100.000			

Table 4 Factor load matrix for principal component 1

Quality indexes	Principal component 1
Hardness	−0.989
SSC	0.990
Single-fruit weight	0.996
Fruit longitudinal diameter	0.995
Fruit equatorial diameter	0.988
L^*	0.999
a^*	0.998
b^*	0.998
Titratable acid	−0.993

3.7 Construction of evaluation index expressions

A comprehensive evaluation was performed to investigate variations of quality indexes in the maturity process of Korla fragrant pears. From Table 5, a linear relation between principal components scores and Korla fragrant pear quality indexes could be established as follows:

$$F = -0.111\times f_1 + 0.111\times f_2 + 0.112\times f_3 + 0.112\times f_4 + 0.111\times f_5 + 0.112\times f_6 + 0.112\times f_7 + 0.112\times f_8 - 0.112\times f_9 \quad (1)$$

where, f_1 is the hardness, kg/cm^2; f_2 is the SSC, %; f_3 is the single-fruit weight, g; f_4 is the fruit longitudinal diameter, mm; f_5 is the fruit equatorial diameter, mm; f_6, f_7, and f_8 are the L*, a*, and b*, respectively; f_9 is the titratable acid, %; F is the factor score value.

Table 5 Matrix of score coefficients of principal component 1

Quality indexes	Score coefficient of principal component 1
Hardness (f_1)	−0.111
SSC (f_2)	0.111
Single-fruit weight (f_3)	0.112
Fruit longitudinal diameter (f_4)	0.112
Fruit equatorial diameter (f_5)	0.111
L^* (f_6)	0.112
a^* (f_7)	0.112
b^* (f_8)	0.112
Titratable acid (f_9)	−0.112

4 Establishment of quantitative evaluation model of maturity

4.1 Establishment of score prediction model of principal components based on accumulated temperature

To get a comprehensive quantitative assessment of the maturity of Korla fragrant pear, the scores from Equation (1) were fitted with the corresponding accumulated temperature. Following this, a mathematical model of relations between accumulated temperature and scores of principal components was constructed. SigmaPlot 12.5 software was used to fit the score value and accumulated temperature. A fitting analysis showed that accumulated temperature and principal component scores conform to the Sigmoidal model. The mathematical model and the Sigmoidal fitting model are shown in Figure 2.

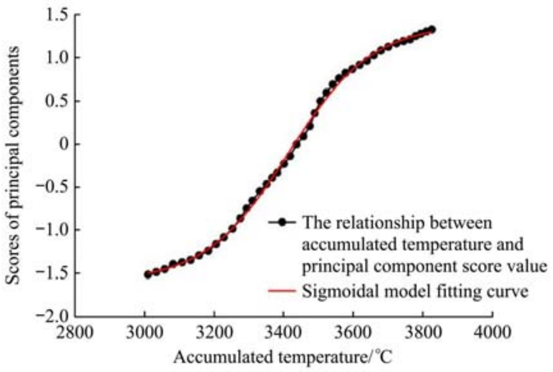


Figure 2 Fitting curves of relations between accumulated temperature and scores of principal components

The Sigmoidal model equation is

$$y = y_0 + \frac{a}{1 + e^{-(\frac{x - x_0}{b})}} \tag{2}$$

where, a is the factor stability constant, which reflects the initial state of a factor change; b is the ripening kinetic constant, which reflects the ripening power of a factor change; y_0 is the initial value of a factor change, which reflects the inherent properties of a factor change with effective accumulated temperature; x_0 is the mutation point of the change rate of a factor, which reflects the accumulated temperature value when the change rate of a factor changes suddenly, °C; x is the effective accumulated temperature value, °C, y is the value of a certain factor. The numerical values of the constants y_0, a, b, and x_0 were substituted into the above equation to obtain the fitting equation as Equation (3), which reflected the relationship between accumulated temperature and principal component scores in the maturity variation process of Korla fragrant pears.

$$Y = -1.597 + \frac{2.987}{1 + e^{-(\frac{x - 3414.073}{119.844})}} \tag{3}$$

where, x is the numerical value of accumulated temperature in different maturity periods, and Y is the principal components score.

The coefficient of determination is R^2=0.9988, which proved the good fitting of the mathematical model of relations between accumulated temperature and the principal components score. This mathematical model reflected the relations between accumulated temperature and the principal components score.

4.2 Establishing a maturity model based on scores of principal components

The quality index scores of the Korla fragrant pears during the maturity period can be gained based on Equation (3), which could be used to quantify the maturity of Korla fragrant pears. Based on the quantitative maturity equation method of Lan et al.[2], the quantitative maturity equation of Korla fragrant pears can be expressed as,

$$M_i = \left| \frac{Y_i - Y_1}{Y_2 - Y_1} \right| \times 100\% \tag{4}$$

where, M_i is the maturity of Korla fragrant pear, %; Y_1 is defined as the score of the initial principal components in the maturity period of the Korla fragrant pears; Y_2 is the score of the final principal component at harvest; Y_i is the parameter value of any principal component in the maturity period.

The scores of principal components under different accumulated temperatures could be gained from Equation (3). Subsequently, the scores of principal components were substituted into Equation (4), and the quantitative maturity model of Korla fragrant pears was obtained as follows.

$$M_i = 0.351Y_i + 0.533 \tag{5}$$

Quantitatively evaluating Korla fragrant pear maturity can be performed based on the quantitative maturity model Equation (5), which could be used to determine the optimal harvest period of Korla fragrant pears. The quantitative maturity model was established according to several quality indexes. Comprehensive information on more Korla fragrant pear quality indexes could consider the maturity of Korla fragrant pears beyond single quality indexes. To prove the necessity of maturity quantitative assessment based on multiple quality indexes, the maturity can be quantified according to single quality, and the difference degree of single quality index to the maturity measurement was gained.

4.3 Comparative analysis on maturity measuring errors of single quality indexes

Variation ranges of single quality indexes are different. Data from different quality indexes in 10 d of the test period were randomly selected for a comparative analysis to analyze maturity differences among different quality indexes. The maturity of Korla fragrant pears at the same accumulated temperature was quantified according to the quantitative maturity equation of a single quality index as follows.

$$m_i = \left| \frac{y_i - y_1}{y_2 - y_1} \right| \times 100\% \tag{6}$$

where, m_i is the maturity at any point of the quality index value y_i in the maturity period; y_1 is the initial value of a quality index in the maturity period; y_2 is the final value of a quality index in the maturity period.

Test data from different quality indexes were brought into Equation (6), and the maturity corresponding to any single quality index was gained (Table 6). Different quality indexes quantified the maturities of Korla fragrant pears harvested at the same accumulated temperature. Table 6 shows that the difference between hardness and SSC in maturity quantization was relatively small, with the maximum reaching 4.32%. Further, the difference between single-fruit weight and fruit longitudinal diameter in maturity quantization was relatively small, with the maximum at 3.88%. In addition, differences among the rest of the quality indexes in maturity quantization were relatively high. None of them could evaluate the maturity of Korla fragrant pears alone. Moreover, the comprehensive comparative analysis on maturity showed small differences among quality indexes in maturity quantization in two stages based on different quality indexes with low and high maturity. There were large differences in the medium maturity stage since Korla fragrant pears grow and develop quickly at medium maturity, causing complicated variations of quality indexes. The quality indexes increased and decrease quickly. If a single quality index is used to quantify the maturity of Korla fragrant pears in the medium maturity stage, it will cause great differences, influencing the accurate matching between harvest maturity and target market demands.

There is no maturity standard to measure differences in quality indexes for maturity quantization at present. Therefore, the maturity standards for the Korla fragrant pear were explored. Maturity standards can be used to compare maturity measuring errors from a single quality index and maturity measuring errors from multiple quality indexes. Table 6 shows great differences among different quality indexes in quantizing the maturity of Korla fragrant pears, which are harvested under the same accumulated temperature and are inapplicable to complicated situations. Hence, it is necessary to quantify the maturity of Korla fragrant pears based on multiple quality indexes.

Table 6 Comparative analysis between the maturity measurement by multiple quality indexes and maturity measurement by a single quality index

Test number	Hardness maturity M_{I}/%	SSC maturity M_{II}/%	Single-fruit weight maturity M_{III}/%	Fruit longitudinal diameter maturity M_{IV}/%	Fruit equatorial diameter maturity M_{V}/%	L^* maturity M_{VI}/%	a^* maturity M_{VII}/%	b^* maturity M_{VIII}/%	TA maturity M_{IX}/%	Multi-quality index maturity M/%
1	0.51	0.77	1.20	1.60	1.00	0.85	1.00	0.86	1.72	1.16
2	1.53	1.03	5.31	7.11	5.76	8.18	5.78	7.10	10.34	6.01
3	6.38	7.44	18.54	22.42	14.29	18.05	15.54	16.56	15.52	15.23
4	14.54	14.87	37.03	35.39	40.94	27.64	31.87	28.82	36.21	30.11
5	26.79	27.95	46.61	49.57	58.00	41.47	40.24	36.56	44.83	41.61
6	45.92	46.92	63.46	66.00	68.73	58.39	52.99	55.48	50.00	56.50
7	73.21	74.36	79.30	78.14	80.10	75.46	71.51	69.03	68.97	74.25
8	85.71	89.49	87.47	88.86	89.48	85.90	74.70	78.92	75.86	83.66
9	92.60	96.92	94.58	93.19	92.54	93.51	88.25	86.88	86.21	91.30
10	96.94	98.72	95.70	97.09	95.88	96.33	94.62	92.90	96.55	95.85

Note: M_{I}, M_{II}, M_{III}, M_{IV}, M_{V}, M_{VI}, M_{VII}, M_{VIII}, and M_{IX} are maturities that are calculated by hardness, SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, b^* and titratable acid, respectively.

4.4 Feasibility analysis of quantitative maturity assessment based on multiple quality indexes

The quantitative maturity assessment method was applied to quantify the maturity of Korla fragrant pears in 2020 to verify its feasibility in assessing Korla fragrant pears. The same pear garden was chosen. The management mode, sample selection criteria, acquisition method of quality indexes, and the accumulated temperature acquisition method were the same as those in 2019. Scores were gained through PCA of the test data collected in 2020. The practical maturity of the Korla fragrant pears in 2020 was gained from Equation (4). Meanwhile, scores in 2020 were brought into Equation (5), and a Korla fragrant pear model was gained to verify maturity. The practical maturity of Korla fragrant pears in 2020 was compared with maturity which was gained based on the quantitative maturity model (Table 3). RMSE=3.05 between fitting curves, evidencing small differences in the maturity quantification of Korla fragrant pears in the same pear garden over two years. This reflects that the proposed quantitative maturity assessment method of Korla fragrant pears is feasible to some extent.

In a word, the proposed quantitative maturity assessment method of Korla fragrant pears can quantify maturity scientifically. However, it has certain geographical limitations in its practical applications. The maturity of Korla fragrant pears has the same variation trend in different environments. Still, the proposed method shall be calibrated according to the test to guide the harvesting of Korla fragrant pears due to differences in specific climates, terrains, and management modes.

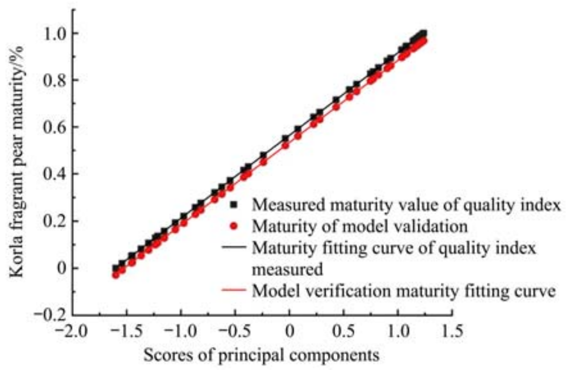


Figure 3 Scatter diagram of comparison between the practical maturity of Korla fragrant pears and model verified maturity

5 Conclusions

The quality indexes in the maturity stage of the Korla fragrant pears (SSC, single-fruit weight, fruit longitudinal diameter, fruit equatorial diameter, L^*, a^*, and b^*) increased gradually with the increased accumulated temperature, showing significant positive correlations. Hardness and titratable acid decreased continuously with increased accumulated temperature, showing significant negative correlations.

Within the range of test parameters, principal component scores gained by PCA and accumulated temperature conform to the Sigmoidal model. Further, the coefficient of determination is

0.9988. The Sigmoidal model can express their relations sufficiently. The construction of the quantitative maturity model of Korla fragrant pear is $M_i = 0.351Y_i + 0.533$, indicating that it can quantify the maturity of Korla fragrant pears.

The proposed quantitative assessment method of the maturity of Korla fragrant pears is feasible to some extent. It can further act as a reference to select the harvest time and quantitative maturity assessment of fruits.

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