Mechanical characteristics of Hanfu apple at low temperature

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Abstract: To find out a low temperature storage method for the maintenance of Hanfu apple's firmness, crispness and moisture content, three storage methods in refrigerator, large cellar, and small cellar were experimented. Tests and comparisons were conducted for parameters including maximum absolute deformation, elastic modulus, firmness in compression test, and weight loss rate using mechanical characteristics monitoring and regular weighing during and after storage. Five testing groups with different pretreatments were arranged for refrigerator tests. The results showed that lower weight loss rates were achieved in two cellars than in the refrigerator; and difference between the large and small cellars was insignificant. However, cellar storage was only feasible for a relatively short term. Refrigeration storage with humidification sealing treatment yielded the optimal result in maintaining firmness, crispness and moisture of Hanfu apples, showing advantage in long-term storage.

Keywords: Hanfu apple, low temperature storage, mechanical characteristics, weight loss rate

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1 Introduction

Bred by Shenyang Agricultural University, Hanfu apple is an excellent variety with characteristics of bright color, large size, delicious flavor, and cold resistance, suitable for both ready-to-eat and further processing[1]. As the cultivating area of Hanfu Apple expands, storage is becoming a challenge considering that there are not air conditioning storages, refrigeration storages, or ventilated storages in mountainous regions in North China resulted from the geographic limitation and economic insufficiency[2]. Therefore, a simple and low-cost storage method appears to be particularly important. Aimed at the issues of static loading, vibration minimization and impact damage during fruit harvest, storage and transport process, a large number of mechanical characteristics research on fruit and vegetables including oranges[3-5], cucumbers[6], watermelons[7], litchi[8]and apples[9,10] had been carried out in past years using the method of compression. It turned out that different picking periods and storage conditions could lead to apples' mechanical injury in the process of harvest, storage and transport. With regard to storage issues of Hanfu apples, a number of studies have been done on the issue of extension of apples' storage and shelf life in which 1-methylcyclopropene (1-MCP) is widely used. 1-MCP has the ability of inhibitting the ripening effect of ethylene, due to which physiological metabolism process is suppressed during storage and shelf life. Fruit's edible quality can be maintained for a longer period of time[1, 11, 12].

By setting different storage ways (refrigerator, large cellar and small cellar) and conducting different pretreatments on refrigerator groups, the present study was therefore planned to find out rules of Hanfu apple quality change under low temperature condition by monitoring and analyzing weight loss rate, maximum absolute deformation, elastic modulus and firmness.

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The study intended to find good storage methods suitable for long term storage in North China context. The result may offer theoretical basis and references for the future research of Hanfu apples' preservation.

2 Materials and methods

2.1 Materials and equipments

The Hanfu apples were produced in the area of Lixiang town in Shenyang, Liaoning Province. The weight of apples ranged from 139.41 g to 213.02 g. The average scales of temperature and humidity in three storage ways during test period were reported in Table 1. The sizes of refrigerator, the large cellar and the small cellar are roughly 10 m × 2 m × 2.5 m, 100 m × 20 m × 4 m and 5 m × 2 m × 2 m, respectively. Water bath (HH-6, Shangyu, China), ultraviolet lamp (20 watts, Shanghai, China), electronic scale (DJ-5002, China) and universal testing machine (CMT8102, China) were used as main equipments in our experiments. The universal testing machine has the following parameters: max testing force at 100 N, repetition accuracy at ±0.5%, deformation resolution at 0.08 μm, force resolution at 1/300 000 FS, and speed range at 0.001-500 mm/min.

Table 1 Average temperature and relative humidity during test period in three storage methods

Storage methods	Temperature/℃	Humidity/%
Refrigerator	2.5	75
Large cellar	-2.5	85
Small cellar	-3	88

2.2 Groups and treatments in tests

Apples in tests were put into plastic fruit boxes. Each box with forty apples in it represented one testing group. Five boxes with each box being a testing group was put in the refrigerator, and one box was put in each of the two cellars. Each of the five testing groups in the refrigeration was treated with a different pretreatment, being ltraviolet irradiation (four hours every 10 days), bathing pretreatment (heating for 4 min at 50℃), sealing (the size of sealing bags was 30 cm × 40 cm × 0.05 mm), humidification sealing (humidifying for 25 min every 10 days), and no treatment, respectively. The large cellar and the small cellar as control groups were compared with the refrigerator for analysis. Literature indicated an appropriate dose of UV- C could control the anthracnose infection rate of apple fruits[13] and UV-light of the proper wavelength and intensity could degrade residues of pyrethroid pesticide on apples[14]. Due to the cold winter in North China, fresh fruits always had to experience low temperature. Eating fresh apple is harmful to the health of stomach. Some studies showed that water bath serves as a convenient method to warm up apples with little nutritive loss[15]. Weight loss due to respiration can be inhibited effectively with sealing and humidification treatments[9]. The above five groups in refrigerator were analyzed, and the large cellar and the small cellar as control groups were compared with the refrigerator for analysis.

2.3 Parameters and methods in determinations

Test data were acquared in 10-day cycles. Three samples of uniform size and similar maturity were selected in each treatment groups during each cycle, and then all parameters were tested in three repetitions. The total of nine results were analyzed in tests as follows.

2.3.1 Weight loss rate

Weight loss rate is one of the important quality indicators for evaluation of fruit-vegetable storage. The value directly affects other quality factors such as freshness and taste. Weight loss was calculated as follows:

$$W = \frac{W_i - W_1}{W_i} \times 100\% \qquad (1)$$

where, W= weight loss rate in sample, %; W_i = initial mass, g; and W_1 = regularly-weighing mass, g.

2.3.2 Maximum absolute deformation

A 10 mm-diameter screw was used in the loading mode in the compression test. The fixed displacement and rate were set at 7 mm and 10 mm/min, respectively. Each test was repeated three times by lateral compression (equators of apples). The whole force–deformation curves were acquired automatically (Figure 1). At the early part of tests, the correlation between force and deformation was an approximately linear function and the fruit was in the elastic range. Permanent damage occurred after the fracture displacement reached L-Value (Figure 1). L-Value was defined as maximum absolute deformation accordingly[7], which is one of significant parameters in compressive properties [16].

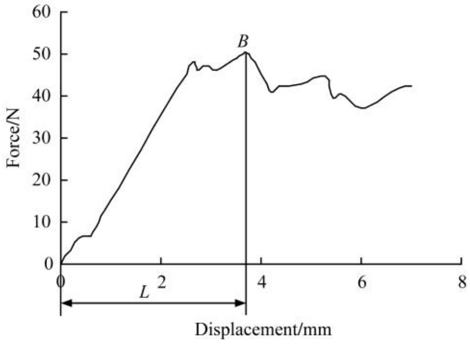

Figure 1 The curve of force-deformation in compression tests

2.3.3 Elastic modulus

Elastic modulus was calculated for entire apple fruits as follows[8]:

$$E = \frac{3F(1-\mu^2)}{4D^{\frac{3}{2}}R^{\frac{1}{2}}} \tag{2}$$

where, E = elastic modulus, MPa; F = external load applied, N; D = deformation (mm); R = material radius, mm; μ (0.33 was taken in this test) = Poisson ratio.

2.3.4 Firmness

The material slope in force-deformation curves by loading is defined as firmness in agricultural products and food materials in general, which was attained in compression tests in this study (Figure 1)[6].

3 Results and discussion

3.1 Impact tests of weight loss rate

3.1.1 Analysis on effect laws of weight loss rate by different storage methods

Weight loss could be ascribed to water loss and fruits respiration[17]. Figure 2 showed that weight loss rate of the no-treatment group in the refrigerator was significantly higher than samples in two cellars, while there was insignificant difference between the two cellar groups. During the first 20 days storage, the extent of weight loss was higher than that in the later period, which was due to the great temperature gap during the transportation between the plantation at -5.5℃ to the testing refrigerator at 2.5℃, as temperature gap could accelerate transpiration of apples[9]. The results showed that cellar storage with no treatment was a better way to inhibit weight loss. When ANOVA indicated extremely significant differences (P<0.01) of storages (Table 2)[18], LSD tests[19] were further used as a furthermore separation method. Specific analysis method was conducted as follows:

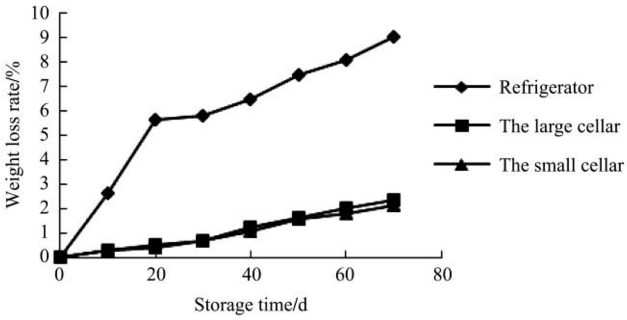

Figure 2 Rules of change in weight loss rate over storage time by three storage methods

Table 2 ANOVA results in four parameters

Variable quantities	Sources of variation		SS	df	MS	F	P-value
Weight loss rate	Three storage ways	Interblock	113.018	2	56.509	16.560	4.819E-05
		Interclass	71.658	21	3.412		
	Refrigerator	Interblock	192.582	4	48.145	12.712	1.723E-06
		Interclass	132.56	35	3.787		
Maximum absolute deformation	Three storage ways (Contain humidification sealing group)	Interblock	4.138	3	1.379	6.064	0.003
		Interclass	6.368	28	0.227		
	Refrigerator	Interblock	14.917	4	3.729	5.286	0.002
		Interclass	24.693	35	0.706		
Elastic modulus	Three storage ways (Contain humidification sealing group)	Interblock	0.209	3	0.07	4.185	0.014
		Interclass	0.466	28	0.017		
	Refrigerator	Interblock	0.701	4	0.175	6.854	0.000
		Interclass	0.895	35	0.026		
Firmness	Three storage ways (Contain humidification sealing group)	Interblock	33.479	3	11.16	3.08	0.044
		Interclass	101.467	28	3.624		
	Refrigerator	Interblock	87.666	4	21.917	5.053	0.003
		Interclass	151.807	35	4.337		

Step one: to calculate the standard deviation of average difference in samples.

$$s_{\bar{x}_1-\bar{x}_2} = \sqrt{\frac{2MS_e}{n}} = 0.37 \quad (3)$$

Step two: checked t-values table as the deviation at eighteen-degree-of-freedom (18-DOF).

$$t_{0.05}(df_e) = t_{0.05}(18) = 2.101 \quad (4)$$

$$t_{0.01}(df_e) = t_{0.01}(18) = 2.878 \quad (5)$$

Therefore, LSD values in 5% significant level and 1% one were procured as follows:

$$LSD_{0.05} = t_{0.05}(df_e)\, s_{\bar{x}_1-\bar{x}_2} = 2.101\times0.37=0.78 \quad (6)$$

$$LSD_{0.01} = t_{0.01}(df_e)\, s_{\bar{x}_1-\bar{x}_2} = 2.878\times0.37=1.06 \quad (7)$$

Step three: averages were contrasted with each treatment group (Table 3).

Table 3 Results of weight loss rate multiple comparisons among three storage ways

Treatment	$\bar{x}_i$	$\bar{x}_i$ -0.98	$\bar{x}_i$ -1.08
The refrigerator	5.63	4.65 **	4.55 **
The large cellar	1.08	0.1	
The small cellar	0.98		

The difference in two cellar groups was insignificant (Table 3), but very significant difference was achieved between cellar storage and the refrigerated storage. Combined with Figure 2, the results showed cellars have more advantages in preserving apples' moisture with no processing.

3.1.2 Analysis on effect laws of weight loss rate among different treatment methods in refrigerator

Figure 3 showed that weight loss rates in all treatment groups were less than the control group, which proved the mass loss of fruit was restrained effectively by processed group. In the first 20 days, great temperature fluctuation had led to substantial weight loss[9], which was effectively overcome by sealing treatment. Only the humidification sealing showed a slightly decreasing trend (other groups were on increase), it could be attributed to regular humidification and transpiration inhibition. The net weight of apples increased slightly in the effect of epidermis excessive vapor-absorbing[20]. Although the UV and the water bath treated groups had restrained weight loss in various degrees compared to storage with no treatment, there was no obvious advantage in these two groups (Figure 3). Overall, the sealing treatment was found to be efficacious in inhibiting weight loss, and the humidification sealing brought a striking effect. Five groups have very significant difference (P<0.01). The result of multiple comparisons for weight loss rate among treatment groups was shown in Table 4.

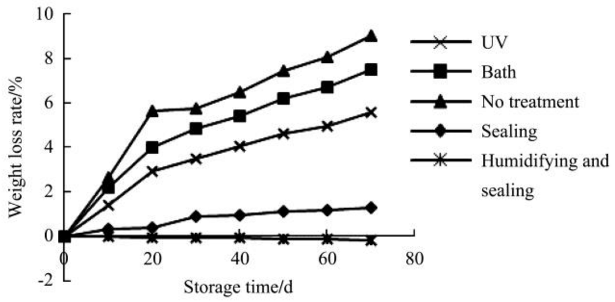

Figure 3 Change rules of weight loss rates along with the storage time by each treatment groups in refrigerator

Table 4 Results of weight loss rate multiple comparisons among different treatment groups in refrigerator

Treatment	$\bar{x}_i$	$\bar{x}_i$ -(-0.08)	$\bar{x}_i$ -0.76	$\bar{x}_i$ -3.38	$\bar{x}_i$ -4.61
No treatment	5.63	5.71 **	4.87 **	2.25 **	1.02 *
Bathing	4.61	4.69 **	3.85 **	1.23 *	
UV	3.38	3.46 **	2.62 **		
Sealing	0.76	0.84 *			
Humidifying and sealing	-0.08				

Note: $\bar{x}_i$ for averages of samples; ** for extremely significant difference; * for significant difference; no marks for indistinctive difference.

Differences with the control group were reported in Table 4, demonstrating extremely significant difference except the water bath-pretreatment group, and presenting significant difference from the control group. Combined with Figure 3, humidification sealing had the best effect to inhibiting weight loss of Hanfu apples. Respiration had been inhibited effectively in virtue of sealing and relative humidity increased by humidification termly, which could reduce water vapor pressure between apples and ambient air. Little moisture ran off when water vapor in the air reached saturation, thereby inhibiting weight loss rate of apples and keeping freshness [9].

3.2 Impact tests of mechanical characteristics

3.2.1 Analysis on effect laws of mechanical characteristics by different storage methods

In order to find an advantageously storage method, analyses with humidification sealing in refrigerator for no treatment in three storage ways were done. Change laws of maximum absolute deformation, elastic modulus and firmness were shown as Figure 4, Figure 5 and Figure 6, respectively. On account of the restriction on test conditions, only the small cellar was observed to compare with refrigerator in mechanics characteristic tests at the end of 30-day storage.

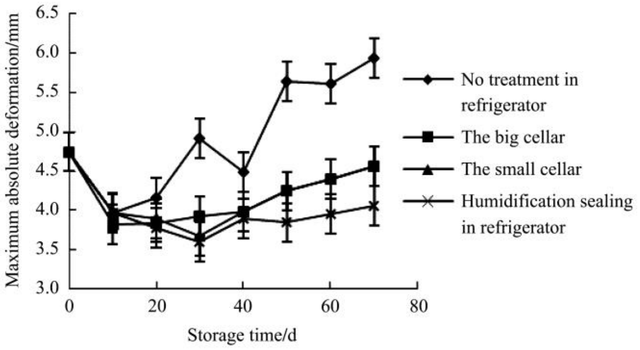

Figure 4 Change rules of maximum absolute deformations along with the storage time by three storage ways

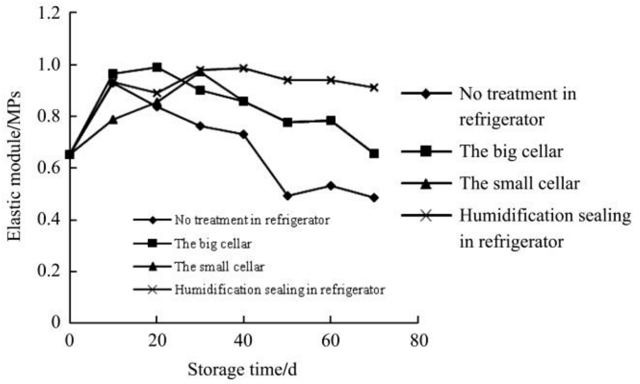

Figure 5 Change rules of elastic module along with the storage time by three storage ways

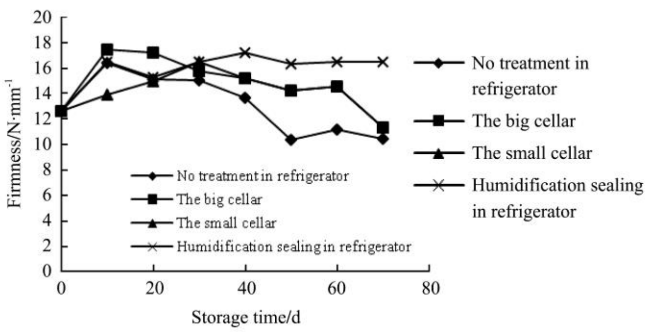

Figure 6 Change rules of firmnesses along with the storage time by three storage ways

Although the change rules of three indexes were not exactly the same, the same issues had been showed from Figure 4, Figure 5 and Figure 6, which were varying trends in three parameters clear shown at the end of 30 days. The humidification sealing group possessed minimum deformation but maximum elastic modulus and firmness after 30 days of storage. In addition, very slight variations presented in the humidification sealing group, showing advantage in apples' long-term storage. However, the cellar storage had advantage over the refrigerator group with no treatment in specified test period. It was revealed from change trends of three indexes that cellars were not suitable for long term storage. In contrast, the refrigerator exhibited greater value for Hanfu apples' long-term storage[21].

3.2.2 Analysis on effect laws of mechanical characteristics among different treatment methods in refrigerator

In order to meet long-term storage needs of Hanfu apple, since the natural environment had a great influence on the cellar storage, the research was mainly focused on the refrigerator storage. As Figure 7 implied, maximum absolute deformations in five groups all presented uptrend. Apples' compression resistance had increased for the loss of moisture and changing of internal structure component as the storage progressed. In other words, more deformation was required to make pericarp fracture[22]. During the first 50 days, the sealing group possessed minimum deformation, which was presented in humidification sealing group after the 50th day. In summary, water bath-pretreatment group had the maximum compression resistance. It was indicated that high-temperature water bath accelerated fruit respiration, causing quality decrease and fruit softening [20].

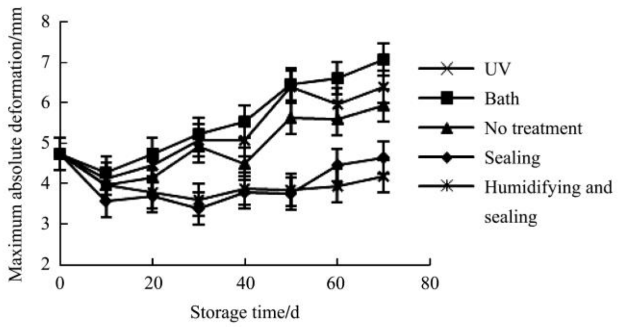

Figure 7 Change rules of maximum absolute deformations along with the storage time by each treatment group in refrigerator

It was apparent from Figure 8 that elastic modulus decreased as storage progressed. During the first 50 days, the sealing group presented maximum elastic modulus while the maximum value after 50 days appeared in the humidification sealing group. The results indicted that the humidifying-sealing treatment had the ability to maintain elastic modulus of apples during long-period storage.

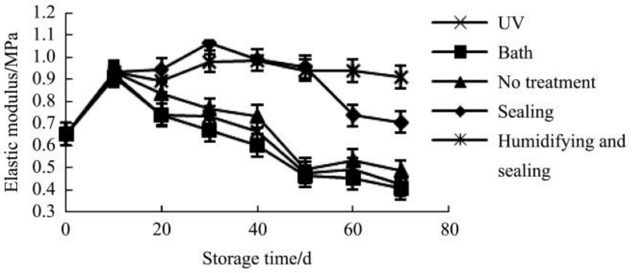

Figure 8 Change rules of elastic module along with the storage time by each treatment group refrigerator

Firmness appeared in downtrend in all treatment groups as was expressed in Figure 9. It was observed that humidification sealing group possessed a higher firmness which dropped slowly as well after 50 days during storage. Therefore, humidifying-sealing treatment was judged to be excellent in all groups and beneficial to long-term storage.

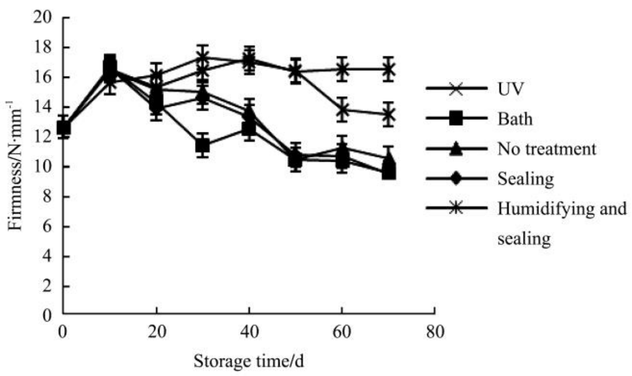

Figure 9 Change rules of firmnesses along with the storage time by each treatment group in refrigerator

The three storage ways had significant differences (0.01<P<0.05) in elastic modulus and firmness while extremely significant differences (P<0.01) in maximum absolute deformation from ANOVA (Table 1). And all refrigerator treatment groups had extremely significant differences (P<0.01) in three parameters. The significance contrast between treatment groups and the control group in refrigerator was shown in Table 5.

Differences with the control group in all indexes were reported in Table 5 demonstrating extremely significance except the UV and water bath-pretreatment group in firmness analysis, presenting no significant difference to control. Combined with three mechanical indexes, the humidification sealing group had maximum firmness, elastic modulus and minimum deformation. In terms of firmness and moisture maintenance, the humidification sealing treatment proved a good method.

Table 5 Comparison results of variances significant analysis between refrigerator treatments and the control group on mechanical indexes

Testing parameters	UV	Bathing	Sealing	Humidifying and sealing
Maximum absolute deformation	0.33 **	0.58 **	0.87 **	0.82 **
Elastic modulus	0.04 **	0.07 **	0.19 **	0.22 **
Firmness	0.42	0.92	2.16 **	2.82 **

Note: ** for extremely significant difference; no marks for indistinctive difference.

4 Conclusions

Compared to cellar storage (the large and the small cellars), refrigeration storage with no treatment had obvious weight loss, and lower elastic modulus and firmness (signaling apparent softening). However, weight loss rate dropped sharply since the humidification sealing treatment was conducted on refrigerator groups, presenting superiority over other ways (Figure 4, Figure 5 and Figure 6). Water bathing pretreatment proved to show the strongest pressure resistance but weakest brittleness in later storage. It was confirmed that water bathing unsuited to long-term storage, yet it could alleviate chilliness when apples are eaten in winter[15]. Therefore, it was a good choice to Hanfu apples' fresh winter consumption in North China. Drawn from the variation tendency of all testing indexes, humidification sealing was a good method to preserve brittleness, moisture and qualities, presenting advantages in long-term storage.

ANOVA indicated significant difference among groups in all test indexes. Processing methods were confirmed as feasible and could achieve ideal storage conditions through improvement according to the test results. All test indexes suggested cellar storage had advantages with no treatment within a specified period. While notable decrease appeared for the superiority of this method as the storage progressed, it was susceptible for large temperature fluctuation in the outside environment which poisoned cellar circumstances[9]. Nevertheless, the humidity of refrigerator was roughly constant. Test results and variation trends of indexes proved that humidification sealing was capable of conserving Hanfu apple's overall qualities. In conclusion，humidification sealing treatment provided a potential method for long-term storage of Hanfu apples.

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