Study of Impact and Compression Damage on Asian Pears

Pictiaw Chen, Margarita Ruiz, Fuming Lu, Adel A. Kader
MEMBER ASAE MEMBER ASAE

ABSTRACT

RESULTS of impact and compression tests on Chojuro, Twentieth Century, Tsu Li, and Ya Li varieties of Asian pears indicate that Chojuro pears are the firmest and most resistant to mechanical damage. At the time of harvest, Tsu Li and Ya Li pears could resist mechanical damage nearly as well as Chojuro pears, but they become more susceptible to bruising in cold storage. Twentieth Century pears are most sensitive to impact and compression bruising. Increased time in the ripening room produces more softening and increased bruise resistance of Chojuro and Twentieth Century pears than of Tsu Li and Ya Li pears.

INTRODUCTION

Asian pears, sometime known as apple pears, Japanese pears, Chinese pears, or Oriental pears, differ from European pears in that they remain firm, crisp, and juicy when eating-ripe, whereas European pears such as Barlett and Comice become soft when ripe. Information on origin, descriptions of horiticultural requirements, and photographs of different varieties of Asian pears in California can be found in Griggs and Iwakiri (1977). Asian pears have been commercially produced in Asian countries such as China and Japan for many decades but have not been so popular in California until recent years. Before 1980, California had only about 200 ha of Asian pears in commercial orchards. However, because of the rapid increase in demand for these crisp and juicy pears, commercial plantings of Asian pears in California increased to about 800 ha by the end of 1983. At present there are about 1500 ha of commercial orchards, of which 400 ha are bearing.

Asian pears are bruised more easily than European pears. However, these pears do not change texture after picking and can be stored at 0 °C for several months. Tsukamoto (1981) studied the mechanical injury of two varieties of Asian pears and found a difference between the two varieties in their ability to resist mechanical damage. There is a need for additional information about the ability of Asian pears to resist mechanical injury.

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The authors are: PICTIAW CHEN, Professor, Agricultural Engineering Dept., University of California, Davis; MARGARITA RUIZ, Associate Professor, Agricultural Mechanization Dept., Polytechnic University, Madrid, Spain; FUMING LU, Associate Professor, Agricultural Machinery Engineering Dept., National Taiwan University, Taiwan; and ADEL A. KADER, Professor, Pomology Dept., University of California, Davis.

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OBJECTIVE

The objectives of this study were:

1. To determine the differences among varieties of Asian pears in ability to resist impact and compression damage.
2. To determine the effect of storage time on susceptibility to mechanical injury.
3. To determine if there are correlations between mechanical injury and other physical variables such as flesh-firmness, compression force, maximum force, and deformation during impact.

EXPERIMENTAL PROCEDURE

The following four varieties of Asian pears were tested: Twentieth Century (Nijisseiki) and Chojuro—round varieties, and Ya Li and Tsu Li—pear-shaped varieties. About 300 fruits of each variety were harvested in August from the University Experimental Orchard in Winters, CA. From these, 200 fruits of each variety were selected for study.

On the harvest date, 30 fruits of each variety were placed in a 20 °C ripening room and the remaining 170 fruits of each variety were stored in a 0 °C room for future testing. The 30 fruits in the 20 °C room were divided into three groups of ten fruits. One group was tested on the day it was stored at 20 °C (day 0), another was tested on day 2, and the final group was tested on day 4. At the end of each month after the harvest date, 30 fruits of each variety were taken from the 0 °C room and placed in the 20 °C room and tested in the same manner as the first 30 fruits. The same procedure was repeated at the end of each month for a total of 5 months. The last test was conducted at the end of the 5th month after harvest. Thus, a total of 180 fruits of each variety were tested.

The following tests and measurements were made on each pear:

Compression Test: Compression tests were performed using an Instron universal testing machine (model 1122). A 19-mm-diameter sherical indenter was used to compress the pear at a deformation rate of 10 mm/min until the total deformation reached a predetermined value. Two compression tests, one at 1.5-mm deformation and one at 3-mm deformation, were performed at two different locations (about 2 cm apart along the equator) on each pear. The force-deformation curve for each test was recorded.

Impact Test: Impact tests were conducted using the impact tester developed by Chen et al. (1985). A 43.2-g instrumented steel rod with a 19-mm-diameter spherical tip was dropped from a predetermined height onto the fruit. Two impact tests, one 6-cm drop and one 10-cm drop, were conducted on each fruit. The acceleration of the rod during impace was measured, and other pertinent impact variables (maximum force, maximum deformation, absorbed energy, and duration of impact) were calculated (Chen et al., 1985) and recorded on a computer disk file.

Other Measurements: Other measurements included flesh-firming reading, mass and volume of the fruit, and the percent soluble solids of the fruit juice. Flesh-firmness was measured with a U.C. fruit firmness tester, which gives the peak force required to puncture the peeled surface of the fruit with a 7.9-mm-diameter cylindrical plunger. The volume of the fruit was obtained by measuring the buoyant force of the submerged fruit. The percent soluble solids was measured with a refractometer.

Bruise Evaluation: During each compression and impact test, the spherical tip was first smeared with ink. When the tip came in contact with the fruit, it left an ink mark showing the area of contact. Each contact point was labeled, and the bruises in the fruit were allowed to develop for about 2 h. The degree of bruise was evaluated by cutting through the center of the bruised region and measuring the maximum width and depth of the bruise with a scale. The pattern of the bruised area was also recorded.

STATISTICAL ANALYSIS

A 4 × 5 × 3-factorial-treatments analysis was applied in a completely randomized design. Variables included the four varieties, six lengths of cold storage time (0, 1, 2, 3, 4 and 5 months), and three lengths of ripening time (0, 2 and 4 days). Data were analyzed with the BMDP (Dixon and Brown, 1979) statistical packages.

RESULTS AND DISCUSSION

Bruise Characteristics

In all four varieties of Asian pears tested, the pattern of bruise cause by impact was quite different from that caused by slow compression. The cross section of the compression bruise resembled a parabola (Fig. 1). Such a bruise pattern is similar to that found in European pears and other types of fruits such as apples and peaches. The cross section of the bruise caused by impact often had long spikes extending radially from the impact area into the fruit (Fig. 1). Such a bruise pattern seems to be unique to Asian pears. This difference between impact- and compression-bruise patterns in Asian pears was reported by Tsukamoto (1981).

The irregular pattern of the impact bruise made it difficult to quantify the degree of bruise caused by impact. We measured the maximum width and depth of the cross section of the bruise. Although these measurements can uniquely describe a parabolic shape and, thus, estimate the area of parabolic bruise, they are not adequate for estimating the irregularly-shaped area of the impact bruises.

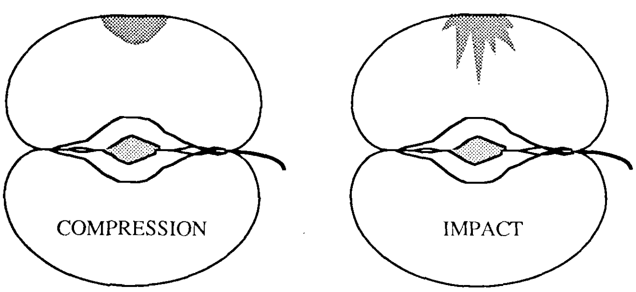

Fig. 1—Compression and impact bruise patterns in Asian pears.

TABLE 1. SPECIFIC GRAVITY, SOLUBLE SOLIDS, AND FLESH FIRMNESS OF FOUR VARIETIES OF ASIAN PEARS

Variety	Specific gravity	Soluble solids, %	Flesh firmness, N
Twentieth Century	1.036±0.031*	12.58±1.17	26.29±4.72
Chojuro	1.030±0.032	10.93±0.80	39.99±5.20
Tsu Li	1.002±0.010	13.11±0.65	30.51±7.70
Ya Li	1.010±0.063	11.61±0.98	31.98±5.20

*Mean±standard deviation of 180 fruits.

The difference in patterns of impact and compression bruises indicates that the loading rate greatly affects the pattern of failure in Asian pears. Therefore, it is important to consider the type of loading and the loading rate when analyzing the strength and failure of fruits.

Physical Properties

Table 1 shows the average values of specific gravity, percent soluble solids, and flesh firmness of the four varieties of Asian pears tested. The two round varieties, Chojuor and Twentieth Centruy, have slightly higher specific gravity than the two pear-shaped varieties, Tsu Li and Ya Li. Twentieth Century and Tsu Li, which were classified as "sweet" by Griggs and Iwakiri (1977), have higher soluble solids contents than Chojuro and Ya Li, classified as "mildly sweet." The average flesh firmness value of Chojuro is the highest, followed by those of Ya Li, Tsu Li, and Twentieth Century.

Results of Statistical Analyses

The results of analysis of variance (Table 2) indicate that the variety of pear significantly affected all measurements. Cold storage time significantly affected all measurements except the bruise depth caused by dropping the impacting rod from a 10-cm height. The only two variables that were not significantly affected by time in the 20 °C room were the soluble solids and

TABLE 2. EFFECTS OF PEAR VARIETY, COLD STORAGE TIME, AND RIPENING TIME ON VARIOUS TEST MEASUREMENTS

Measurements	Level of significance		
	Variety	Time in 0 °C cold storage	Time in 20 °C room
Flesh firmness	**	**	*
Soluble solids	**	**	ns
Bruise width (6-cm drop)	**	**	**
Bruise depth (6-cm drop)	**	*	**
Bruise width (10-cm drop)	**	**	**
Bruise depth (10-cm drop)	**	ns	**
Bruise width (comp. to 1.5 mm)	**	**	**
Bruise depth (comp. to 1.5 mm)	**	**	**
Bruise width (comp. to 3.0 mm)	**	**	**
Bruise depth (comp. to 3.0 mm)	**	**	**
Compression force (1.5 mm)	**	**	**
Compression force (3.0 mm)	**	**	**
Max. impact force (6-cm drop)	**	**	**
Max. impact deformation (6-cm drop)	**	**	**
Final impact deformation (6-cm drop)	**	*	**
Absorbed energy (6-cm drop)	**	**	*
Duration of impact (6-cm drop)	**	**	*
Max. impact force (10-cm drop)	**	**	**
Max. impact deformation (10-cm drop)	**	**	**
Final impact deformation (10-cm drop)	**	**	**
Absorbed energy (10-cm drop)	**	**	**
Duration of impact (10-cm drop)	**	**	ns

**1% significance level.
* 5% significance level.
ns - not significant.

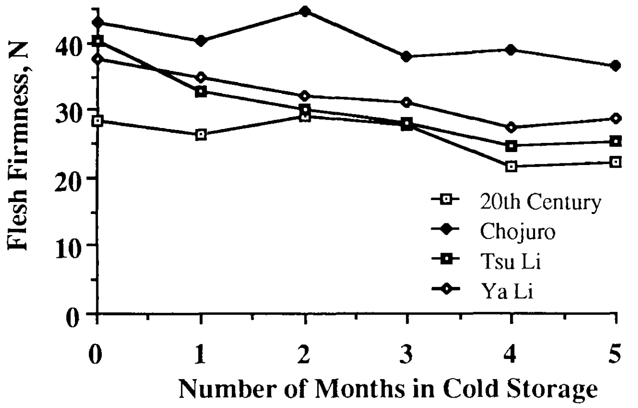

Fig. 2—Effect of 0 °C storage time on flesh firmness (puncture force) of four varieties of Asian pears.

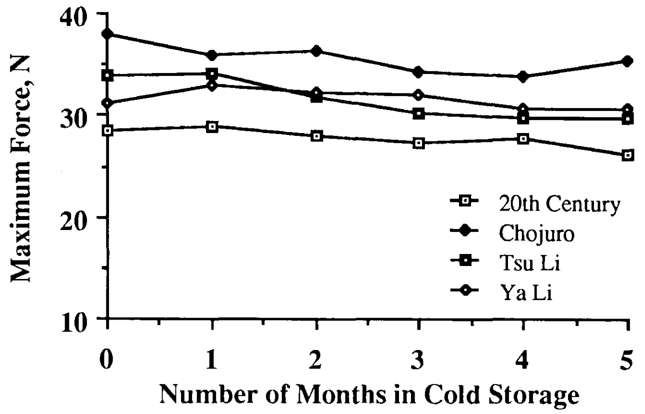

Fig. 4—Effect of 0 °C storage time on the maximum impact force on four varieties of Asian pears. The impact was done by dropping a 43.2-g rod with a 19-mm-diameter spherical tip from a 6-cm height onto the fruit.

duration of impact resulting from a 10-cm drop. The analysis also indicates strong interactions among varieties. Further analyses were made on each variety separately in order to determine the response of each variety in various tests.

Effects of Time in Cold Storage

Fruit Firmness

Fruit firmness was determined by measuring puncture force (flesh firmness), compression force, and impact force. Fig. 2 shows puncture force of all four varieties of pears over time in cold storage. Maximum compression force, measured at 1.5-mm deformation, is shown in Fig. 3. Maximum impact force resulting from dropping the impacting rod from a 6-cm height onto the fruit is shown in Fig. 4. The four varieties can be ranked in descending order for degree of fruit firmness at harvest as follows: Chojuro, Tsu Li, Ya Li, and Twentieth Century. The firmness of fruits in all four varieties tended to decrease as the time in cold storage increased. The firmness of Chojuro, Twentieth Century, and Ya Li tended to decrease at about the same rate, whereas that of Tsu Li decreased faster in all three types of measurements.

Degree of Bruise

Impact bruise: Because of the difficulty in quantifying the degree of bruise caused by impact, the data on the depth and width of impact bruise are quite scattered. Although the data show some differences among the varieties in ability to resist impact damange, the effects of time of storage at 0 °C and ripening at 20 °C on impact-bruise size are inconclusive.

Compression bruise: Fig. 5 shows that Chojuro pears resisted compression bruising better than the other varieties: Twentieth Century pears were most susceptible to compression bruising. The ability of both the Chojuro and Twentieth Century varieties to resist compression bruising degraded gradually through the 5 months in cold storage.

Although the bruise sizes in the Tsu Li and Ya Li varieties were small at the beginning of cold storage, they increased rapidly after the first month in storage. Such a decline in resistance to bruising may indicate some physiological changes in the fruit while in cold storage. Data on ethylene production by Asian pears (A. A. Kader, unpublished) indicate that, at 0 °C storage temperature, ethylene production by either Tsu Li and Ya Li pears is about 30 times as high as that by Twentieth Century pears. Since ethylene production by a fruit is related to ripening, the ethylene production data indicate that Tsu Li and Ya Li pears may ripen in 0 °C storage much faster than Twentieth Century pears. Therefore, the decrease in resistance to bruising in Tsu Li and Ya Li may be a result of continued ripening in 0 °C storage.

Effect of Time in 20 °C Ripening Room

The length of time in the ripening room had a greater

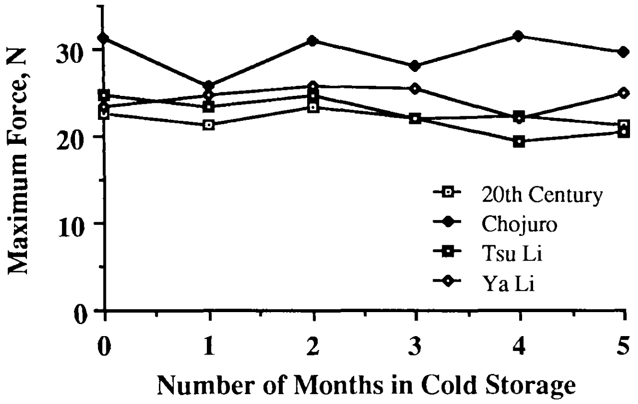

Fig. 3—Effect of 0 °C storage time on the maximum compression force (at 1.5 mm deformation) on four varieties of Asian pears.

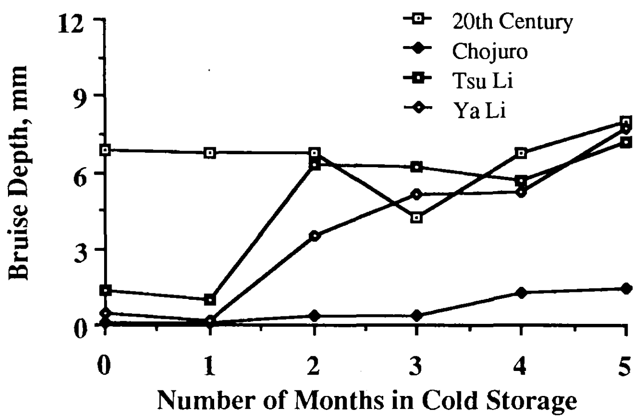

Fig. 5—Effect of 0 °C storage time on the depth of compression bruise on four varieties of Asian pears. The bruise was caused by pressing a 19-mm-diameter spherical indentor 1.5 mm into the fruit at 10 mm/min deformation rate.

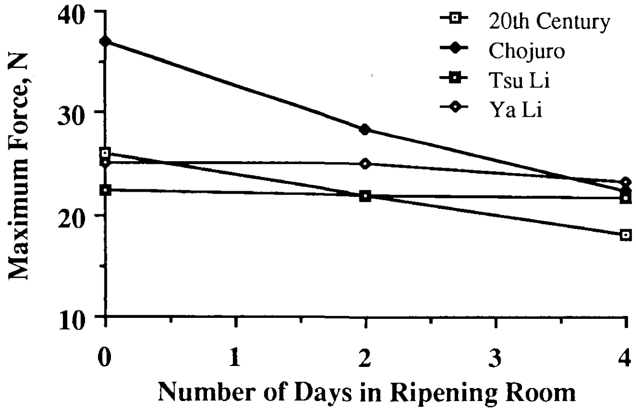

Fig. 6—Effect of 20 °C ripening time on the maximum compression force (at 1.5 mm deformation) on four varieties of Asian pears.

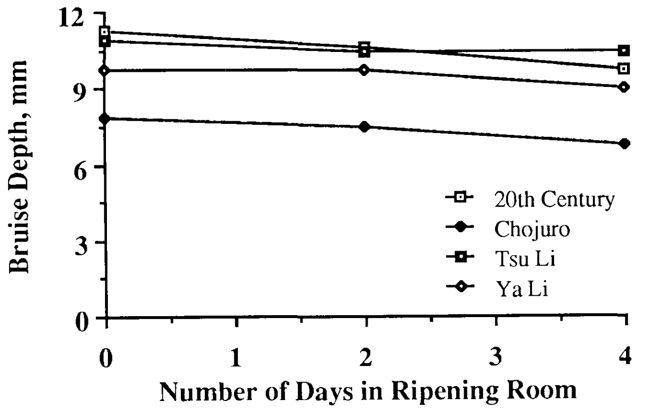

Fig. 9—Effect of 20 °C ripening time on the depth of impact bruise on four varieties of Asian pears. The impact was achieved by dropping a 43.2-g rod with a 19-mm-diameter spherical tip from a 10-cm height onto the fruit.

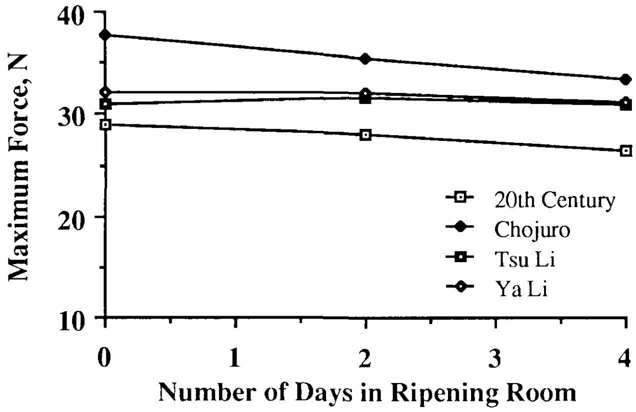

Fig. 7—Effect of 20 °C ripening time on the maximum impact force on four varieties of Asian pears. The impact was achieved by dropping a 43.2-g rod with a 19-mm-diameter spherical tip from a 6-cm height onto the fruit.

effect on Chojuro and Twentieth Century than on Tsu Li and Ya Li pears. Figs. 6 to 10 show that the firmness and ability to resist bruises of Tsu Li and Ya Li remained relatively unchanged during the four days in the ripening room. In contrast, the firmness readings of Chojuro and Twentieth Century dropped appreciably during the same period, as shown by both the maximum compression force (Fig. 6) and maximum impact force (Fig. 7) tests. The softening effect on Chojuro and Twentieth Century pears was also shown by the increase in maximum deformation resulting from a 6-cm drop impact (Fig. 8). As these pears became softer in the ripening room, they also became less susceptible to impact bruising (Fig. 9) and compression bruising (Fig. 10).

Horsfield et al (1972) showed that, when a fruit is impacted by a rigid sphere, the maximum normal and shear stresses are proportional to one-fifth the power of the impact energy and four-fifth the power of firmness (elastic modulus) of the fruit. Therefore, an impact of a given energy level will result in higher maximum stresses in a firm fruit than in a soft fruit. Since our data show that an impact of equal energy resulted in larger bruises in firmer fruits, we can conclude that the cause of tissue failure in Asian pears is mainly due to excessive stresses in the fruit. The results in Figs. 7 and 8 also show that the size of bruise decreased as the maximum impact deformation increased, indicating that maximum deformation, or maximum strain, is not a critical factor in the cause of failure in Asian pears. Thus, the strain failure criterion which Dal Fabbro et al. (1980) observed in apples, potatoes, and (European) pears is not applicable for Asian pears, especially Chojuro and Twenthieth Century.

Correlations Between Mechanical Injury and Other Variables

Table 3 shows the correlation coefficients for those

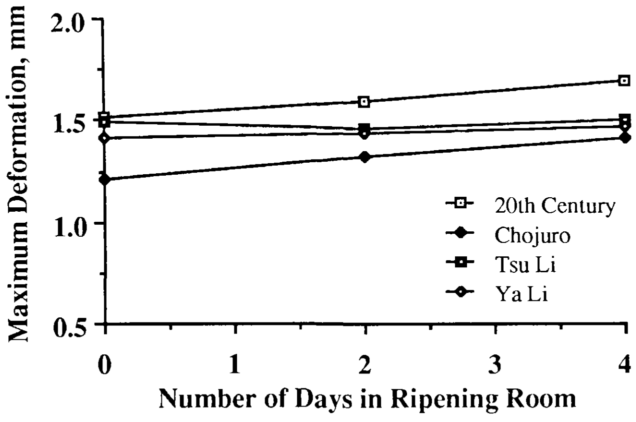

Fig. 8—Effect of 20 °C ripening time on the maximum impact deformation on four varieties of Asian pears. The impact was achieved by dropping a 43.2-g rod with a 19-mm-diameter spherical tip from a 6-cm height onto the fruit.

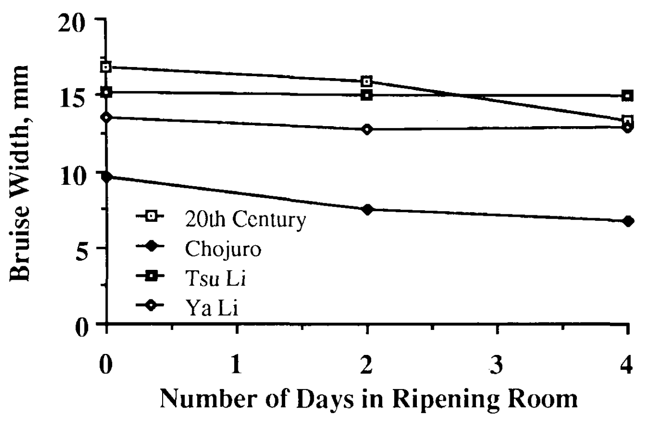

Fig. 10—Effect of 20 °C ripening time on the width of compression bruise on four varieties of Asian pears. The bruise was caused by pressing a 19-mm-diameter spherical indentor 3 mm into the fruit at 10 mm/min deformation rate.

TABLE 3. VALUES OF SIGNIFICANT CORRELATION COEFFICIENTS FOR SELECTED PARAMETERS (ALL 720 FRUITS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Flesh firmness	X																
2. Bruise width (6-cm drop)	−0.386	X															
3. Bruise depth (6-cm drop)	−0.385	0.440	X														
4. Bruise width (10-cm drop)	−0.351	0.644	0.361	X													
5. Bruise depth (10-cm drop)	−0.407	0.359	0.445	0.372	X												
6. Bruise width (comp. to 1.5 mm)	−0.635	0.477	0.419	0.493	0.433	X											
7. Bruise depth (comp. to 1.5 mm)	−0.630	0.446	0.419	0.471	0.429	0.909	X										
8. Bruise width (comp. to 3.0 mm)	−0.622	0.529	0.484	0.548	0.486	0.791	0.776	X									
9. Bruise depth (comp. to 3.0 mm)	−0.563	0.342	0.463	0.363	0.462	0.716	0.743	0.788	X								
10. Compression force (1.5 mm)	0.566	−0.206	−0.141	−0.201	−0.173	−0.282	−0.262	−0.254	−0.182	X							
11. Compression force (3.0 mm)	0.699	−0.345	−0.269	−0.345	−0.302	−0.479	−0.455	−0.445	−0.348	0.881	X						
12. Max. impact force (6-cm drop)	0.678	−0.322	−0.348	−0.299	−0.326	−0.551	−0.575	−0.533	−0.532	0.646	0.752	X					
13. Max. impact deformation (6-cm drop)	−0.631	0.264	0.278	0.215	0.274	0.433	0.451	0.405	0.398	−0.702	−0.759	−0.909	X				
14. Duration of impact (6-cm drop)	−0.515	0.244	0.291	0.207	0.172	0.379	0.445	0.378	0.417	−0.377	−0.452	−0.719	0.662	X			
15. Max. impact force (10-cm drop)	0.636	−0.266	−0.332	−0.281	−0.277	−0.495	−0.511	−0.475	−0.465	0.631	0.710	0.804	−0.755	−0.699	X		
16. Max. impact deformation (10-cm drop)	−0.524	0.183	0.213	0.169	0.161	0.331	0.334	0.288	0.283	−0.629	−0.655	−0.699	0.712	0.623	−0.894	X	
17. Duration of impact (10-cm drop)	−0.467	0.235	0.235	0.256	0.194	0.359	0.428	0.371	0.421	−0.322	−0.404	−0.637	0.545	0.836	−0.689	0.579	X

variable pairs that show highly significat correlations. Highest correlations are found among compression-bruise measurements (measurements 6 to 9 in Table 3) and among measurements of applied compression and impacts (measurements 10 to 17). The compression-bruise measurements also correlate fairly well with flesh firmness, with compression force at 3-mm deformation, and with most of the impact measurements (12 to 17). Because of the difficulty in quantifying the impact bruises, the impact-bruise measurements (2 to 5) do not correlate well with measurements of either compression force (10 to 11) or impact (12 to 17), but they do correlate fairly well with flesh firmness. These correlation coefficients can be used to determine which measurements are important for future studies of mechanical damange in fruits.

CONCLUSIONS

Twentieth Century, Chojuro, Ya Li, and Tsu Li varieties of Asian pears differed in firmness, in susceptibility to impact and compression damage, and in response to storage at 0 °C and ripening at 20 °C. Chojuro pears were firmest and resisted mechanical damage better than pears of the other three varieties. At the initial stage of cold storage, Tsu Li and Ya Li pears resisted mechanical damage nearly as well as Chojuro pears; however, they became more susceptible to bruising as the time in cold storage increased. Therefore, Tsu Li and Ya Li pears that have been in cold storage for a long time require more careful handling. Twentieth Century pears were very sensitive to impact and compression bruises throughout the entire storage period; extreme care must be exercised at all times when handling Twentieth Century pears. The firmness and ability to resist bruises of Tsu Li and Y Li pears remained relatively unchanged during the four days in a ripening room. In contrast, Chojuro and Twentieth Century pears became softer and less susceptiable to impact and compression bruises.

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