RESEARCH ON THE CONTRIBUTION RATIO OF APPLE PEEL PUNCTURE BEHAVIOR TO FRUIT FIRMNESS
/
苹果果皮穿刺质地对果实硬度贡献率的研究

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DOI: *https://doi.org/10.35633/inmateh-60-19*

Keywords: *puncture test; peel texture; fruit firmness; peel contribution*

ABSTRACT
The texture of apple peel, as an important quality attribute of the fruit, is directly relevant to a fruit's ability to resist mechanical injury. In order to explore the variations in texture of two apple peels under different puncture test conditions and evaluate the relation of apple peel puncture force to whole fruit firmness percentage, at 0.1, 1, 5, 11, and 17 mm/s loading speeds, puncture mechanical measurements were performed using an electronic testing machine mounted with 2, 3.5, 7.9 or 11 mm-diameter probes. For the same probe, the mean values of peel puncture force and stiffness, as well as the fruit puncture force, for Danxia and Fuji cultivars increased firstly and then changed a little with the increase of loading speed. Moreover, at the same loading speed, the puncture measurements of each cultivar increased significantly ($P \le 0.05$) with increasing probe diameter and the peel puncture force has a significant linear correlation with probe diameter. Among the different cultivars, under the same loading speed, the Fuji peel and fruit samples had the greater puncture force; the Fuji peel contribution change was relatively big with the increasing of loading speed, and Fuji cultivar was more likely to be injured than the other cultivar. The results were expected to serve as a reference for investigating the puncture injury sensitivity of different apple varieties during transportation and storage and to enrich the texture evaluation index of apple peel.

摘要
苹果果皮作为果实的最外层组成部分，其质地特征是评价果实抵抗机械损伤能力的重要指标。为探索不同品种苹果果皮穿刺质地的差异及研究果皮穿刺质地对果实硬度的贡献率，采用直径为2, 3.5, 7.9, 11 mm的圆柱体压头，在0.1, 1, 5, 11, 17 mm/s的加载速度下对红富士和丹霞苹果果皮及整果果实进行了穿刺力学特性试验，获得果皮及果实的穿刺载荷—位移曲线、破裂抗力与果皮的刚度。试验结果表明：同一品种苹果，在相同压头下随着加载速度的增加，果皮破裂抗力及刚度、果实破裂抗力均呈现先增大后变化幅度不大的趋势；在相同加载速度下随着压头尺寸的增大，果皮及果实的穿刺力学特性参数间存在显著性的差异（$P \le 0.05$），果皮破裂抗力与压头直径之间呈显著正线性相关。不同品种苹果，在相同的加载速度下果皮及果实的破裂抗力均以红富士的为最大；随着加载速度的增加，红富士果皮穿刺质地对果实硬度贡献率的变化相对较大；红富士苹果比丹霞更容损伤。研究结果为不同品种苹果果皮贮运损伤敏感性的评价提供参考依据，丰富苹果果皮质地的评价指标。

INTRODUCTION
Peel texture of fruits and vegetables, which is an important index of fruit quality *(Ma et al., 2011; Singh et al., 2006; Grimm et al., 2012; Li et al., 2019)*, is directly relevant to the fruit-resistance ability to mechanical damage *(Shao et al., 2009; Tobi et al., 2016; Liu et al., 2018; Chukwutoo et al., 2017)* and the injury of puncture between fruits and fruit stems *(Allende et al., 2004; Jiang et al., 2009)*; meanwhile peel texture is one of the main factors affecting fruit firmness*(Allende et al., 2004; Jiang et al., 2009; Vanstreels et al., 2005; Wang et al., 2019)*.

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The firmness and compactness of fruit texture, which are closely related to fruit quality *(Veringă et al., 2015; Veringă et al., 2018;)* could be determined by the puncture strength test, and during postharvest handling, the fruit bears mechanical stress causing peel punctures injuries *(Singh et al., 2006; Zhao et al., 2015)*. Currently, when puncture method is used in assessing peel texture, and when evaluated, research has mainly turned on two sides: direct evaluation of peel texture after peel puncture *(Hetzron et al., 2011; Wang et al., 2015)* and indirect evaluation of peel texture after the whole fruit and flesh are used to perform puncture tests *(Rao et al., 2011; Costa et al., 2012; Costa et al., 2016)*. Puncture properties of different tomato peels, which were cut from the epidermal segments of each fruit and were made circular in shape, were measured and analysed. It was found that the stiffness and puncture force of various tomato peels were successfully determined using puncture test, and puncture forces were able to represent the resistance of a tomato peel to chewing and peeling satisfactorily *(Hetzron et al., 2011)*. To determine the differences of injury susceptibility of Fuji and Starkrimson apples, two kinds of peel were utilized in puncture tests with 2 mm-diameter punch at 1 mm/s loading speed. The puncture properties of the sunlit-side part were better than those of the shadow-side part, and the puncture resistance ability of Starkrimson peel was superior to that of Fuji peel *(Wang et al., 2015)*.

The whole fruit and flesh without skin were tested under overall puncture load displacement to obtain the mechanical behaviour of various apple skins precisely. Apple skin is important during forced ripening, and the percent contribution of the skin to the overall firmness is greater during cold storage *(Grotte et al., 2011)*. To determine the relation between mechanical properties of two tomato varieties and puncture injury susceptibility, puncture experiments of tomatoes with and without skin were conducted. Fruit elasticity and the toughness of tomato skins affected the susceptibility to fruit puncture injury *(Desmet et al., 2002)*. Puncture tests were executed on Golden Delicious and Red Delicious apple fruits with and without skin. It was discovered that skin is important in puncture properties of apples and that it has a high percent of toughness and rupture force for two apple varieties; but the contribution of skin is higher in Golden Delicious than Red Delicious *(Shafiee et al., 2008)*. Mechanical properties of apple slices with and without skin under puncture tests were examined at a 50 mm/min crosshead speed to a depth of 15 mm. It was indicated that peak puncture force values of Crimson Gala and Honey Crisp were higher than those of McIntosh, Red Delicious, and Empire; the contribution of the skin of Honey Crisp apples to the peak force was the least among all the studied apples *(Rao et al., 2011)*.

To date, the relationship between peel puncture texture and fruit firmness of apples has not been reported under different probe diameters and loading speed test conditions. This study aimed to: (1) examine the variations in texture of two apple peels and whole fruit firmness in two apple cultivars under different puncture test conditions, and (2) determine the relationship between the peel puncture texture and fruit firmness of apples. The results were expected to enhance the objectivity and accuracy of the texture evaluation of apple peel and to serve as a reference for investigating the puncture injury sensitivity of different apple varieties during transportation and storage.

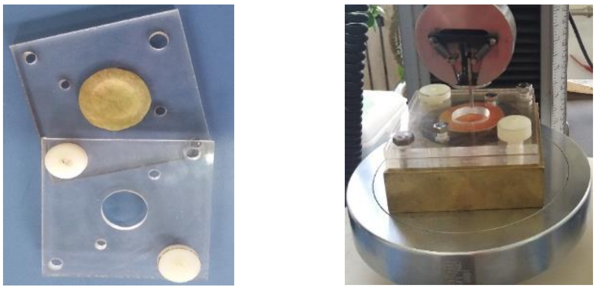
MATERIALS AND METHODS

Apple fruits

Two autumn ripening apple cultivars, Danxia and Fuji, grown in Shanxi Fruit Institute Academy of Agriculture Sciences, were simultaneously picked in October 2017. Sample apples were uniformly shaped and sized, no pests and no mechanical damage. When the fruits were taken to the laboratory on the day of harvest, puncture tests were conducted immediately at room temperature (21°C and 80% RH).

Peel samples

The diameter of puncture circular peel samples is 31 mm (as shown in Fig. 1a). To decrease the influence of peel micro-buckled state on experimental results and consider that the bottom of apples is the main injured part during transportation, peel samples were collected from the flat peridermal segment which was located below equatorial plane of the fruit. On each fruit, two peel samples, which located in the opposite sites, were performed in a one-by-one puncture. The preparation of peel samples used the same method by Wang et al *(Wang et al., 2017)*. Appropriate samples were immediately tested. Ten peel samples originating from five apples were analysed for each cultivar. Sample thickness was checked with a raster thickness gauge (JC010-1, China). The mean and standard deviation of the samples thickness was 0.275 ± 0.026 for Danxia and 0.257 ± 0.028 mm for Fuji.



a. Circular peel sample *b. Puncture test*

Fig. 1 - Circular peel sample and puncture test of peel

Puncture tests

Five puncture tests were completed on apple peel and whole fruit samples using an electronic testing machine (Instron-5544, USA) at room temperature. The cylindrical probes used were 2, 3.5, 7.9 and 11mm in diameter, and the test speeds were 0.1, 1, 5, 11 and 17 mm/s. A jig comprising an upper and lower film *(Wang et al., 2015)* was used to fix peel samples (as shown in Fig. 1b).

During the puncture test, apples were placed upon a flat plate, and their stem calyx axis was parallel to the flat plate. The process of acquiring a whole fruit sample was exceptionally simple and efficient. Ten apples were experimented with 10 mm penetration depth for each cultivar, and each fruit was measured at shadow and sunlit sides of the maximum transverse diameter of the fruit. The longitudinal diameters of the fruits were measured using Vernier callipers with a resolution of 0.01 mm. The measured values of the longitudinal diameters ranged from 75.81 ± 1.74 mm and 77.59 ± 2.04mm for Danxia and Fuji apples, respectively; and transverse diameters ranged from 64.07 ± 1.56 and 65.73 ± 2.35mm for Danxia and Fuji apples, respectively.

Data analysis

Puncture mechanical parameters were obtained using Duncan's multiple range tests in the ANOVA procedure of SAS, version 8 (SAS Institute, Cary, NC, USA). The differences were assessed with a 95% confidence interval.

RESULTS

Puncture test of peel

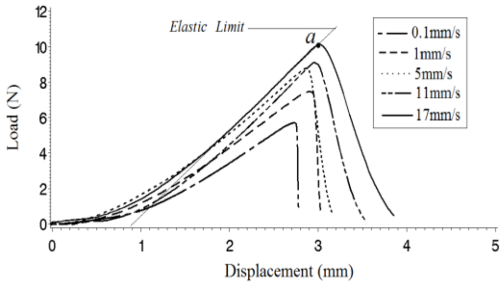


Fig. 2 - Puncture force–displacement curves of peel with different loading speeds under 3.5 mm-diameter probe

Peel puncture force–displacement curves of peel stress-strain curves

In Fig. 2, under 3.5 mm-diameter probe, typical peel puncture force–displacement curves at 0.1, 1, 5, 11 and 17 mm/s loading speeds are shown for the peel of Danxia apple. And at 11 mm/s loading speed, Fuji peel puncture force–displacement curves with 2, 3.5, 7.9, and 11 mm-diameter probes are shown in Fig. 3. As seen with the puncture curves of apples peel, the curves do not have obvious bio-yield point and are composed of two stages, such as that puncture curve subjected to 17 mm/s loading speed. In the initial stage, the load only makes the buckling peel extend gradually, so puncture displacement rapidly increases but the load is significantly small and almost constant. In the second curve stage, when the puncture probe continues to squeeze the sample, the buckling state of peel disappears, and the load raises with increasing puncture displacement until the sample is disrupted at the failure point (a point), however the part curve keeps the maximum slope, which exhibits a linear relation between force and displacement from the upper part of the curve up to the failure point; the curve linear region is known as elastic region and the slope of this portion curve represents the sample elastic modulus that is usually considered as an index of the sample stiffness in material field. Hetzroni et al. *(2011)* considered the part of the curve with the maximum slope to represent the stiffness of the skin sample.

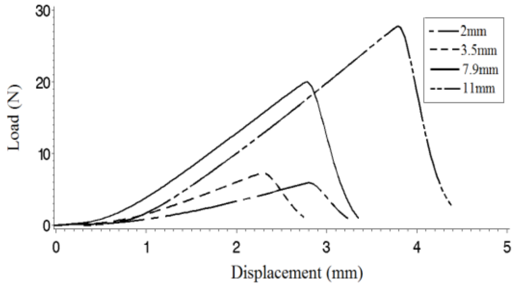


Fig. 3 - Puncture force–displacement curves of peel with different probe diameters at 11 mm/s loading speed

As shown in Fig. 2 and Fig. 3, the portions with the greatest slope were in the top section of the curves until they reached the failure points, which could express the stiffness of peel samples. The measurements of peel puncture force and stiffness extracted from the curves are shown in Table 1. For four parts of peel – i.e. sunlit longitudinal, shadow longitudinal, sunlit transverse and shadow transverse–the results obtained in the maximum load test, tensile strength test, elastic modulus test and failure strain test were as shown in Table 1.

Peel puncture property analysis

Table 1 shows that under the same probe diameter, the means of peel puncture force and stiffness for the same cultivar increased firstly and then changed little with the increase of loading speed. When the loading speed ranged from 0.1 mm/s to 5 mm/s, the puncture force and stiffness of the peel samples increase constantly in the experiment. The reason is that the sample failure takes longer time in the process of the puncture tests, and the deformation of peel sample is based on viscous deformation and grows more slowly. Therefore, under the circumstances, the peel puncture macro-mechanical properties are strongly dependent upon the force action time. As loading speed increased, the puncture force and stiffness of the peel samples show little change compared to those of 5mm/s loading speed. This is because once a certain loading speed has been reached, such as 5mm/s, the deformation of peel sample is on the basis of the elastic deformation and the elastic deformation is elastic wave propagation whose speed is far greater than the loading speed. As a result, the loading speed has almost no influence on elastic deformation in the test. However, for 11 mm/s and 17 mm/s loading speed, the sample fracture period was close to that of 5 mm/s loading speed in Table 1.

With each diameter probe, at 0.1, 1 and 5 mm/s loading speed, the mean values of the peel puncture force had significant differences ($P \leq 0.05$) between each pair of loading speeds for each cultivar. However, the mean values for Danxia and Fuji peel at 5, 11, and 17 mm/s loading speeds did not have a significant difference from each other.

In Table 1, it can be also seen that as probe diameter increased, the puncture force and stiffness of the peel samples increased constantly at the same loading speed; and with each cultivar, the puncture force and stiffness of 2, 3.5, 7.9 and 11 mm-diameter probes had significant differences ($P \leq 0.05$) between each other, except for the Danxia peel stiffness of 2 and 3.5 mm-diameter probes. This could be due to the fact that when the probe diameter is bigger, the larger contact induces between the probe and the sample, and simultaneously, apple peel has the viscous nature, this increases the contact area between liquid layers of peel organizational structure, which causes the increasing friction between liquid layers. These phenomena result in the increasing internal resistance to viscosity of the sample; therefore, the puncture force and stiffness are enlarged with probe diameter increased.

For different cultivars, at the same loading speed, no matter what probes, the Fuji peel samples had greater puncture force than Danxia peel samples; the stiffness of Danxia peel was lower than that of Fuji peel in addition to 2 mm-diameter probe. With the different diameter probe, at 0.1, 1, 5, or 11 mm/s loading speeds, only the Fuji peel puncture force values of 11 mm-diameter probe had a significant difference ($P \leq 0.05$), compared with Danxia peel; and at 1, 5, or 11 mm/s loading speeds, for mean values of peel stiffness, only the Fuji peel stiffness values of 7.9 mm-diameter probe was significantly larger ($P \leq 0.05$), compared with Danxia peel. Based on the above analysis, for the two kinds of peel, the little differences of puncture mechanical parameters could be caused by peel texture. It is observed that the two peels' texture was heavily weighted in elasticity, and contribution rate of viscosity factor in the Danxia and Fuji peel was 24.2% and 29.17% *(Wang et al., 2016)*. These reflected that the resistance ability of puncture rupture was similar for Danxia and Fuji peel.

Table 1

Values of puncture force and stiffness of apple peel at different loading speeds

Breed	Loading speed (mm/s)	Experimental period of sample fracture (s)				Puncture force (N)				Stiffness (N·mm^{-1})			
		2 mm in diameter	3.5 mm in diameter	7.9 mm in diameter	11 mm in diameter	2 mm in diameter	3.5 mm in diameter	7.9 mm in diameter	11 mm in diameter	2 mm in diameter	3.5 mm in diameter	7.9 mm in diameter	11 mm in diameter
Danxia	0.1	21.4	26.82	30.58	32.27	3.69±0.63c,D	5.60±0.68c,C	12.29±1.90c,B	14.99±1.29c,A	2.33±0.23c,C	2.87±0.37c,C	4.93±0.42c,B	5.99±1.13cA
	1	2.328	2.624	3.083	3.435	4.66±0.52b,D	6.91±1.00b,C	14.43±1.59b,B	19.59±2.58b,A	2.87±0.23b,D	3.57±0.23b,C	5.72±0.60b,B	6.82±0.54bA
	5	0.466	0.591	0.677	0.517	5.38±0.51a,D	8.78±0.71a,C	17.85±1.82a,B	23.82±2.82a,A	3.21±0.34a,D	4.52±0.27a,C	6.83±0.64a,B	8.95±0.71a,A
	11	0.232	0.27	0.319	0.334	5.31±1.08a,D	9.10±1.23a,C	18.49±1.94a,B	25.13±1.58a,A	3.51±0.32a,D	4.68±0.64a,C	7.13±0.58aB	9.09±0.74a,A
	17	0.179	0.188	0.22	0.209	5.41±0.85a,D	9.05±0.82a,C	19.00±2.25a,B	25.32±2.46a,A	3.24±0.44a,D	4.71±0.32a,C	7.29±1.00a,B	9.19±1.15a,A
Fuji	0.1	24.27	27.42	31.6	35.74	4.13±0.56c,D	6.64±1.14c,C	13.89±2.09c,B	19.18±3.89c,A	2.26±0.25c,D	3.13±0.45c,C	5.17±0.87c,B	6.17±0.95c,A
	1	2.52	2.952	2.864	3.693	4.89±0.56b,D	8.35±1.24b,C	16.75±2.35b,B	24.63±4.45b,A	2.79±0.27b,D	3.76±0.31b,C	6.82±0.64b,B	7.97±0.98b,A
	5	0.495	0.612	0.661	0.702	5.89±0.44a,D	9.16±1.03a,C	19.82±2.67a,B	27.23±3.25a,A	3.18±0.43a,D	4.69±0.50a,C	8.13±0.62a,B	9.84±1.47a,A
	11	0.254	0.257	0.308	0.336	5.85±0.59a,D	9.25±1.39a,C	20.38±2.91a,B	28.09±3.14a,A	3.15±0.31a,D	4.83±0.49a,C	8.38±1.05a,B	9.54±1.34a,A
	17	0.169	0.179	0.216	0.212	5.76±0.77a,D	9.07±1.30a,C	19.68±2.36a,B	27.16±2.37ab,A	3.19±0.32a,D	4.75±0.69a,C	8.02±0.87a,B	10.22±1.20a,A

Note: Means within rows with a different uppercase letter are significantly different ($p \leq 0.05$).
Means within columns with a different lowercase letter are significantly different ($p \leq 0.05$)

Relation between peel puncture force and probe diameter

To determine relation between peel puncture force and probe diameter at the same loading speed, the data of puncture force of all the peel samples was used the procedure of Statistical Analysis System for line regression. Results indicated that the linear line satisfied the chosen function. The fitting equation was:

$$y = \beta x + k \tag{1}$$

where: *F* is the puncture force, [N];
β is fitting coefficient;
x is the probe diameter, [mm];
k is intercept.

Table 2, respectively, summarizes the fitting coefficients, significance level and determination coefficient ($P \le 0.0001$) for Danxia and Fuji peel. Results show that at the same loading speed, the puncture force has a significant linear correlation with the probe diameter. In the regression equations, the fitting coefficient reached extremely significant level ($P \le 0.0001$) for the two cultivars and only the intercept of the regression line has a significant level ($P \le 0.05$) for Danxia cultivar; moreover, the regression model was better with high determination coefficient which was over 0.88. It is reflected that the measurements have higher accuracy and the puncture force will keep growing when the probe size continues to widen.

Table 2

Linear fitting coefficient, intercept, significance level, determination coefficient of peel

Breed	Loading speed (mm/s)	fitting coefficient		intercept		R^2
		β	Pr > |t|	*k*	Pr > |t|	
Danxia	0.1	1.2962	<0.0001	1.2336	0.0045	0.9297
	1	1.6706	<0.0001	1.2082	0.0191	0.9377
	5	2.0459	<0.0001	1.4755	0.0089	0.9505
	11	2.1843	<0.0001	1.1809	0.0144	0.9673
	17	2.1968	<0.0001	1.2473	0.0108	0.9670
Fuji	0.1	1.6686	<0.0001	0.7813	0.2711	0.8820
	1	2.1465	<0.0001	0.5675	0.4874	0.9024
	5	2.3837	<0.0001	0.9830	0.1476	0.9441
	11	2.4854	<0.0001	0.7293	0.3001	0.9439
	17	2.3879	<0.0001	0.8489	0.1381	0.9598

Puncture test of a whole fruit

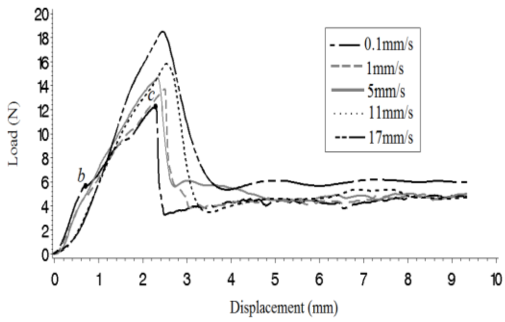


Fig. 4 - Puncture force-displacement curve of whole apples with different loading speeds under 3.5 mm-diameter probe

Relation between peel puncture force and probe diameter

Typical results of puncture load–displacement curves on whole apples of Danxia cultivar, subjected to 3.5 mm-diameter probe puncture at 0.1, 1, 5, 11 and 17 mm/s loading speeds, are shown in Fig. 4. For 0.1, 1 and 5 mm/s loading speeds, such as 0.1 mm/s, b is the yield point and the c-point stands for apple macrostructure failure. But For the 11 and 17 mm/s loading speeds, the curves have no obvious bio-yield points. At 11 mm/s loading speed, typical force vs. displacement curves of whole fruits of Fuji cultivar with 2, 3.5, 7.9, and 11 mm-diameter probes are shown in Fig. 5. In this diagram, with the different probes, the curves have also no obvious bio-yield points in the curves.

Typical results of puncture load–displacement curves on whole apples of Danxia cultivar, subjected to 3.5 mm-diameter probe puncture at 0.1, 1, 5, 11 and 17 mm/s loading speeds, are shown in Fig. 4. For 0.1, 1 and 5 mm/s loading speeds, such as 0.1 mm/s, b is the yield point and the c-point stands for apple macrostructure failure. But For the 11 and 17 mm/s loading speeds, the curves have no obvious bio-yield points. At 11 mm/s loading speed, typical force vs. displacement curves of whole fruits of Fuji cultivar with 2, 3.5, 7.9, and 11 mm-diameter probes are shown in Fig. 5. In this diagram, with the different probes, the curves have also no obvious bio-yield points in the curves.

Apple fruit puncture property analysis

Table 3 shows that the regulation of fruit experimental data change was similar to the peel experimental data. It can be also seen that under the same probe diameter, the means of fruit puncture force for the same cultivar increased first from 0.1mm/s to 5mm/s loading speed, and as loading speed increased, the fruit puncture forces show little change compared to those of 5mm/s loading speed. Moreover, the fruit puncture force means between 0.1 and 5 mm/s loading speeds had a significant difference ($P \le 0.05$) for Danxia and Fuji fruits. However, at 5, 11, and 17 mm/s loading speeds, no significant effect was observed between any two speeds.

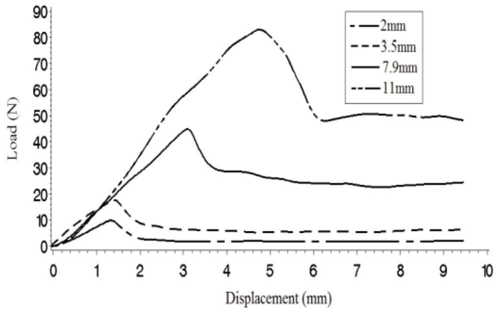


Fig. 5 - Puncture force–displacement curves of whole apples with different probes at 11 mm/s loading speed

Table 3 shows that as probe diameter increased at the same loading speed, the puncture force values of the fruit samples increase constantly; and a significant difference for the fruit puncture force ($P \le 0.05$) existed between each pair of diameter probes.

Table 3

Values of puncture force of apple fruits at different loading speeds

Breed	Loading speed (mm/s)	Puncture force (N)			
		2 mm in diameter	3.5 mm in diameter	7.9 mm in diameter	11 mm in diameter
Danxia	0.1	7.55±0.65b,D	11.38±0.87c,C	30.62±2.63c,B	51.33±4.95c,A
	1	8.22±0.25b,D	13.15±1.57b,C	37.88±4.95b,B	56.76±2.54b,A
	5	9.25±0.64a,D	16.11±1.32a,C	42.02±2.76a,B	67.42±5.19a,A
	11	9.08±1.01a,D	16.87±1.09a,C	44.03±2.14a,B	71.41±8.19a,A
	17	9.12±1.17a,D	17.26±1.53a,C	45.56±5.23a,B	68.23±0.98a,A
Fuji	0.1	7.51±0.96c,D	13.86±1.41b,C	38.28±4.31b,B	58.26±10.66c,A
	1	8.81±0.99b,D	16.53±2.07a,C	41.83±5.28ab,B	67.76±6.33b,A
	5	10.21±0.67a,D	17.36±1.28a,C	44.43±6.44a,B	70.97±11.68ab,A
	11	10.33±1.10a,D	17.43±2.20a,C	46.73±6.99a,B	74.34±13.42ab,A
	17	10.01±1.23a,D	16.83±1.43a,C	46.95±2.99a,B	78.87±5.46a,A

Note: Means within rows with a different uppercase letter are significantly different ($P \le 0.05$).
Means within columns with a different lowercase letter are significantly different ($P \le 0.05$).

Peel contribution percentage

In the process of transporting and storing, the injury between apples was closely related to peel texture. The puncture mechanical characteristics of fruit peel and the puncture injury susceptibility of fruits could be confirmed by the puncture tests *(Desmet et al., 2002; Hetzroni et al., 2011)*. Moreover, fruit firmness is commonly used for puncture test evaluation.

Therefore, contribution percentage of peel to apple fruit firmness could yield information on the evaluation quality and injury susceptibility of fruits; and the contribution percentage was calculated as:

$$Peel\ contribution\ percentage = \frac{Apple\ peel\ puncture\ strength}{Apple\ fruit\ puncture\ strength} \times 100 \quad (2)$$

Using the same probe diameter, apple peel puncture force to the whole fruit puncture force percentage at the same speed is shown in Fig. 6. As probe diameter increased, the contribution percentage of the peel kept a downward trend for the two cultivars; and contribution percentage of 0.1 mm/s loading speed reduced from 48.83% to 29.20% for Danxia peel, from 54.94% to 30.04% for Fuji peel, that of 1 mm/s loading speed reduced from 56.67% to 34.50% for Danxia peel, from 55.51% to 36.53% for Fuji peel, that of 5 mm/s loading speed reduced from 58.16% to 35.33% for Danxia peel, from 57.09% to 38.52% for Fuji peel, that of 11 mm/s loading speed reduced from 58.44% to 35.19% for Danxia peel, from 55.27% to 37.03% for Fuji peel, and that of 17 mm/s loading speed reduced from 59.36% to 35.91% for Danxia peel, from 57.58% to 35.71% for Fuji peel; and the contribution percentages of Danxia and Fuji peels were respectively reduced by an average of 39.57% and by an average of 36.61%.

Under the same probe diameter, at 0.1, 1 and 5 mm/s loading speeds, contribution percentages of peel increased constantly. The contribution percentage of 2 mm-diameter probe ranged from 48.83% to 58.16% for Danxia peel, from 54.94% to 57.09 % for Fuji peel, that of 3.5 mm-diameter probe ranged from 49.21% to 53.91% for Danxia peel, from 47.36% to 52.75% for Fuji peel, that of 7.9 mm-diameter probe ranged from 37.67% to 42.48% for Danxia peel, from 34.23% to 44.27% for Fuji peel, and that of 11 mm-diameter probe ranged from 29.20% to 35.33% for Danxia peel, from 30.04% to 38.52% for Fuji peel. Along with the increase of loading speed, the contribution percentages of Danxia and Fuji peels were respectively reduced by an average of 15.61% and by an average of 18.21%. But at 11 and 17 mm/s loading speed, the contribution percentages of peel did not change much in comparison with 5mm/s loading speed; and the average of change was no more than 2.77% for Danxia peels and 4.35% for Fuji peels.

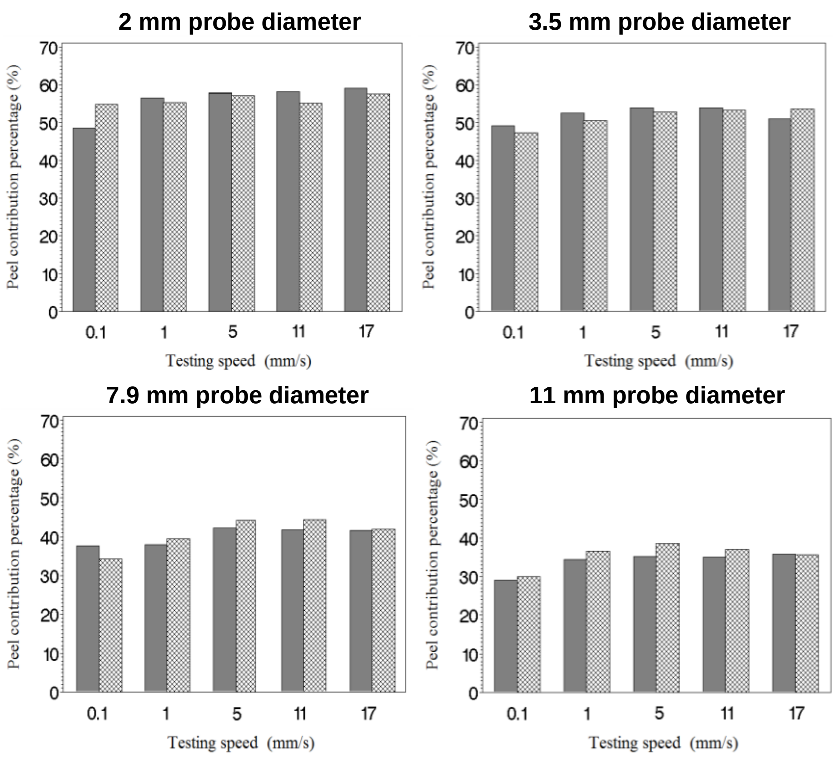


Fig. 6 - Peel contribution percentage to apple fruit firmness at different speeds

In Fig. 6, it shows that under 2, 3.5, 7.9 and 11 mm-diameter probes, the peel contribution percentage for two cultivars remained more than 48%, 47%, 34%, and 29% relatively, and as probe diameter increased, that of peel decreased gradually. These data suggest that peel texture had a lower influence on fruit firmness as probe diameter increased.

At 0.1, 1, 5, 11 and 17 mm/s loading speeds, the contribution percentage of peel remained more than 29%, 34%, 35%, 35%, and 36%, relatively for Danxia and Fuji cultivars and as loading speed increased, that largely remained the same. This result indicates that peel texture had a similar influence on fruit firmness as loading speed increased. Meanwhile, under the same probe diameter, the average of Fuji contribution percentage change was relatively big. This shows that the peel texture of Danxia cultivar had a greater effect on fruit firmness than that of Fuji cultivar and that the peel of Fuji cultivar was more prone to injury than that of Danxia cultivar. Based on whole-fruit test results, the puncture force of a whole Fuji fruit was the larger among the two cultivars. This reflects that cell adhesion of Fuji pulp was larger than that of the other kind of pulp and that Fuji pulp texture had more density than Danxia pulp texture.

Many studies show that the storage period of Fuji apples is longer *(Xiao et al., 2016; Wang et al., 2002)*, and that the character and microstructure of apple peel are closely related to fruit shelf life *(Deng et al., 1995; Liu et al., 2012)*. This also reflects that pulp texture is closely related to storage period of fruits.

CONCLUSIONS

This research evaluated the changes in apple peel and apple fruit puncture properties under different loading speeds and probe diameters. For the same variety, the mean values of peel puncture force and stiffness, and fruit puncture force increased as the probe diameters increased at the same loading speed, and significant difference ($P \le 0.05$) existed for those puncture parameters between the two probe diameters. With the same probe diameter, as loading speed increased, the above puncture parameters for each cultivar increased firstly then made a few changes and peel texture had a similar influence on fruit firmness. At the same loading speed, under any probe diameter, the Fuji peel and fruit samples had the greatest puncture force in the two varieties, while relating the peel puncture force and fruit firmness, Danxia peel textures had a greater effect on fruit firmness than Fuji. Peel texture had a lower influence on fruit firmness as probe diameter increased and peel puncture force had a significant linear correlation with probe diameter. Based on test results, Fuji cultivar was more likely to obtain injury, compared with Danxia cultivar, and Fuji pulp texture had more density than Danxia. At the same time, the puncture texture of apple peel affected variety difference and fruit maturity, therefore the influence of that will have a better research for the same cultivar of different maturity and different cultivars of same maturity.

ACKNOWLEDGEMENT

This research, titled 'RESERACH ON THE CONTRIBUTION RATIO OF APPLE PEEL PUNCTURE BEHAVIOUR TO FRUIT FIRMNESS', was funded by the National Natural Science Foundation of China (11802167), the applied basic research of Shanxi Province (201801D221297), the Doctor Scientific Research Foundation of Shanxi Agricultural University (2017YJ15) and the Excellent Doctor Scientific Research Foundation the Excellent Doctor Foundation of Work Reward for Shanxi Province (SXYBKY201754). The authors are grateful and honoured to have obtained support from the Key Laboratory of Biomechanics.

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