RESEARCH ON TEARING PROPERTY OF APPLE PEELS BASE ON MICROSTRUCTURE
/
基于微观结构的苹果果皮撕裂性能研究

Juxia Wang, Decong Zheng*), Qingliang Cui[1]
College of Engineering, Shanxi Agriculture University, Taigu/China
Tel: +86-0354-6289686; E-mail: zlsgxy_2018@163.com
DOI: 10.35633/INMATEH-58-24

Keywords: *apple, peel, tearing property, experiment, microstructure*

ABSTRACT

In order to research the relationship between macroscopic tearing properties and microstructure of peels, Fuji and Danxia peels were performed longitudinal and transverse tearing tests at the shadow side and sunlit side using electronic universal testing machine and the load-displacement curve, tearing force and tearing strength were gained. The peel cross-section microstructure and tearing fracture morphology of peel samples were observed by means of scanning electron microscopy. The results showed that the peel tearing curves were curves with many peaks and the fracture pattern of the tearing peel was the stripping between cells and a certain peak in the tearing curve was formed when the cells were stripped. The apple peel has composite film properties. Tearing strength has differences with different parts of the same peel and the same part of different peel. It is showed that crack shape and pattern of fruit cracking and fruit surface rupture had the character of variety. Tearing strength of Danxia peel was the biggest in two kinds of peels; the significant difference in tearing strength between shadow sides of Danxia peel and Fuji peels existed (p<0.05) and the tearing strength of Danxia longitudinal peel had significant differences (p<0.05) from Fuji longitudinal peel. This reflected that the flexibility of Danxia peel surface was greater and Fuji peel surface was easy to surface rupture injury in the process of fruit growth. Because the Fuji peel cuticle is more uniform and thicker, solid contact is strengthened and the slippage is lessened between epidermal cells; meanwhile, the number of concurrent loaded cells decreased. That results in minor tearing strength of Fuji peel and the apple surface rupture is closely related to cuticle structure of peel through the analysis of peel microstructure. The study provides quantitative evidence of evaluating peel ability of cracking fruit and fruit surface rupture and riches evaluation index of apple peel texture.

摘要

为探索微观组织与苹果果皮抵抗裂果及果面碎裂能力的关系，在微机控制的电子万能试验机上对红富士和丹霞向阳面和向阴面果皮的纵横向进行了撕裂试验，获得果皮撕裂载荷—位移曲线、撕裂力、撕裂强度；采用扫描电子显微镜观察果皮横截面及试样撕裂裂缝形态的显微结构。结果表明：果皮撕裂的载荷—位移曲线为多峰曲线，试样撕裂的破坏模式是以细胞间剥离为主，苹果果皮材料具有复合薄膜的属性；同种果皮不同部位的撕裂强度均不相同，反映出果实裂果及果面碎裂的开裂形状及方式具有多样性；不同品种果皮相同部位的撕裂强度均以丹霞的为最大，2 种果皮间的撕裂强度存在显著性差异（$p \le 0.05$），丹霞果皮的柔性较好，红富士果皮表面易于开裂；果实裂果及果皮碎裂的发生与果皮上角质层的结构密切相关，角质层均匀致密且较厚时，果实易于开裂。研究结果为苹果果皮抵抗裂果及果面碎裂能力的评价提供力学特性方面的参考依据，丰富苹果果皮质地的评价指标。

INTRODUCTION

As the biggest country of apple production in the world, China has abundant apple germplasm resources *(Sheng et al., 2015)*. The apple quality is closely related to the stress relaxation and creep property of the fruit *(Veringă et al., 2015; Wang et al., 2016; Veringă et al., 2018),* meanwhile the phenomena of apple cracking and apple surface cataclasm occur under the internal and external loads in the

---

[1] *Juxia Wang, As. Lec. Ph.D. Eng.; Decong Zheng, Prof. M.S. Eng.; Qingliang Cui, Prof. Ph.D. Eng.*

process of growth, which directly affects the appearance and quality of fruits, reduces the commodity performance, and thus causes huge economic losses to producers *(Ren et al., 2013)*. Tearing test has been widely used in the performance testing of coated fabrics, such as tents, hammocks, etc. *(Scelzo et al., 1994; Wan et al., 2011)*. As an important index to evaluate the quality of flexible materials, the tearing performance can reflect the durability of materials *(He et al., 2007)*. Apple peel is the outermost part of the fruit which plays a role of protection. Its tearing performance is of great significance to the analysis of apple surface cataclasm and peel cracking resistance. The cracking resistance of peels is closely related to their tissue structure and extensibility *(Gerschenson et al., 2011)*. In recent years, scholars at home and abroad have conducted a lot of research on fruit cracking and surface cataclasm of fruits and vegetables. The research results have clarified the mechanism of fruit cracking from the symptoms and time of fruit cracking occurrence, and the anatomic structure, physiology, biochemistry, water conditions, soil conditions, tree management of fruits *(Musel et al., 2001; Sun et al., 2015)*. Zhao et al. *(2015)* determined the thickness of the cuticle layer on Red Fuji apples to explore the occurrence mechanism of fruit cracking, and concluded that the thickness of the cuticle layer was positively correlated with the average width of cracks. Liu et al. *(2008)* discussed the relationship between the fruit surface cataclasm of red Fuji apples and the micro-environment temperature and humidity and found that the higher the temperature was, the lower the relative humidity was, the more serious the fruit surface cataclasm was. He and Xu *(1995)* studied the tissue structures of the shadow and light peels of Hongjiang orange fruits and found that the tissue structure of the peel directly affected its tensile strength and it was closely related to fruit cracking. Yang et al. *(2011)* explained that the mechanical properties of the peel directly affected the occurrence of fruit cracking. The research on the tearing properties and microstructures of apple peel is still rare at home and abroad. For this, the tearing properties and microstructure of apple peels were measured and observed in the paper to obtain the tearing characteristic indexes of the apple peels of different varieties and thus analyse the relationship between the macro tearing properties and microstructure of apple peel, so as to provide a reference for expressing the properties of composite films of peel materials and the quantitative basis for evaluating the ability of peels of different apple varieties to resist fruit cracking and fruit surface cataclasm.

MATERIALS AND METHODS

Apple variety

Test materials were ripe Red Fuji and Danxia apples picked from Fruit Tree Research Institute of Shanxi Academy of Agricultural Sciences in October 2017. In order to minimize the loss of moisture and other nutrients, the fruits were transported back to the laboratory on the day of harvest. Those with regular shape, no pests and no mechanical damage were selected and tested immediately.

Testing instrument

The material performance testing system (INSTRON-5544, USA) controlled by Instron Microcomputer was used to measure the tearing properties of apple peels. It can automatically collect and store test data, and dynamically display load and displacement measurements and related curves. The grating thickness gauge (JC010-1, China), with the measurement range of 0 to 10 mm and the measurement accuracy of 0.001 mm, was adopted to measure the thickness of apple peels.

Samples for tearing test

a. Peel sample *b. Structure specimen* *c. tearing test*

Fig. 1 - Peel tearing samples and tearing test

To obtain the difference of peel materials in tearing properties, samples were collected from the vertical (direction connecting the pedicle and calyx ends of fruits) and horizontal directions (parallel to the equatorial surface of the fruits) at room temperature. Fruit peels were removed from the apples with a knife blade, and placed on a smooth rubber pad, then the inner pulps were gently removed. The peel samples were observed with a magnifying glass to ensure no damage. After that, the peels were prepared into 30×15×t mm (t being the thickness of the peel samples) strip samples, as shown in Fig.1a. The samples for the longitudinal and transverse tests on the shadow and light of the peels were 6, respectively.

SEM sample observation

5 fruits were collected for each Red Fuji and Danxia apples. Their peels were sampled and then cut into appropriate segments for reserve. The samples were quickly put into 3% glutaraldehyde stationary solution (0.1 mol/L, pH=7.2 phosphate buffer). A vacuum pump was used to pump the solution to make the samples sink and then fixed for 2d at 0~4^{o}C. The samples were washed for 3 times with the same buffer solution, 15 minutes each time. Then, they were dehydrated by the series ethanol (30%, 50%, 70%, 80%, 90% and 95%) step by step, 20 minutes for each. After that, they were put in tert-butyl alcohol and JEOL JFD-320 frozen for drying. The dried materials were stuck to the sample table with conductive tape. Platinum was sprayed on them with JEOL JFC-1600 ion sputtering coating instrument. Finally, the sprayed materials were put under JEOL JEM-6490 LV SEM for morphological observation. The tearing samples of peels for SEM observation were prepared in the same process

Data analysis

GLM program in SAS (SAS Institute, Cary, NC, USA) was used to conduct the significance analysis on the tearing parameters of peels from different parts of the same variety of apples and from different varieties of apples.

RESULTS

Tearing performance test of peels

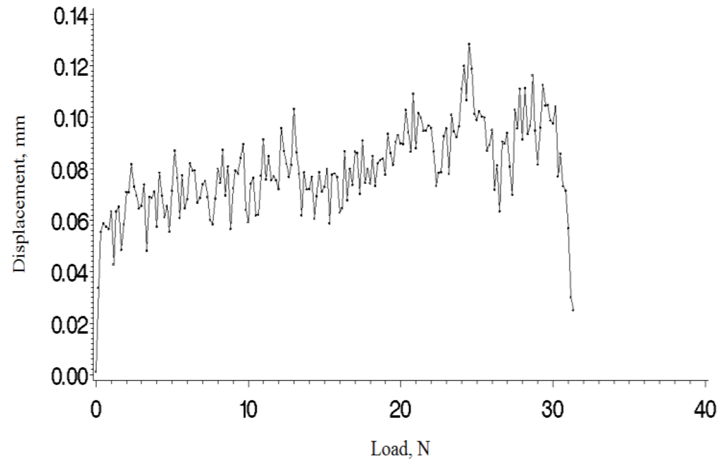


Fig. 2 - Force-deformation curve of apple peel tearing test

Principle of the Trouser Tear Method. The tearing performance of peel samples was tested by the trouser tear method, i.e. the uniaxial mid-slit method. By this method, the tearing crack length of each peel sample could be the same, so that the average tearing forces obtained by different peel samples from different varieties or the same variety of apples were comparable. Referring to Section 1 of GB/T 16578.1-2008 Tear Resistance Test of Plastic Films and Thin Sheets - Trouser Tear Method *(2008)*, a 15 mm long notch which was parallel to the length direction was cut in the centre of the sample width direction, as shown in Fig.1b. The edge of the cut specimen was ensured to be smooth without notches with a magnifying glass. In order to prevent moisture loss, the peel samples were immediately put on the fixture of test machine for test. Two trouser legs formed by the notches were stretched, as shown in Fig. 1c.

The notch line of the samples was straight between the upper and lower wedge fixtures. The test machine was started to apply the tension force to the notch direction until the samples were pulled apart. The loading speed of the tearing test was 20 mm/min and the speed remained unchanged throughout the test process.

Load-Displacement Curve of Peel Tearing. The load-displacement curves of peel tearing were shown in Fig. 2. According to the figure, the loads changed continuously when the samples were tearing, and the resulting tearing curve was a multi-peak curve, which was similar to the tearing curves of fabrics and Red Star apple peels under trouser tearing *(Wan et al., 2011; Wang et al., 2015)*. At the same time, it could be observed during the tearing test that the failure of the samples started from the notches on them and then extended linearly along the notches.

Table 1

Mean value and standard error of tearing property parameters of apple peels

parts	Sample number	Fuji peel			Danxia peel		
		Sample thickness [mm]	Tearing force [N]	Tearing strength [kNm^{-1}]	Sample thickness [mm]	Tearing force [N]	Tearing strength [kNm^{-1}]
sunlit longitudinal	1	0.210	0.0930	0.4430	0.177	0.0703	0.3979
	2	0.200	0.0674	0.3370	0.218	0.0787	0.3619
	3	0.190	0.0880	0.4631	0.180	0.0905	0.5029
	4	0.210	0.0737	0.3512	0.182	0.0765	0.4208
	5	0.205	0.0757	0.3691	0.210	0.1011	0.4814
	6	0.200	0.0674	0.3372	0.198	0.1315	0.6632
	Mean ± SD (	0.203±0.008	0.0775±0.0107	0.3834±0.0556	0.194±0.017	0.0914±0.0225	0.4714±0.1075
Sunlit transverse	1	0.195	0.0960	0.4924	0.218	0.0667	0.3067
	2	0.198	0.0945	0.4764	0.218	0.1018	0.4683
	3	0.218	0.0953	0.4379	0.168	0.0853	0.5095
	4	0.192	0.0850	0.4435	0.190	0.0801	0.4215
	5	0.190	0.0824	0.4335	0.200	0.1127	0.5637
	6	0.205	0.0467	0.2276	0.200	0.0743	0.3715
	Mean ± SD	0.200±0.008	0.0833±0.0188	0.4186±0.0964	0.199±0.019	0.0868±0.0174	0.4402±0.0935
Shadow longitudinal	1	0.208	0.0918	0.4408	0.185	0.0920	0.4972
	2	0.190	0.0825	0.4344	0.218	0.0871	0.4002
	3	0.212	0.0788	0.3722	0.208	0.1153	0.5535
	4	0.207	0.0737	0.3564	0.177	0.1001	0.5668
	5	0.210	0.0725	0.3454	0.212	0.1248	0.5894
	6	0.190	0.0565	0.2973	0.198	0.0615	0.3100
	Mean ± SD	0.203±0.010	0.0760±0.0118	0.3744±0.0550	0.200±0.016	0.0968±0.0224	0.4862±0.1098
Shadow transverse	1	0.200	0.1224	0.6118	0.165	0.0840	0.5092
	2	0.193	0.0861	0.4453	0.218	0.0823	0.3783
	3	0.200	0.0741	0.3706	0.212	0.1033	0.4880
	4	0.212	0.0835	0.3944	0.183	0.0936	0.5108
	5	0.200	0.0738	0.3692	0.202	0.1166	0.5783
	6	0.217	0.0737	0.3402	0.208	0.1254	0.6017
	Mean ± SD	0.204±0.009	0.0856±0.0188	0.4219±0.0994	0.198±0.020	1.009±0.0175	0.5111±0.0786

In order to obtain the tearing strength, referring to Section 2 of GB/T 3917.2-2009 fabric tearing performance: determination of tearing strength of trouser samples (single seam) *(2009)*, the tearing curve was divided into four regions on average from the first peak to the last peak. Two peaks and two lowest peaks were marked in each 2nd, 3rd, and 4th regions (a total of 12 peaks). The average load of these 12 peaks was regarded as the tearing force of the sample. The tearing strength of the sample along the long axis was as follows:

$$T = \frac{F}{d} \tag{1}$$

where: F is the tearing force of the sample, [N];

d is the original thickness of the sample, [mm].

The tearing strength of the peel could be obtained by using the tearing data and Formula (1). The thicknesses, tearing forces and tearing strengths of peels were shown in Table 1.

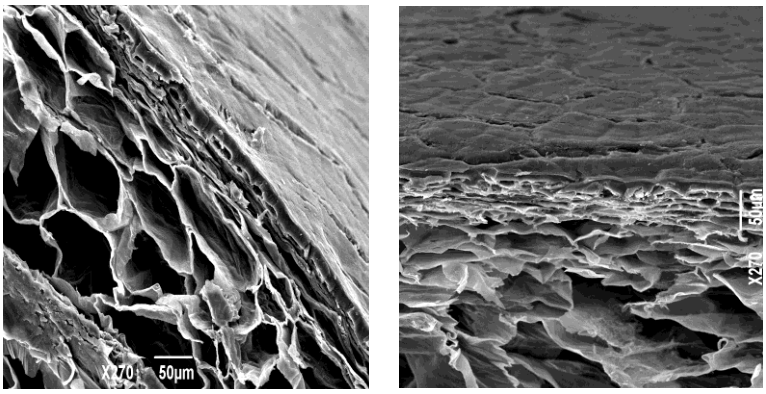
Analysis of the tearing performance of peels

According to Table 1, the tearing strengths of different parts of the same peel were different. For Red Fuji apple peels, the average transverse tearing strength was greater than the longitudinal tearing strength, and that in the light was greater than in the shadow; for Danxia apple peels, the tearing strength in the shadow was greater than that in the light, and the transverse tearing strength was similar to the longitudinal tearing strength. It reflected that the shape and mode of fruit cracking and fruit surface cataclasm were diverse. An independent-samples t-test was conducted on the tearing strengths of different parts of the same peel, and 95% confidence interval was adopted. Results showed that the tearing strengths of different parts of the same peel were not significant. The average tearing strengths of Danxia and Fuji apple peels were 0.4772 kN/m and 0.4000 kN/m, respectively. Significant difference existed between the tearing strengths of two varieties of apple peels (p<0.05). The tearing strengths of Danxia apple peels were largest in the comparison of the peels in the same part of different varieties of apples. The tearing strengths of Danxia apple peels in the shadow and the longitudinal direction were significantly different from those of Red Fuji apple peels in the same parts (p<0.05). The differences in other parts were not significant. The above analysis showed that Danxia apple peel was more flexible than Red Fuji apple peel and its ability to resist fruit cracking and surface cataclasm was stronger.

It could also be known from Table 1 that the ratio of the standard deviation to the mean of tearing strengths of the peels from different parts of Red Fuji and Danxia apples ranged from 14.50% to 23.56% and from 15.38% to 22.58%, respectively, which reflected that the physiological activities of the apple peel continued during harvest as the outermost tissue of the fruit, and there were differences in the tissue structure of the peel samples of the same variety and of different varieties, leading to the high dispersion degree of its tearing performance parameters.

Microstructure analysis of peels

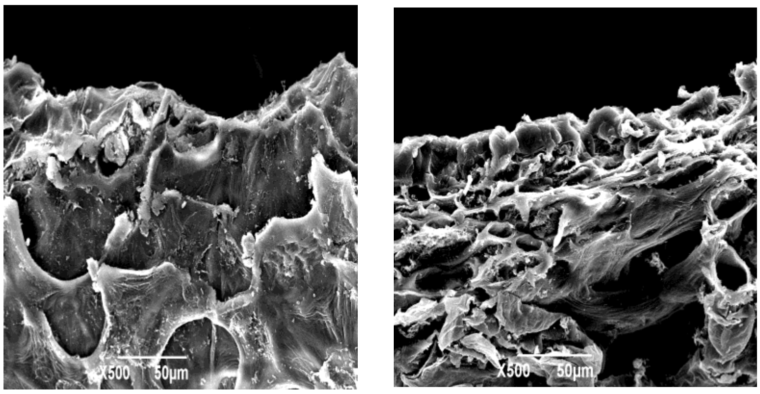
Cross-sectional Microstructures of Peels. Fruits are protected by their peels which were the outermost tissue structure. Their macro-mechanical characteristics are closely related to the microstructure *(Hou, et al., 2016; Cai et al., 2019)*. Fig. 3 presents the cross-sectional structures of Red Fuji and Danxia apple peels. According to the figure, the apple peel was a layered composite material which was composed of cuticle, epidermal cells and subcortical cells *(Zamorskyi, et al., 2007)*. The cuticle layer on Red Fuji apple peel was uniform in texture, the epidermal cells were neatly and compactly arranged in long strips. The cuticle layer on Danxia apple peel was uneven, with deep V-shaped depression, and the epidermal cells are loosely arranged in round or elliptic form. After analysis, the reason why the tearing strength of Danxia apple peel was greater than that of Red Fuji apple peel was that the cuticle layer on the surface of Red Fuji apple peel was thicker and more uniform and dense, which enhanced the fixed junction between epidermal cells, and reduced the relative slip between cells. As a result, fewer cells were under the tearing force at the tearing part when the peel was torn, so the tearing strength of the peel was small. The cuticle layer on the surface of Danxia apple peel had many V-shaped depressions which were deep below epidermal cells, so there were large gaps between cells, and the relative slip was large. Thus, more cells were under the tearing force when the peel was torn. In addition, the cells were round or elliptic, and their ability to resist deformation was stronger than that of long strip cells, so the tearing strength was large. From the above analysis, the fact that Red Fuji apples easily suffer fruit cracking and fruit surface cataclasm is closely related to the structure of the upper cuticle layer of the peel.



a. Fuji b. Danxia

Fig. 3 - The Cross-section microstructure of apple peels

Morphological Microstructure of Tearing Cracks of Peel Samples. The morphological scanning microstructures of tearing cracks of apple peels were shown in Fig. 4. According to the figure, parts of the cuticles were pulled out and stripped at both ends of the tearing cracks. At the same time, it could be known from Table 1 that the tearing force of the peel was far less than the tensile load on it *(Wang, et al., 2017)*. Thus, the damage mode of peeling between cells caused by the crack extension at the notch mainly occurred during peel tearing, which reflected that the peel materials of apples had the property of composite film. Under such a damage mode, the load-displacement curve of peel tearing presented a multi-peak curve. In other words, when the peel sample began to receive the trouser tearing, the cracks at the upper and lower notches of two trouser legs were torn first as the places with concentrated stress. Despite the medium between cells to realize the relative slip, the surface of the peel was covered by the non-flowing cuticle, which made the epidermal cells locked by the cuticle and resulted in the smaller relative sliding between cells. When the stressed cells were gradually peeled up and down, the maximum of a tearing load in the tearing curve was obtained. The load on the cells which were not peeled in the tearing process due to tensile deformation formed the minimum of the tearing load in the curve.



a. Fuji b. Danxia

Fig. 4 - Tearing fracture morphology of apple peels

CONCLUSIONS

Tearing tests were conducted to investigate *peel resistance ability of cracking fruit and fruit surface rupture.* This research revealed the difference in flexibility of different apple peels and *the relationship between macroscopic tearing properties and microstructure of peels and provided quantitative evidence of evaluating peel ability of cracking fruit and fruit surface rupture and rich evaluation index of apple peel texture.* The main conclusions of this study are as follows.

(1) The load-displacement curves of peel tearing of Danxia and Red Fuji apples were multi-peak curves. The damage mode of peel tearing was mainly peeling between cells. The apple peel materials had the properties of composite film.

(2) The tearing strengths of different parts of the same peel and the same part of different varieties of peels were different. The tearing strength of Red Fuji apple peel in the light was greater than that in the shadow, and that in the transverse direction was greater than that in the longitudinal direction. The tearing strength of Danxia apple peel had little difference between the transverse and the longitudinal directions, but the tearing strength in the shadow was greater than that in the light, which reflected the diversity of the cracking shape and mode on fruit cracking and fruit surface cataclasm.

(3) Danxia apple peel had the largest average tearing strength among those of different varieties at the same part. The tearing strengths of Danxia apple peels in the light and shadow had significant difference compared with those of Red Fuji apple peels at the same part (p<0.05). Thus, Danxia apple peel had better flexibility than Red Fuji apple peel, and Red Fuji apple peel was more prone to fruit cracking and fruit surface cataclasm in the growth process.

(4) Apple fruit cracking and fruit surface cataclasm were closely related to the structure of the apple peel upper cuticle. The cuticle layer on the apple peel surface was uniform, dense and thick, which enhanced the fixed junction between epidermal cells. As a result, the tearing strength of the peel was small and the fruit was prone to cracking. It provided a reference for establishing the relationship between the macro-mechanical properties and the microstructure of the peel.

ACKNOWLEDGEMENT

This research, titled 'Research on tearing property of apple peels base on microstructure', 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.

REFERENCES

[1] Cai J.R., (2019), Three-dimensional imaging of morphological changes of potato slices during drying. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 35, Issue 1, pp. 278－284, Beijing/P.R.C.;

[2] GB/T 3917.2-2009 *Textile Fabric–Tearing Performance–Part 2: Breeches Sample (Single Slit) Determination of the Tear Strength*, Standardization Administration of China, Beijing/P.R.C.;

[3] GB/T 16578.1-2008 *Plastics–Film and Sheeting–Determination of Tear Resistance–Part 1: Trouser Tear method*, Standardization Administration of China, Beijing/P.R.C.;

[4] Gerschenson L., (2001), Effects of processing on kiwi fruit dynamic rheological behaviour and tissue structure. *Food Research International*, Vol. 2001, Issue 34, pp. 1－6, Ed. Elsevier, London/ England;

[5] He Q., (2007), Tearing and Peeing Performances of Calendered Flexible Composites Reinforced with Weaving Fabrics. *Journal of Donghua University (Nature Science)*, Vol. 33, Issue 1, pp.130-134, Shanghai/P.R.C.;

[6] Hou J.M., (2016), Analysis of microstructure and macrotextures for different apple cultivars based on parenchyma morphology. *Microscopy Research and Technique*, Vol. 79, Issue 4, pp.304－312, Hoboken/U.S.A.;

[7] Liu W.F., (2008), Study on the relationship among microenvironment temperature and humidity and the apple fruit skin micro-breakage. *Journal of Fruit Science*, Vol. 25, Issue 4, pp.458-461, Zhengzhou/P.R.C.;

[8] Ren G.H., (2013), Advances on Fruit Cracking and Prevention Measures of Some Important Fruit Trees. *Plant Physiology Journal*, Vol. 49, Issue 4, pp. 324-330, Shanghai/P.R.C.;

[9] Scelzo W.A., (1994), Mechanistic role of yam and fabric structure in determining tear resistance of woven cloth. Part I：Understanding tongue tear. *Textile Research Journal*, Vol. 64, Issue 6, pp. 291-304, London/England;

[10] Sheng J.P., (2015), Issues on Quality Safety and Strategy of Apple and Its Processing Products. *Journal of Food Science and Technology*, Vol. 33, Issue 4, pp. 11-15, Beijing/P.R.C.;

[11] Silverio G.L., (2004), The role of pericarp cell wall component in maize weevil resistance. *Corp Science*, Vol. 44, Issue 5, pp.1546-1552, Madison/U.S.A.;

[12] Sun Y., (2015), Development of Epidermal Structure and Its Relationship with Cracks in Bagged 'Red Fuji' Apples. *Northern Horticulture*, Vol. 2015, Issue 17, pp.5-10, Haerbin/P.R.C.;
[13] Veringă D., (2015), Determination of the Relaxation Time at Static Compression of Idared Apples Variety. *INMATEH-Agricultural Engineering*, Vol. 47, Issue 3, pp. 75-80, Bucharest/Romania;
[14] Veringă D., (2018), Determination of the Relaxation Period at Static Compression of Golden Delicios Apples Variety. *INMATEH-Agricultural Engineering*, Vol. 48, Issue 1, pp. 61-66, Bucharest/Romania;
[15] Wan Z.M., (2011), Research on Tensile and Tearing Properties of Vectran Fabric Composites. *Spacecraft Recovery and Remote Sensing*, Vol. 32, Issue 4, pp. 75-81, Beijing/P.R.C.;
[16] Wang J.X., (2016), Evaluation on peels texture of different apple cultivars based on rheological properties. *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 32, Issue 21, pp. 305-314, Beijing/P.R.C.;
[17] Wang J.X., (2015), Experimental Research on Mechanical Properties of Apple Peels. *Journal of Engineering and Technology Science*, Vol. 47, Issue 6, pp.688-705, Bandung / Indonesia;
[18] Wang J.X., (2017), Mechanical Properties and Microstructure of Apple Peels during Storage. *International Journal of Food Properties*, Vol. 2017, Issue 20, pp. 1159-1173, Philadelphia/U.S.A.;
[19] Yang W.H., (2011), An Overview of the Roles of Cell Wall Modification in Fruit Pericarp Cracking. *Chinese Journal of Tropical Crops*, Vol. 32, Issue 10, pp.1995-1999, Hainan/P.R.C.;
[20] Zamorskyi V., (2007), The role of the anatomical structure of apple fruits as fresh cut produce. *Acta Horticulturae*, Vol. 2007, Issue 746, pp. 509－512, Beijing/P.R.C., Leuven/Belgium;
[21] Zhao D., (2015), Study on the Mechanism of 'Fuji' Apple Flesh Cracking. *Northern Horticulture*, Vol. 2015, Issue 17, pp.15-21, Haerbin / P.R.C.;
[22] Zhou H.Q., (1995). Studies on the Relation between Peel Anatomical Structure and Fruit-cracking in Hongjiang Sweet Orange. *Journal of South China Agriculture University*, Vol. 16, Issue 1, pp.90-96, Guangzhou / P.R.C.