STUDY ON THE INFLUENCE OF MOISTURE CONTENT AND COMPRESSION RESISTANCE CHARACTERISTICS OF CORN GRAIN ON THRESHED BREAKAGE RATE /

玉米籽粒含水率及抗压特性对脱粒破碎率的影响研究

Yinping ZHANG[1)], Zehua HAO[1)], Lihang JIAO[1)], Qinghua LUAN[*2)], Hua ZHOU[*1)], Meizhou CHEN[1)]
[1)]School of Agricultural and Food Science, Shandong University of Technology, Zibo (255000), China;
[2)]Agricultural machinery business service center of Zichuan, Zibo (255100), China.

DOI: https://doi.org/10.35633/inmateh-71-49

Keywords: *corn, moisture content, compression resistance characteristics, breakage rate, mechanical grain harvesting*

ABSTRACT

High breakage rate is the bottleneck that restricts corn grain mechanical harvesting in double-cropping area in China. The moisture content and compression resistance characteristics of corn grain have important effects on the breakage rate at threshing. In this paper, 5 corn varieties planted in double cropping area were selected and the effects of grain moisture content and compression resistance characteristics on threshed breakage rate were studied. Results showed that both the grains moisture content and the compression resistance characteristics had effects on the threshed breakage rate. The lower the moisture content, the greater the force required for breakage, and the more difficult it was to break. Meanwhile the breakage rate was also related to the displacement during pressing. The smaller the displacement, the lower the breakage rate, but if the displacement was too small, the corn was a silty variety and the breakage rate was still high. When the moisture content was 33%±1%, the threshing verification test showed that the average breakage rate of DH605, LY296 and KN21 was 5.39%, 5.02% and 7.13%, respectively, which was not suitable for grain mechanical harvesting under high moisture content (moisture content higher than 30%). However, the average breakage rate of LK868 and LD6018 was 4.76% and 4.25% respectively, which was suitable for grain mechanical harvesting under high moisture content. This research could provide a reference for corn varieties selection suitable for mechanical kernel harvesting in double cropping area.

摘要

脱粒破碎高是制约中国两熟区玉米机械粒收的瓶颈，玉米籽粒的含水率及抗压特性对脱粒破碎率有重要影响。本研究选取两熟区种植较多的5 个夏玉米品种，研究籽粒含水率及抗压特性对脱粒破碎率的影响。结果表明，籽粒含水率及抗压特性均对脱粒破碎率产生影响，籽粒含水率越低，破碎时所需的力越大，越不易破碎;同时破碎率也与破碎时的位移有关，位移越稳定，破碎率越低，但位移太小时，玉米可能为粉质品种，破碎率仍较高。在含水率为33%±1%时，进行脱粒验证试验，得到DH605、LY296 和KN21 的平均破碎率分别为5.39%、5.02%和7.13%，不适宜高含水率（含水率大于30%）机械粒收；LK868 与LD6018 的平均破碎率分别为4.76%和4.25%，适宜高含水率机械粒收。本研究为两熟区筛选适宜机械粒收的玉米品种提供了参考。

INTRODUCTION

Corn is one of the main food crops in the world. With the large-scale circulation of land and the reduction of rural labor force, corn mechanical harvesting is an effective way to reduce labor intensity and improve harvesting efficiency (*Liu et al, 2013; Wang et al., 2021*). At present, the high breakage rate in mechanical harvesting in China's double-cropping area has become a bottleneck that restricts grain mechanical harvesting (*Wang et al, 2017*). It is of great significance to research the influence of moisture content and compression resistance characteristics on the breakage rate at threshing, select varieties suitable for grain mechanical harvesting, and reduce the breakage rate at threshing during harvest, which will promote the mechanization process of corn production and ensure food security.

Scholars had done more research on corn grains moisture content at harvest. *Zhang Wanxu et al.* (*2018a; 2018b*) found that moisture content had a significant effect on grain breakage rate, and the difference was significant among different varieties. *Waelti (1967)* studied the response of grain crushing rate of different varieties to the change of drum speed in the range of grain moisture content between 20% and 31%, and found that the water content with the lowest crushing rate was different in different varieties during mechanical harvest.

Brass (1970) believed that when the grain water content was higher, the grain crushing rate increased rapidly with the increase of the roller speed. *Plett (1994)* found that the breakage rate was the lowest when the moisture content was 16.70% ~ 22.10%.

According to *Hall et al., (1970)*, the yield breakage rate was the lowest when the grain water content was 20%-23%. *Chowdhury et al. (1978),* believed that the mechanical damage rate was the lowest when the moisture content was 23%. *Li Lulu et al., (2017)* pointed out that when the moisture content was lower than 26.92%, the grain breakage rate was less than 8%. *Kang Yunyou et al., (2019),* found that the breakage rate was less than 5% when the moisture content did not exceed 25%. Using the fitting equation, *Chai Zongwen et al. (2017)* predicted that the breakage rate was less than 5% when the grain moisture content was about 19%. *Dutta, (1986),* believed that the rate of harvesting machinery damage increased sharply when the grain moisture content exceeded 20%. It is generally believed that high moisture content was the main factor to grain breakage, but there was few researches on the effect of grain compression resistance characteristics on breakage rate.

In this paper, the moisture content and compression resistance characteristics of different corn varieties were studied, and the effects of moisture content and compression resistance characteristics on the breakage rate at threshing were analyzed. The results could provide reference for the selection of varieties suitable for corn grain mechanical harvesting.

MATERIALS AND METHODS

Test materials

Five corn varieties, Denghai 605(DH605), Liyuan 296(LY296), Laike 868(LK868), Ludan 6018(LD6018) and Kono 21(KN21), were picked from Yueyang Agricultural Cooperative of Taian City, Shandong Province (117°E, 36°N), and different varieties were sown in one day.

Test methods

(1) Moisture content measurement

The sampling started from the disappearance of milk line of kernel on September 29. Samples were taken at 5:00 PM in 10 consecutive days, with 15 ears picked each time and kept in sealed storage. During the test, proper number of grains were hand-threshed and weighed in an aluminum box and recorded as wet weight WS. After weighing, the grains were dried at 105℃±3℃ for 480 min. After taking out the sample, the grains were weighed and recorded, and then continued to be dried for 60 min. If the difference in drying quality between the two times before and after is less than 0.02 g, recorded as dry weight Wg. The grains moisture content was calculated as Hy=(WS-WG)/ WS×100%.

(2) Determination of compression resistance characteristics

To measure the compression resistance characteristics, 10 corn grains were randomly selected from the hand-threshed grains. The breakage was mainly because by the threshing elements which stroke on the top of grains (*Zhang et al, 2012; Zhang et al, 2015*). As shown in Figure 1, a universal testing machine was used to press the top of the grain (*Yang et al, 2008*) and the grains was placed in the center of the compression fixture plate.

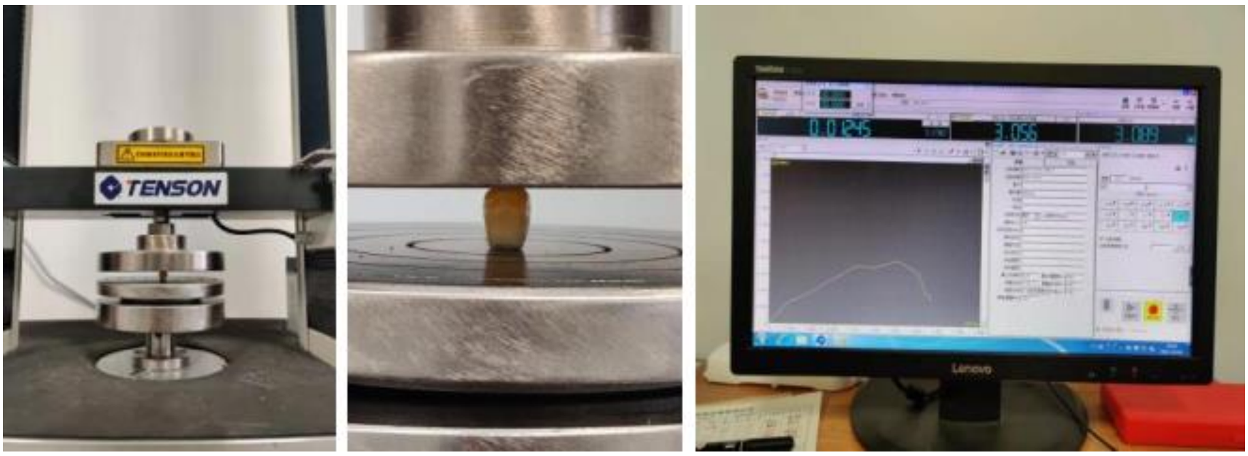


Fig. 1 - Test of grain compression resistance characteristics

The initial rise speed of the beam was set at 12 mm/min, and the clearing contact force was set at 5 N, that is, the upper beam touched the corn kernel. After the contact force with the grain exceeded 5 N, the universal testing machine entered the compression test state. After that, the rising speed of the test beam was set at 4 mm/min. The computer recorded the "force-displacement" curve of the compression test and stored the data. When the compression force reached 75% of the maximum breaking compression force, the beam stopped moving and the test ended.

Data Processing

Microsoft Excel 2016 was use for data analysis and processing.

RESULTS AND ANALYSIS

Figure 2 shows the change curve of grain moisture content of different corn varieties over time. Generally, the moisture content of different corn varieties at the beginning of physiological maturity was 41%-43%, the difference was not significant, and then all showed a downward trend. Comparing the changes of moisture content of different varieties of corn grains after entering the physiological maturity stage, it could be seen that the moisture content of LY296 and LD6018 decreased rapidly in the early stage and dropped below 36% on the third day after physiological maturity, while the moisture content of DH605, LY296 and KN21 decreased slowly in the early stage, and was still 36% to 40% on the third day. The moisture content exceeds 30% was high moisture content, LY296 was reduced to below 30% on the 7th day, LD6018 and LK868 was reduced to below 30% on the 8th day, and DH605 and KN21 was still above 30% on the 10th day. Therefore, it was preliminarily determined that DH605 and KN21 was in slow dehydration speed and were not suitable for grain mechanical harvesting.

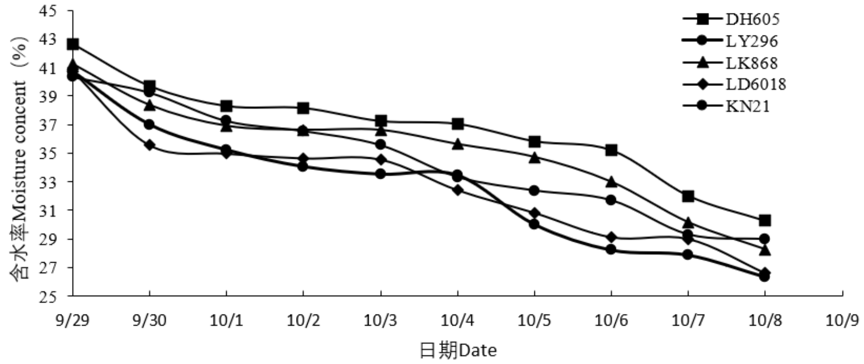
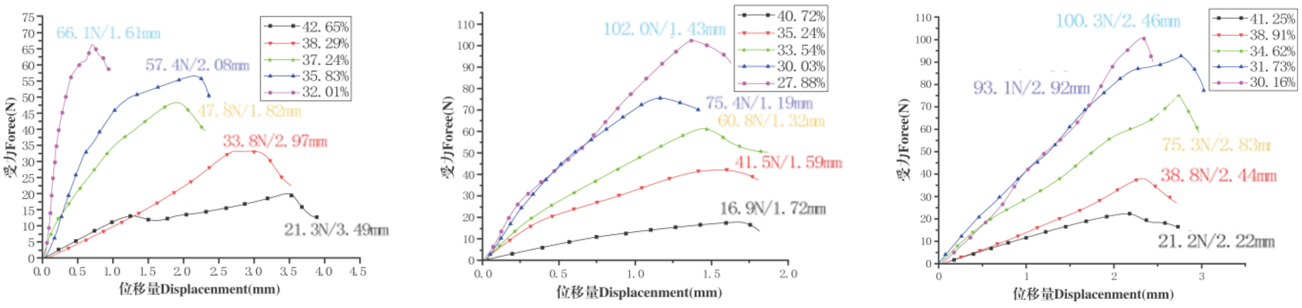


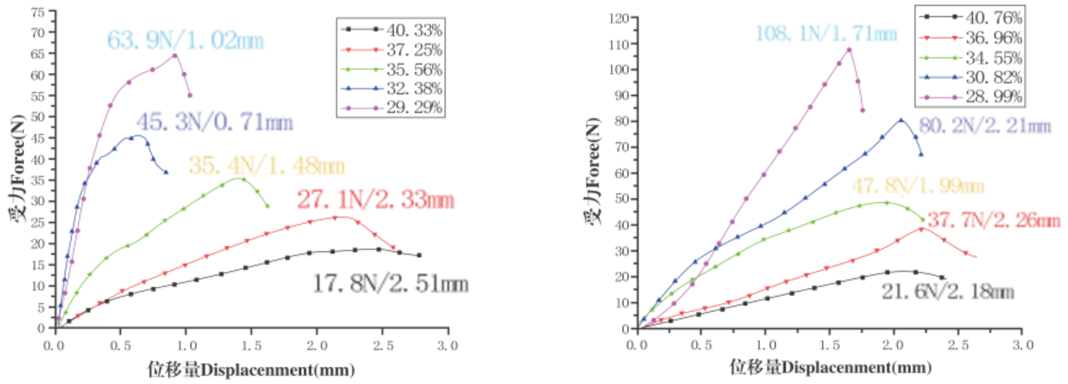
Fig. 2 - Curve of moisture content with time

Displacement and deformation would occur after compression (*Volkovas et al, 2006; Babiic et al, 2013; Mohamed et al., 2019; Zhang et al, 2012*), the maximum force and displacement deformation values when grains breakage reflected the compression resistance characteristics of corn grains.

Figure 3 showed the force and deformation of corn grains in the process of the grains being compressed. Abrupt change points appear in the curve and the compression drops abruptly, indicating that the grain was broken at this time, the horizontal coordinate of the mutation point represented the maximum displacement at grains breakage and the ordinate indicated the maximum compression on the grain when it was broken.



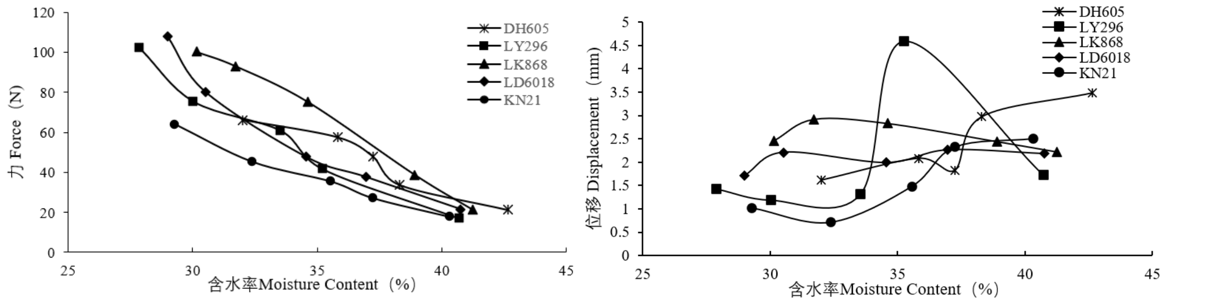
DH605 LY296 LK868



LD6018 KN21

Fig. 3 – Change curve of compression resistance characteristics of different varieties under different moisture content

Figure 4 shows the relationship between force and displacement of grain breakage and moisture content. According to Figure 4 (a), the force of the five varieties were increased with the decrease of moisture content, indicating that the lower the moisture content, the greater the force required for grain breakage and the more difficult it was to break. Comparing the breakage forces of different varieties with the same moisture content, it could be seen that when the moisture content exceeded 35%, the maximum force of the five varieties was small, indicating that the grain mechanical harvesting was not suitable. When the moisture content was 30% ~ 35%, the force of LK868 was much greater than of the other four varieties, which indicates that LK868 was suitable for grain mechanical harvesting when the moisture content was 30 ~ 35%. When the moisture content was 30% ~ 32%, the force of LY296 and LD6018 was greater than of DH605 and KN21, and there was a large upward trend, indicating that LY296 and LD6018 can perform grain mechanical harvesting when the moisture content was 30% ~ 32%, while DH605 and KN21 were not suitable for grain mechanical harvesting when the moisture content exceeded 30%. It was generally believed that the corn varieties that could have the grains harvested when the moisture content exceeded 30% were varieties suitable for grain mechanical harvesting (*Wang, 2016; Zhao et al, 2019*), but it can be seen that DH605 and KN21 were not suitable for grain mechanical harvesting.



(a) The relationship between force and moisture content (b) The relationship between displacement and moisture content

Fig. 4 - Relationship between grain compression resistance characteristics and moisture content

FIG. 3 and FIG. 4 (b) showed that with the decrease of moisture content, the displacements of the broken grains of the five varieties was in decreasing trend overall, indicating that with the decrease of moisture content, corn grains became compact. Under different moisture content conditions, the displacements during the breakage of LK868 (was between 2 ~ 3 mm) and LD6018 (was between 1 ~ 2 mm) were in small change range, and moisture content had no significant effect on the displacement of LK868 and LD6018 which indicated that the displacement of LK868 and LD6018 grains during breakage were not affected by moisture content. While DH605 (was between 1.5 ~ 3.5 mm), LY296 (was between 1 ~ 3.5 mm), and KN21 (was between 0.5 ~ 2.5 mm) were in a larger change range, and moisture content had significant effect on them. That indicated LK868 and LD6018 were stable and suitable for grain mechanical harvesting. As mentioned in the previous analysis, LY296 and LD6018 could be grain mechanical harvesting when the moisture content was 30% ~ 32%, but the maximum displacement of LY296 can withstand in this moisture content condition was small, only about 1mm, indicating that LY296 was a silty variety, easy to break, so that even if the moisture content met the requirements, it still couldn't for grain mechanical harvesting.

Based on the analysis of the force and displacement of different corn varieties, it could be preliminarily determined that DH605, LY296 and KN21 were not suitable for grain mechanical harvesting, LK868 and LD6018 were suitable, and LK868 could be harvested under the condition of the moisture content of 30% ~ 35%, LD6018 could be harvested under the condition of the moisture content of 30% ~ 32%.

Bench experiments

The results of laboratory experiment showed that the moisture content alone couldn't determine whether a corn variety was suitable for grain mechanical harvesting, and the compression resistance characteristics of the variety should be considered at the same time. In order to verify the influence of grains compression resistance characteristics on the breakage rate, the threshing bench experiment was carried on with a moisture content of 33%±1%. The threshing equipment shown in FIG 5 was self-made as in the paper of *Wang et al. (2020)*. Before the test started, the clearance of the concave plate was adjusted to 40 mm and the rotating speed of the drum to 400 r/min, and after the roller run stable, the corn ear was put into the ear elevator according to the variety and it was sent into the feeding inlet. When all the grains fell from the concave screen, the threshing device was turned off and the grains were collected. The test was repeated three times, the average breakage rate of corn grains was obtained, and the results were statistically analyzed.

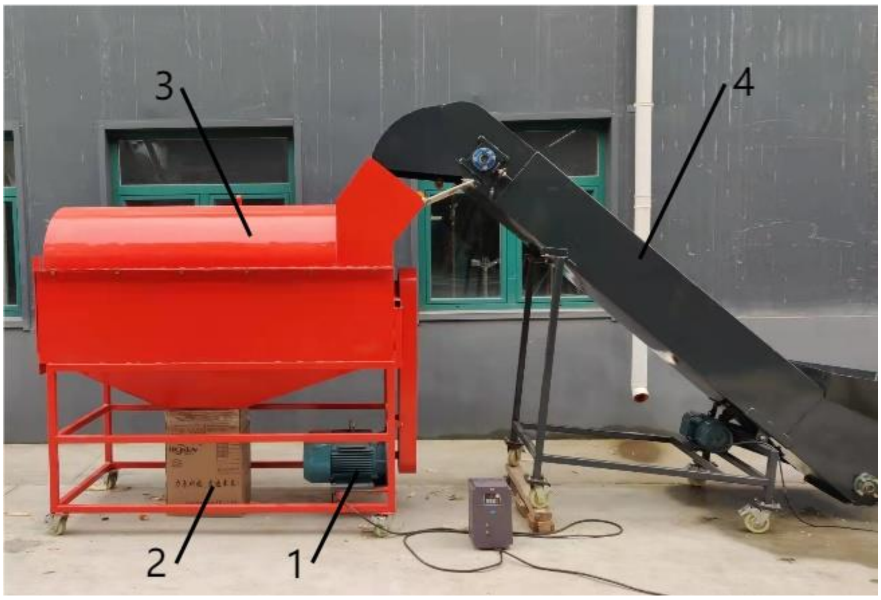


Fig. 5 - Threshing test site

1. Electrical machinery; 2. Grain collection box; 3. Corn threshing device; 4.Ear elevator

After the end of each group of experiments, all the collected grains were weighed, and the corn grains with visible cracks or broken skins were manually picked out and weighed too. Then the breakage rate was calculated. The grains after threshing were shown in Figure 6, and the results were shown in Table 1.

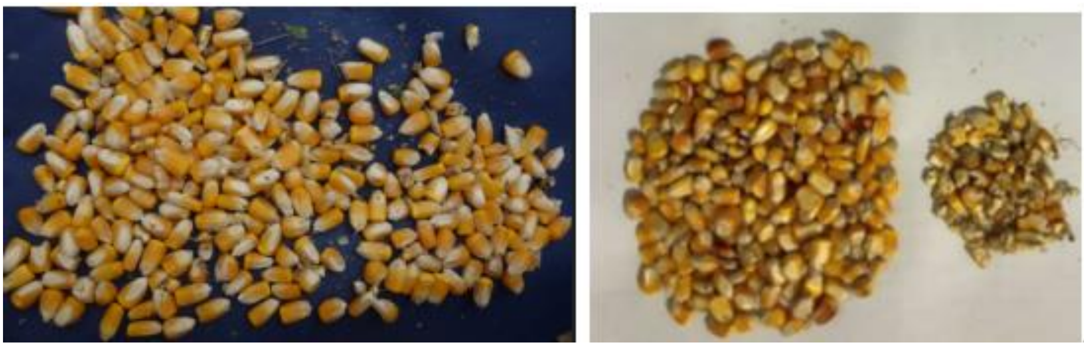


Fig. 6 - Threshing test results

Table 1

Grain breaking rate of different varieties

Corn varieties	DH605	LY296	LK868	LD6018	KN21
Breakage rates %	5.91	5.16	5.17	4.17	6.41
	5.02	4.98	4.31	3.96	7.74
	5.24	4.92	4.80	4.62	7.24
Average breakage rates%	5.39	5.02	4.76	4.25	7.13

As can be seen from Table 1, when the moisture content was 33%±1%, the average breakage rates of DH605, LY296 and KN21 were 5.39%, 5.02% and 7.13%, and 4.76% and 4.25% of LK868 and LD6018, respectively. According to "Agricultural Machinery Test Conditions", the breakage rate of grain mechanical harvesting was required to be less than 5%, indicating that DH605, LY296 and KN21 were not suitable for grain mechanical harvesting when the moisture content was 33%±1%, while LK868 and LD6018 were suitable. This is consistent with the previous analysis results.

CONCLUSIONS

(1) By analyzing the influence of grain compression resistance characteristics on the threshing breakage rate of five corn varieties with different moisture content, it was found that the force that the grain could withstand during compressing was negatively correlated with the moisture content. The lower the moisture content, the greater the force that the grain could withstand and the more difficult it was to break. The maximum displacement was not related to the moisture content, but mainly to the variety.

(2) The analysis of water content and compression resistance characteristics and threshing test showed that DH605, LY296 and KN21 had high average grain breakage rate and were not suitable for grain mechanical harvesting, while LK868 and LD6018 were suitable with low average grain breakage rate. This research provides a reference for the corn varieties selection of grain mechanical harvesting.

ACKNOWLEDGEMENTS

This work was supported by the Major agricultural technology in Shandong Province (No. SDNYXTTG-2023-01) and the Modern Agricultural Industrial System of Shandong Province (SDAIT-02-12).

REFERENCE

[1] Babić L.J., Radojèin M., Pavkov I. et al., (2013). Physical properties and compression loading behaviour of corn seed [J]. *International Agrophysics*, Vol. 27(2), pp.119－126. Poland.

[2] Brass R W. (1970). *Development of a low damage corn shelling cylinder* [D]. Ames: Iowa State University.

[3] Chai Zongwen, Wang Keru, Guo Yinqiao, et al., (2017). Current status of maize mechanical grain harvesting and its relationship with grain moisture content (玉米机械粒收质量现状及其与含水率的关系). *Scientia Agricultura Sinica*, Vol. 50(11), pp.2036-2043. Beijing/China.

[4] Chowdhury M.H., Buchele W. F. (1978). The nature of corn kernel damage inflicted in the shelling crescent of grain combines[J]. *International Journal for Engineering Modelling*, 21(4):610－614. Austria.

[5] Dutta P K. (1986). *Effects of grain moisture, drying methods, and variety on breakage susceptibility of shelled corns as measured by the Wisconsin Breakage* Tester[D]. Ames: Iowa State University.

[6] Gao Lianxing, Li Fei, Zhang Xinwei et al., (2011). Mechanism of moisture content affect on corn seed threshing (含水率对种子玉米脱粒性能的影响机理). *Transactions of Agricultural Machinery*, Vol. 42(12), pp.92-96. Beijing/China.

[7] Hall G.E, Johnson W.H. (1970) Corn kernel crackage induced by mechanical shelling. *Transactions of the ASABE*, 13(1): 51-55.

[8] Kang Yunyou, Zhang Daolin, Lu Xiufeng et. al., (2019). Experimental Study on Mechanized Directly Harvesting Technology and Machinery for Corn Grain [J]. (玉米籽粒机械化直收技术与机具试验研究). *Journal of Agricultural Mechanization Research,* Vol. (04), pp.176-181. Heilongjiang/China.

[9] Liu Fenghe, Wang Keru, Li Jian, et al, (2013). Factors Affecting Corn Mechanically Harvesting Grain Quality (影响玉米机械收粒质量因素的分析). *Crops*, Vol. (04), pp. 116~119. Beijing/China.

[10] Li Lulu, Lei Xiaopeng, Xie Ruizhi et al (2017). Analysis of influential factors on mechanical grain harvest quality of summer maize[J] (夏玉米机械粒收质量影响因素分析). *Scientia Agricultura Sinica*, Vol. 50(11), pp. 2044-2051. Beijing/China.

[11] Mohamed A F, Abdel M., (2009). Mechanical properties of corn kernels[J]. *Misr Journal of Agricultural Engineering*, Vol. 26(4), pp.1901-1922. USA.

[12] Plett, S., (1994). Corn kernel breakage as a function of grain moisture at harvest in a prairie environment[J]. *Canadian Journal of Plant Science*, Vol. 74(3), pp.543-544. Canada.

[13] Steele J.L., Saul R.A., Hukill W.V. (1967) Deterioration of shelled corn as measured by carbon dioxide production. *American Society of Agricultural Engineers*, 12(5): 685-689.

[14] Volkovas V, Petkevičius S, špokas L., (2006). Establishment of maize grain elasticity on the basis of impact load. *Mechanika*, Vol. 6(62), pp. 64-67. Lithuania.

[15] Wang Lei, (2016). *Screening and Demonstration of Maize Varieties with Early Maturing, Dense Tolerance and Machine Harvest Suitable Traits (早熟耐密宜机收玉米品种筛选与示范)*. Northwest A&F University. Yangling/China.

[16] Wang Keru, Li Lulu, Lu Zhensheng et al., (2021) Mechanized grain harvesting quality of summer maize and its major influencing factors in Huanghuaihai region of China (黄淮海夏玉米机械化粒收质量及其主要影响因素). *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 37(7), pp.1-7. Beijing/China.

[17] Wang Keru, Li Shaokun, (2017). Progresses in research on grain broken rate by mechanical grain harvesting[J] (玉米籽粒机械收获破碎率研究进展). *Scientia Agricultura Sinica*, Vol. 50(11), pp.2018-2026. Beijing/China.

[18] Wang Zhanbin, Wang Zhenwei, Zhang Yinping, et al.,(2020).Design and Test of Longitudinal Axial Flexible Hammer-claw Corn Thresher[J](纵轴流柔性锤爪式玉米脱粒装置设计与试验). *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 51(S2), pp.109-117. Beijing/China.

[19] Yang Yufen, Zhang Yongli, Zhang Benhua, et al., (2008). Experimental Study on Static Pressing Typical Corn Seed Kernel (典型玉米种子籽粒的静压破损试验研究). *Journal of Agricultural Mechanization Research*, Vol. (07), pp.149-151. Heilongjiang/China

[20] Zhang Wanxu, Wang Keru, Xie Ruizhi, et al., (2018a).Relationship Between Maize Grain Broken Rate and Moisture Content as well as the Differences among Cultivars (玉米机械收获子粒破碎率与含水率关系的品种间差异). *Journal of Maize Sciences*, Vol. 26(4), pp. 74-78. Jilin/China.

[21] Zhang WanXu, Ming Bo, Wang KeRu, et al, (2018b). Analysis of Sowing and Harvesting Allocation of Maize Based on Cultivar Maturity and Grain Dehydration Characteristics[J](基于品种熟期和籽粒脱水特性的机收粒玉米适宜播期与收获期分析). *Scientia Agricultura Sinica*, Vol. 51(10), pp.1890-1898. Beijing/China.

[22] Zhang Xinwei, Li Xinping, Yang Dexu, et al., (2012). Micromechanism of Inner Mechanical Cracks Generation and Expansion of Corn Seed Kernel (玉米种子内部机械裂纹产生与扩展的微观机理). *Transactions of the Chinese Society for Agricultural Machinery*, Vol. 43(12), pp.72-76. (in Chinese)

[23] Zhang Xinwei, Yi Kechuan, Gao Lianxing, (2015). Contacting mechanics analysis during impact process between corn seeds and threshing component (玉米种子与脱粒部件碰撞过程中的接触力学分析). *Chinese Agricultural Science Bulletin*, Vol. 31(14), pp.285－290.

[24] Zhao Rulang, Wang Yonghong, Li Shaokun et al., (2019). Screening of maize cultivars suitable for mechanical kernel harvest in Ningxia (宁夏宜机收玉米品种的初步筛选) *Journal of Maize Science*, Vol. 27(1), pp.130-135. Jilin/China.