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Analysis of physical and mechanical properties of maize

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ABSTRACT

In the design process of corn harvester, the influence and action mechanism of corn plant characteristics on the working parts of corn harvester (including cutting device, ear picking device, peeling device and other key parts) should be considered, and the physical and mechanical properties of corn plant need to be analyzed. To prevent serious “gnawing” of ears, high loss rate and crushing rate of ears and grains, and low efficiency of harvesting operation due to high moisture content of ears of corn in harvest period. Therefore, it is particularly important to analyze the physical and mechanical properties of maize plants.

Keywords: Corn; physical properties; mechanical properties; corn harvester

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1. Introduction

The physical characteristics of maize plant refer to the plant size and weight, ear height, ear big end diameter and ear stalk diameter of Maize in the harvest period. The height of maize plant is generally 1600 ~ 3000mm, and the ear setting height is generally 400 ~ 1200mm. The diameter of the big end of the ear is usually 40 ~ 65mm, while the diameter of the ear stalk is 9 ~ 19mm. The more significant the difference between ear diameter and stem diameter is, the more conducive it is to ear picking[1][2][3][4]. When the diameter of the big spike is less than 40mm, the grain loss increases significantly. Because in the process of ear picking, the ear picking roller should not only have the ability to grasp the stem, but also not damage the big end of the ear. The smaller the diameter of the big end of the ear, the greater the possibility of being damaged by the ear picking roller. The mechanical properties of materials refer to the characteristics of materials under various external loads (tension, compression, bending, torsion, impact, alternating stress, etc.) in different environments (temperature, medium and humidity)[5][6]. The performance indexes include: elasticity index, hardness index, strength index, plasticity index, toughness index, fatigue performance, fracture strength, etc. The mechanical properties of maize refer to the resistance of Maize to external force and deformation, which is the inherent characteristics of maize[7].

2 Physical properties of maize plant

In the harvest season of corn ear, the height and weight of straw, the height of ear, the diameter of straw and other parameters are called the physical properties of corn plant[8].

2.1 Physical characteristic parameters of maize plant

GB / T 21962-2020 "corn harvester" in the detection of corn harvester in the provisions of the standard to determine indicators and methods[9][10].

Determination method:

(1) For the characteristics of block planting, short length and narrow width in Hilly and mountainous areas, the test length is selected as 50m, in which the moisture content is guaranteed to be 25% ~ 35%, the plant lodging rate is less than 5%, and the ear drooping rate is less than 15%.

(2) Main measuring equipment and instruments: stopwatch, vernier caliper, electronic scale, steel tape, computer, 500m tape, etc.

(3) Measurement index: randomly select 4 points in the test site for measurement, take a 2m long working width for each measuring point, and continuously measure 10 plants at each point. Straw diameter, plant height, ear height, maximum ear diameter and ear length were measured.

Data1 Table of maize plant characteristics

	Straw root diameter /mm	Plant height /mm	Ear height /mm	Maximum ear diameter /mm	Ear length /mm
	19.6	2274	821	53.1	235
First	27.2	2931	955	58.8	190
point	23.3	2877	999	60.1	184
	20.5	2699	1055	53.2	202

	19.2	2298	834	45.4	201
	22.6	2948	1028	53.1	166
	22.9	2912	1080	55.2	185
	28.2	2953	1012	49.8	247
	27.1	2915	1016	53.0	215
	26.1	2767	965	55.4	202
	25.3	2868	996	55.3	180
	21.3	2469	811	34.2	212
	20.5	2043	841	58.2	193
	17.9	1793	675	51.8	146
Second	20.5	2036	828	39.4	157
point	21.0	2343	838	58.7	178
	24.3	2438	822	59.2	203
	20.9	2309	838	57.8	224
	16.5	2569	850	46.0	158
	18.5	1802	667	45.8	199
	22.5	2848	1084	51.2	198
	26.7	2934	1012	57.9	212
	24.7	2992	1076	57.8	208
	25.8	2879	1021	61.3	171
Third	21.9	2923	986	56.6	179
point	18.6	1514	645	57.2	151
	26.0	2646	980	50.6	231
	24.8	3037	1107	57.3	223
	21.1	2930	1064	61.6	223
	22.8	2348	952	49.9	209
	22.2	2994	967	60.0	208
	25.8	2998	1106	62.3	210
	26.0	2981	1048	48.9	215
	23.9	2832	995	58.5	231
Fourth	23.9	2857	943	50.3	192
point	25.2	3038	1031	55.3	220
	19.7	1881	669	56.9	172
	26.0	2657	844	62.5	203
	25.0	2860	1025	50.5	212
	25.0	2828	973	55.9	228

The above measured data were used for statistical analysis of physical parameters of maize plants.

（1）Correlation analysis between straw root diameter and the maximum ear diameter assumes that the regression equation between the maximum ear diameter and straw root diameter is

$$\hat{y} = \hat{a} + \hat{b}x$$

among，x——Straw root diameter，mm

$\hat{y}$——Maximum ear diameter，mm

$\hat{a}$、$\hat{b}$——Coefficient of regression equation

Statistics show that:

$$\hat{a} = \bar{y} - \hat{b}\bar{x}$$

$$\hat{b} = \frac{l_{xy}}{l_{xx}}$$

among，

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

$$l_{xy} = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) = \sum_{i=1}^{n} x_i y_i - \frac{1}{n}(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)$$

$$l_{xx} = \sum_{i=1}^{n}(x_i - \bar{x})^2 = \sum_{i=1}^{n}(x_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} x_i)^2$$

x_i, y_i——Straw root diameter and maximum ear diameter，i=1,2，……，40。

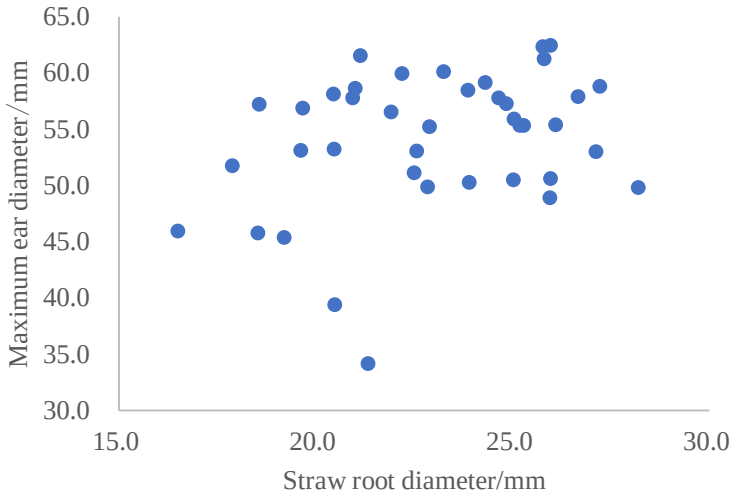


Figure 1 Regression curve and scatter distribution of the maximum ear diameter to the straw root diameter

According to the data collected in Table 1, the following results are obtained:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = 23.0$$

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i = 54.1$$

$$l_{xx} = \sum_{i=1}^{n}(x_i - \bar{x})^2 = \sum_{i=1}^{n}(x_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} x_i)^2 = 335.56$$

$$l_{xy} = \sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y}) = \sum_{i=1}^{n} x_i y_i - \frac{1}{n}(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i) = 217.51$$

$$\hat{b} = \frac{l_{xy}}{l_{xx}} = 0.6482$$

$$\hat{a} = \bar{y} - \hat{b}\bar{x} = 39.19$$

Therefore, the univariate linear regression equation of the maximum ear diameter to the straw root diameter:

$$\hat{y} = \hat{a} + \hat{b}x$$

（a） Regression equation test

Significance level α= 0.05, establish hypothesis test：

H_0：b=0，H_1：b≠0；

Calculate test statistics：

$$t=\frac{\hat{b}}{\hat{\sigma}}\sqrt{l_{xx}}$$

among，

$$\hat{\sigma}=\sqrt{\frac{S_{余}}{(n-2)}}=\sqrt{\frac{l_{xx}l_{yy}-l_{xy}{}^2}{(n-2)l_{xx}}}$$ ；

$$l_{yy}=\sum_{i=1}^{n}(y_i-\overline{y})^2=\sum_{i=1}^{n}(y_i)^2-\frac{1}{n}(\sum_{i=1}^{n}y_i)^2=1449.01$$ ；

Reject domain is

$$|t|\geq t_{\alpha/2}(n-2)=t_{0.975}(38)$$

According to the table, $t_{0.975}$（38）=2.0244

But，

$$t=\frac{\hat{b}}{\hat{\sigma}}\sqrt{l_{xx}}=2.0249>2.0244$$

Therefore, the original assumption of H_0：b=0 is rejected

That is, it shows that the maximum diameter of ear has a significant effect on the diameter of straw root.

（b） Correlation coefficient hypothesis test

H_0：b=0，H_1：b≠0；

Observation statistics：

$$r=\frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\overline{x})^2\sum_{i=1}^{n}(y_i-\overline{y})^2}}=\frac{l_{xy}}{\sqrt{l_{xx}l_{yy}}}=0.3119$$

Among them, the larger the $|r|$ is, the more significant the linear relationship between the maximum ear diameter and the straw root diameter is. Therefore, when $|r|>c$, H_0 is rejected.

That is, reject domain:

$$W=\{|r|>c\}$$

Where, c is the value of significant level, and

$$c=\left[\frac{t_{1-\alpha/2}{}^2(n-1)}{(n-2)+t_{1-\alpha/2}{}^2(n-2)}\right]^{\frac{1}{2}}$$

Look up the table，t1-α/2(39)=2.0227

By calculation，when α=0.05, n=40, c=0.3117

And,

$|r|$=0.3119＞c

Therefore, rejecting H_0 proves that the diameter of the largest ear has a significant linear relationship with the diameter of the straw root.

The maximum ear diameter has a significant linear relationship with the straw root diameter, which provides a strong theoretical support for the design of gap adjustment components in the back ear picking mechanism. During the operation of the corn harvester, the purpose of the ear picking mechanism is to separate the corn ear from the corn straw. However, when the gap between the ear picking roller is too large, the ear picking roller and the corn straw cannot pull the stem effectively, so that the corn ear and the corn straw cannot be effectively separated; On the contrary, when the gap between the ear picking rollers is too small and the corn straw is pulled, the ears will also be squeezed and picked, resulting in ear grain loss and grain crushing.

Similarly, the correlation between straw root diameter and plant height is determined, and the data is entered into Excel for data analysis.

$$\hat{y}=\hat{a}+\hat{b}x_1=9.375+0.0052x_1$$

Among，x_1——Plant height，mm

$\hat{y}$——Straw root diameter，mm

The model output is

Table 2 Regression Statistics

Multiple R	R Square	Adjusted R Square	Standard error	Observed value
0.720812	0.51957	0.506928	2.059666	40

	df	SS	MS	F	Significance F
Regression analysis	1	174.338	174.338	41.09588	1.55881E-07
Residual	38	161.2045	4.242225		
Total	39	335.5425			

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Up 95.0%	Down 95.0%
Intercept	9.375	2.15370	4.3528	9.78411E-05	5.0146	13.7345	5.0146	13.7345
X Variable 1	0.005	0.00081	6.4106	1.55881E-07	0.0035	0.0068	0.0035	0.0068

（a） R^2 or adjust R^2

R^2 or adjusted R^2 reflects the explanatory ability of the univariate regression equation. It can be seen from the regression statistics in Table 2 that both R^2 and adjusted R^2 are greater than 50%, indicating that the fitting degree between the data and the model is good.

（b） F test

F test is to test whether the equation has a linear relationship. As can be seen from table 2, significance f = 1.55881e-07, less than 0.01. Therefore, reject the original hypothesis H_0, that is, the equation is considered to have a linear relationship.

（c） T-test

T-test is to test the intercept and first-order term coefficient in the univariate linear equation, in which the original assumption is H_0：α=0. It is obvious from table 2 that P < 0.01, the rejection of the original hypothesis is H_0, indicating that the original hypothesis is passed.

（c）Normal graph

As can be seen from Figure 2 below, the scattered points are evenly distributed on a straight line, indicating that they obey normal distribution.

The fitting effect of straw root diameter and plant height can be clearly seen from the above figure 3. Plant height and straw diameter directly affect whether the ear picking mechanism is blocked. Therefore, in the process of corn harvest, the corn straw fails to pull out the ear picking roller in the strong pulling section, which leads to the problem that the corn straw is centrally stuck at the end of the ear picking roller and blocks the ear picking roller. According to the plant height and straw diameter, the length, speed and clearance of ear picking roller should be designed reasonably.

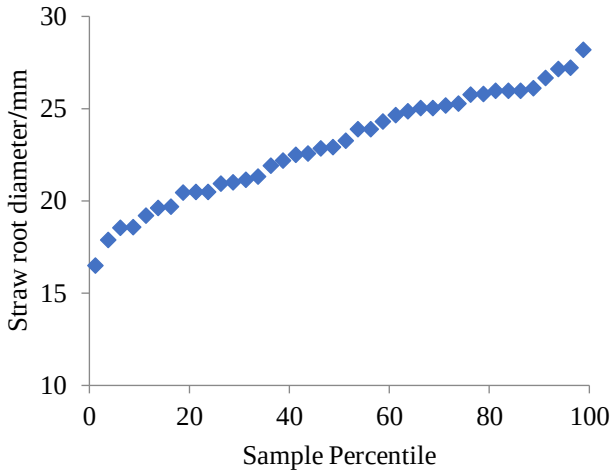


Figure 2 Scatter diagram of straw diameter

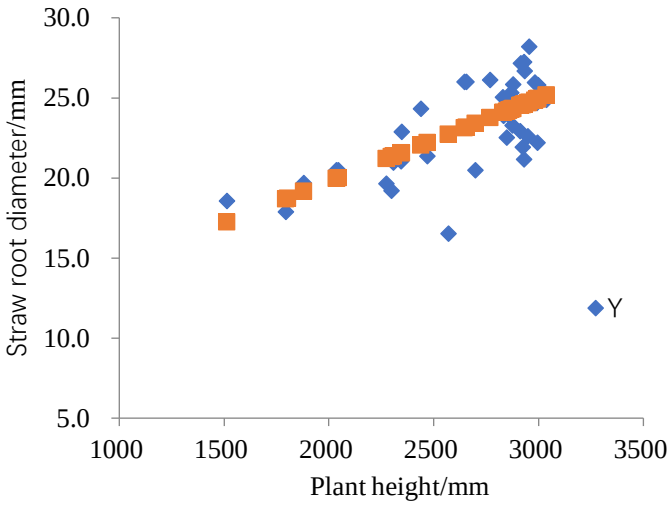


Figure 3 Fitting effect of straw root diameter and plant height

2.2 Mechanical properties of corn stalk

When the corn harvester is working, the ear picking mechanism will squeeze the corn straw, which will break the corn straw, especially at the stem node, so that the ear picking mechanism can not effectively pick the ears. Therefore, this part analyzes the extrusion characteristics of straw with knots[11][12].

（a） Test scheme

The corn straw in the experimental field in sangyuan Town, Rizhao City was selected, and the variety was Xianyu 335. The selection of the straw has the characteristics of no diseases and pests and no damage, so that the selected corn straw can meet the characteristics of most corn straw; In the interception of the whole corn straw, the same parts of different corn straws and the upper, middle and lower parts of the same corn straw were intercepted respectively.

The test instrument used in the extrusion test of corn straw is a universal testing machine. The specific parameters of the universal testing machine are shown in Table 3 below.

Table 3 parameters of universal testing machine

performance parameter	value
Test pressure	0.1N~5000N
Data acquisition rate	200 times/s
Test speed	5~500mm/min
Test stroke	1200mm
Relative error of displacement value	±1%

Then, the intercepted corn straw was numbered, the moisture content was measured, and the diameter was measured with vernier caliper[13]. The determination of water content is mainly based on the determination method of wood moisture content in GB / T 1931-2009, and the intercepted corn straw is measured for the first time; Next, put the corn straw into the drying oven, take it out and weigh it every quarter of an hour, calculate the moisture content, and make the corn straw reach the range of moisture content to be measured.

The preliminary preparation work has been completed. Finally, the universal testing machine is used to carry out the extrusion test of corn straw[14]. The test mainly analyzes the moisture content, interception position and test speed of corn straw. This paper uses design expert to analyze and obtain the coding table shown in the following table.

Table 4 coding table of corn straw extrusion test factors

Code value	Moisture content %	Intercept position	Test speed mm/min
-1.68179	35	1	60
-1	45	2	70
0	55	3	80
1	65	4	90
1.68179	75	5	100

（b） Result analysis

The experiment was designed according to design expert 10. Taking the water content, straw interception position and test speed as the influencing factors and the critical value of corn straw extrusion pressure as the objective function, the three factor and five level regression orthogonal experimental design was carried out. The test results of extrusion characteristics of corn straw are shown in the table below.

Table 5 Analysis of corn straw extrusion test data

Serial number	Moisture content *A*（%）	Intercept position *B*	Test speed *C*（mm/ min）	Critical pressure value *Y*(N)
1	-1	-1	-1	1306.42
2	1	-1	-1	1144.29
3	-1	1	-1	786.28
4	1	1	-1	913.48
5	-1	-1	1	1246.02
6	1	-1	1	1412.43
7	-1	1	1	690.82
8	1	1	1	1243.07
9	-1.68179	0	0	706.55
10	1.68179	0	0	1253.76
11	0	-1.68179	0	1795.90
12	0	1.68179	0	991.75
13	0	0	-1.68179	1035.05
14	0	0	1.68179	1315.85
15	0	0	0	1437.03
16	0	0	0	1372.79
17	0	0	0	1509.24
18	0	0	0	1485.31
19	0	0	0	1486.94
20	0	0	0	1474.89

Using design expert to analyze the above data, the preliminary analysis of variance is shown in the table below.

Table 6 variance analysis of corn straw extrusion test

Terms of polynomials	Sum of squares	freedom	Mean square deviation	F value	Significance
Model	1.601E+006	9	1.779E+005	28.32	< 0.0001
A	1.884E+005	1	1.884E+005	29.99	0.0003
B	5.856E+005	1	5.856E+005	93.21	< 0.0001
C	61185.51	1	61185.51	9.74	0.0109
AB	56978.75	1	56978.75	9.07	0.0131
AC	70988.37	1	70988.37	11.30	0.0072
BC	87.03	1	87.03	0.014	0.9086
A^2	4.960E+005	1	4.960E+005	78.95	< 0.0001
B^2	22210.37	1	22210.37	3.54	0.0895
C^2	1.955E+005	1	1.955E+005	31.12	0.0002
Residual term	62821.57	10	6282.16		
Spurious term	50683.13	5	10136.63	4.18	0.0714
Error	12138.44	5	2427.69		
Sum	1.664E+006	19			

Note: $P > 0.1$ means not significant; $0.05 < P < 0.1$ indicates significant; $0.01 < P < 0.05$ indicates significant; $P < 0.01$ indicates extremely significant

Through the analysis of variance of corn straw extrusion test, it can be seen that the fitting degree of the regression equation of the pressure value of corn straw extrusion is very significant ($P < 0.0001$); The mismatch term $P = 0.0714$, indicating that it is not significant, which indicates that there are no other main factors affecting the pressure value change of corn straw extrusion; Then analyze the significance of each factor and its interaction. From the above table, it can be seen that moisture content a, interception position *B*, interaction term *AC* between moisture content and test speed, quadratic term A^2 of moisture content and quadratic term C^2 of test speed have a very significant impact on the critical value of corn straw extrusion pressure ($P < 0.01$); The interaction term *AB* between test speed *C* and moisture content and interception position had a significant effect on the critical value of corn straw extrusion pressure ($0.01 < p < 0.05$); The quadratic term B^2 of interception position had a significant effect on the critical value of corn straw extrusion pressure ($0.05 < p < 0.1$); The interaction term *BC* between interception position and test speed had no significant effect on the critical value of corn straw extrusion pressure ($P > 0.1$). Therefore, by excluding the non significant item *BC*, the analysis of variance of excluding the non significant item is obtained. Table 7 is as follows.

Table 7 analysis of variance excluding insignificant items

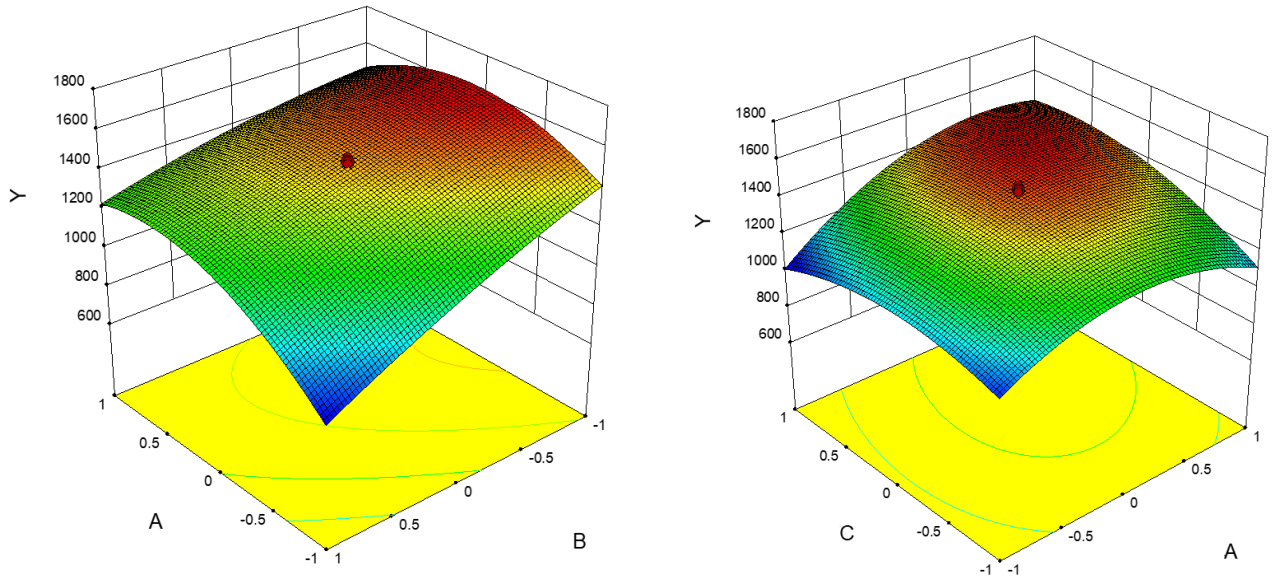
Terms of polynomials	Sum of squares	freedom	Mean square deviation	F value	Significance
Model	1.601E+006	8	2.001E+005	35.00	< 0.0001
A	1.884E+005	1	1.884E+005	32.94	0.0001
B	5.856E+005	1	5.856E+005	102.39	< 0.0001
C	61185.51	1	61185.51	10.70	0.0075
AB	56978.75	1	56978.75	9.96	0.0091
AC	70988.37	1	70988.37	12.41	0.0048
A^2	4.960E+005	1	4.960E+005	86.72	< 0.0001
B^2	22210.37	1	22210.37	3.88	0.0744
C^2	1.955E+005	1	1.955E+005	34.18	0.0001
Residual term	62908.60	11	5718.96		
Spurious term	50770.16	6	8461.69	3.49	0.0960
Error	12138.44	5	2427.69		
Sum	1.664E+006	19			

Note: $P > 0.1$ means not significant; $0.05 < P < 0.1$ indicates significant; $0.01 < P < 0.05$ indicates significant; $P < 0.01$ indicates extremely significant

Therefore, the regression equation obtained after excluding the insignificant term *BC* is

$$Y = 1463.40 + 117.45A - 207.07B + 66.93C + 84.39AB + 94.20AC - 185.51A^2 - 39.26B^2 - 116.47C^2$$

According to the response surface analysis in design expert, the response surface diagram of the interaction between moisture content, interception position and test speed can be obtained, as shown in the following figure.



（a）Interaction between moisture content and interception location

（b）Interaction between moisture content and test speed

Fig. 4 interaction response surface of various influencing factors of corn straw

According to the response surface of the interaction between moisture content and interception position in Figure 4 (a) above, it is obvious that under the influence of interception position, the critical value of anti-extrusion pressure of corn straw first increases and then decreases with the increase of moisture content, which is mainly because the moisture content improves the toughness of corn straw, but with the increase of interception position of corn straw, The upper part of corn straw becomes brittle, so the critical value of anti-extrusion pressure of corn straw increases first with the increase of moisture content.

According to the response surface of the interaction between moisture content and test speed in Figure 4 (b) above, it is obvious that under the influence of moisture content, the critical value of anti-extrusion pressure of corn straw increases first and then decreases with the increase of test speed.

2.3 Mechanical properties of corn bracts

The purpose of analyzing the mechanical properties of corn bracts is to improve the stripping rate of corn ears by the stripping mechanism in the corn harvester[15].

According to Zhao cheng shuai and others' Experimental Research on the mechanical properties of corn bracts, the interaction between the longitudinal tension, transverse tension and the number of layers of corn bracts is analyzed. The test data are shown in Figure 5 below.

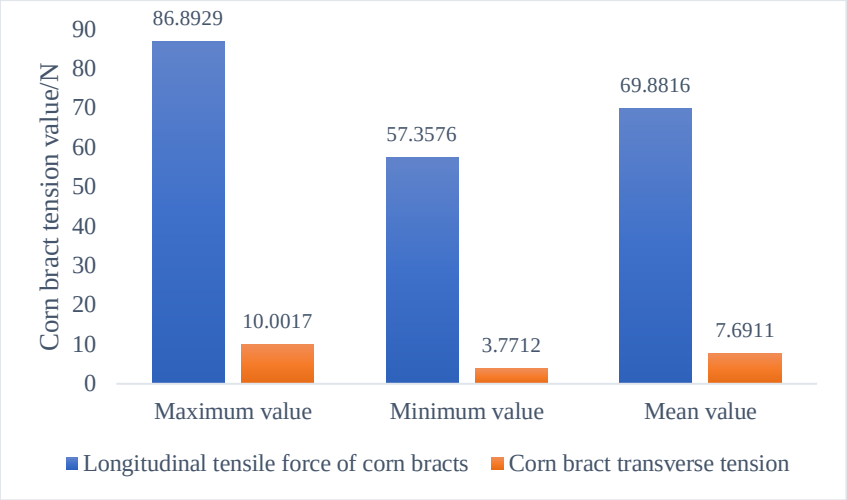


Fig. 5 critical value of corn bract tension

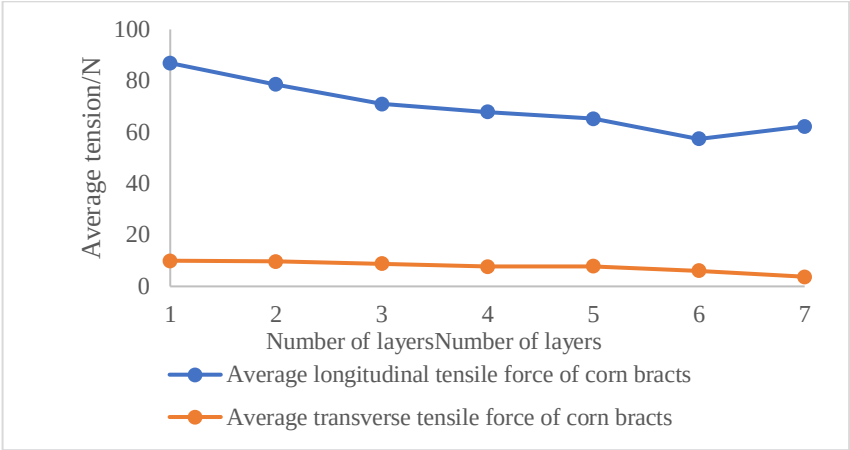
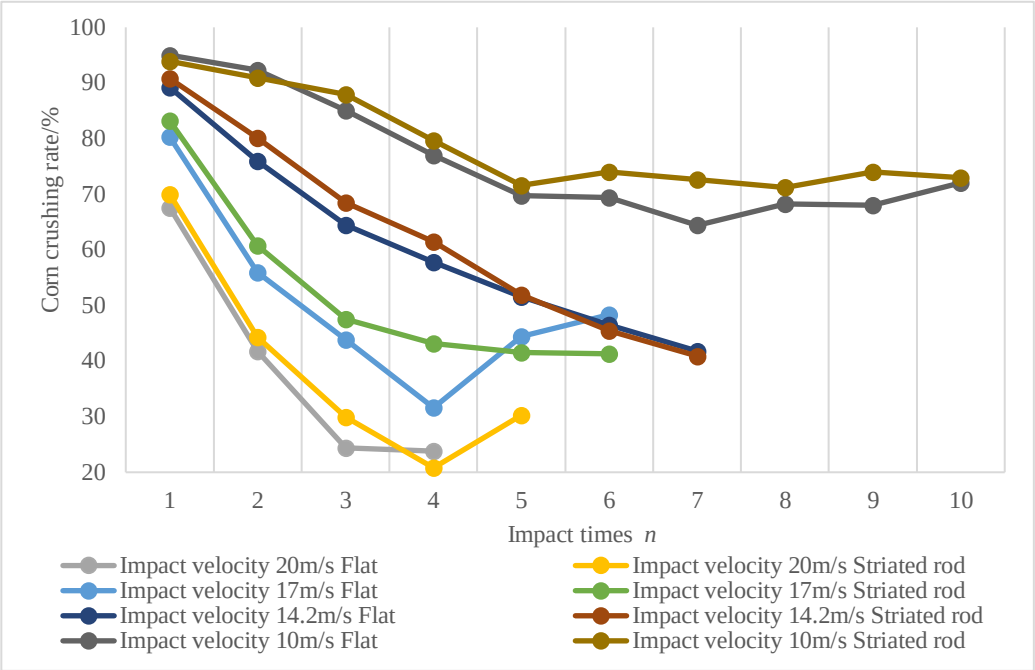


Fig. 6 Relationship between transverse and longitudinal tensile force of corn bracts and layers

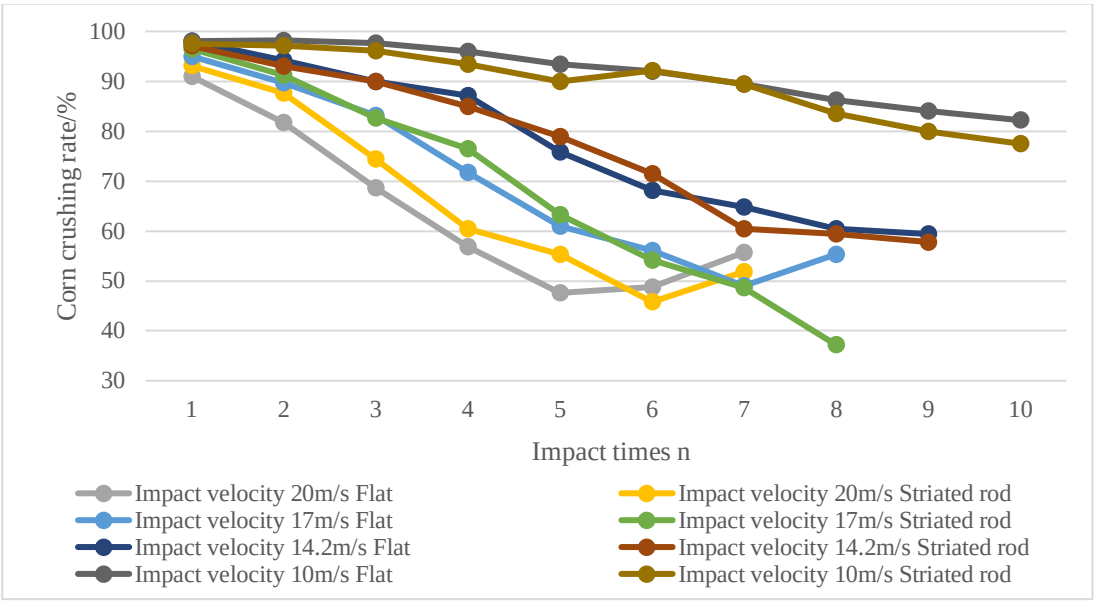
According to the data analysis in Figure 6 above, the longitudinal tension of corn bracts is 8 ~ 10 times larger than the transverse tension, and the tension value of corn bracts from outer layer to inner layer shows a decreasing trend. This requires that when designing the peeling mechanism in the corn harvester in the later stage, we should combine the relationship between the transverse and longitudinal tension of corn bracts to improve the peeling rate of the peeling device.

2.4 Mechanical properties of maize grain

When harvesting the ear of corn, it will inevitably damage the corn grain, especially in the process of peeling. Therefore, in order to reduce the damage of harvesting machinery to corn grains and reduce the rate of grain loss, it is necessary to analyze the mechanical properties of corn grains. In the experimental study on the mechanical properties of corn grains by Zhao Xuedu and others, two different types of elements were used to conduct corn impact tests on corn grains with 12.5% and 16.5% water content at four impact speeds. The test results are shown in Figure 7 below.



（a） When the moisture content is 12.5%



（b） When the moisture content is 16.5%

Fig. 7 Relationship between corn crushing rate and impact times

The above figure shows the relationship between corn crushing rate and impact times when the moisture content is 12.5% and 16.5%, respectively. Where, *A* represents the ratio of the weight of corn grains that do not reach the corresponding size to the total weight of corn grains after impact crushing each time. It can be seen that under the condition of the same impact speed and impact element, the crushing weight ratio decreases steeply with the increase of impact times. With the increase of impact speed and the decrease of corn grain water content, the degree of corn grain fragmentation also showed an accelerated downward trend. At the same time, when the impact speed is high, the flat plate has an advantage in the crushing rate

of corn grains, which can better preserve the integrity of corn grains; However, when the impact speed is low, the corn grain breaking rate of the Striped rod is slightly better, which is mainly because when the corn grain is in the groove of the Striped rod, the groove will reduce the damage to this part.

During corn peeling, the corn ear loses the covering of bracts, making the corn grain directly contact with the peeling element, which is the main cause of corn grain damage. Therefore, the study on the damage degree of different types of impact elements to corn grains will help to carry out the design of corn peeling device in the later stage and minimize the damage of impact elements to corn ears.

3 Conclusion

This chapter mainly studies the physical and mechanical characteristic parameters of maize plants. The research results show that:

（1） The study on the physical and geometric parameters of maize plant shows that the diameter of the ear of lotus stalk is directly proportional to the diameter of the big end of the ear and the natural height of the plant; The lowest panicle height is directly proportional to the natural height of the plant.

（2） The mechanical properties of grains are closely related to the moisture content. When the moisture content of grains is between, it is suitable to harvest ears. When the moisture content of grains is less than, it is suitable to harvest grains directly.

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