EXPERIMENT ON IMPACT DAMAGE OF CASTOR CAPSULE AND ITS INFLUENCING FACTORS OPTIMIZATION
/
蓖麻蒴果冲击损伤试验及影响因素优化研究

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ABSTRACT
Castor is an important oil crop. Impact damage is critical in the process of castor capsule shelling, directly affecting the shelling effect of castor seeds. An experiment was taken to investigate it. To study the damage degree of castor capsule under the impact, water content, impact height, and impact angle were taken as test factors, and the maximum impact force and normal deformation were taken as test indexes. The combination optimization was carried out through the multi-objective genetic algorithm. The results show that the impact height has a significant effect on the maximum deformation (p<=0.01), and the water content and impact angle have a significant impact on the impact force (p<=0.05). The height and angle have a significant impact on the deformation (p<=0.01), and the water content has a significant impact on the deformation (p<=0.05).

摘要
蓖麻是重要的油料作物。蓖麻种子脱壳过程中大量存在冲击现象，直接影响蓖麻种子的脱壳效果。为研究蓖麻蒴果冲击时的损伤程度，以含水率、冲击高度、冲击角度为为试验因素，最大冲击力和法向变形量为试验指标，进行试验。通过多目标遗传算法进行组合优化。结果表明，碰撞高度对最大变形量的影响极显著(p<=0.01)，含水率和碰撞角度对冲击力的影响显著(p<=0.05)；碰撞高度和碰撞角度对变形量的影响极显著(p<=0.01)，含水率对变形量的影响显著(p<=0.05)。

INTRODUCTION
Castor is an important biomaterial, which is widely used in medicine, aviation, and other engineering fields. It is an essential oil crop in China, with a total output of ten million tons in China. During the process of shelling, repeated impacting occurs between the castor capsule and the shelled part. This directly leads to its damage in the process of shelling. The shelling damage affects the yield of crops for about 6% *(Sun et al., 2012)*. Therefore, it is vital to study the impact damage of the castor capsule.

At present, the research on the damage theory of agricultural materials is pervasive. *Huang et al. (2013)* regarded castor bean seeds as approximate spheres and analysed the mechanical model of castor bean under concentrated force by using the elastic thin shell theory. Based on the finite element theory *(Liu et al., 2012)*, numerical simulation of the compression load on the castor capsule was studied and the damage position, deformation, and stress of it was obtained. Based on the explicit dynamic simulation, PETRU M et al. (2012) conducted a static compression load test on jatropha seeds. They obtained the relationship between force, deformation, and energy of fruits with different maturity. ROMULI S et al. (2015) used the energy method to analyse the influence of the physical characteristics of jatropha seeds on the energy consumption of the shelling mode. Based on the collision exfoliation test, the mechanism of peanut seed shelling under the collision exfoliation method is complex *(Yang et al., 2017)*, experimental analysis on the variety, collision location, moisture content, and other factors was studied. Based on the discrete element method, *Zhao et al. (2013)* established the ellipsoid model of rice grains for simulation and used sensors for experimental analysis. The results showed that the normal force of rice grains in the collision test increased with the change of particle size ratio. To explore the damage degree of a cherry collision, *Zhou et al. (2016)* conducted a collision test on cherry to study the collision of collision materials, impact height, and collision

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angle on the damage. *Wang et al. (2018)* reconstructed the corn model by 3D reverse scanning technology and conducted collision analysis.

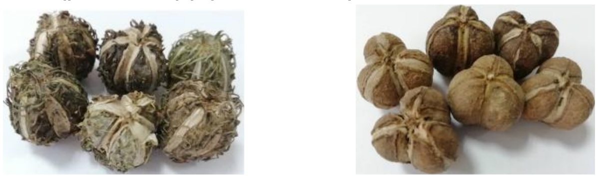
Although *Cao et al. (2010)* used the thin shell theory and the finite element method to analyse the effects of the physical and mechanical properties of castor seeds on the shelling, the studies on the collision characteristics of castor seeds are still relatively few. Because the material properties and geometric characteristics of castor seeds are different, the deformation and stress change dynamically in the process of shelling. Therefore, this study focuses on the damage theory of the castor capsule and its influence factors on the maximum impact force and normal deformation.

MATERIALS AND METHODS

Test materials

The typical castor capsule variety of ZheBi 4 and TongBi 17 are widely planted in the Tongliao areas of China. They were selected as the experimental material, which is shown in Fig.1. The test instrument is Vernier calliper, which is to measure the geometric dimension of castor seed. The mass of castor seed was measured by electronic balance. One hundred samples of castor capsules were taken for measurement. Through the statistical analysis of the geometrical dimensions of the castor capsule. It is concluded that the triaxial dimensions of the castor capsule are D_x=13.65~18.75mm, D_y=14.40~15.90mm, D_z=15.50~17.90mm.

The embedded drop impact testing bench is used for the experiment. Test machine includes USB-6009 data acquisition card, QLMH-P collision sensor (power supply 5-12 V, measuring range 0-1000N, output voltage 2 mV, strain gauge amplifier (power supply 5-9 V, amplification factor k=470).



(a) TongBi 17 *(b) ZheBi 4*

Fig. 1 - Different castor varieties

Test method

In the test of impacting, the sensor was placed in the centre of the test plate. And the castor capsule was placed on the centre of the sensor. In the beginning, the TLB-30B falling darts impact loading test bench was activated to adsorb iron impact block onto the drop darts. And then it was raised to a specified height. When the drop dart and the iron were at rest, the release button is pushed, the iron block would drop to the castor capsule. At the same time, the data of the collision force was transmitted to the signal analysis system through the USB6009 acquisition card and the strain gauge amplifier. The value of the output voltage of each collision force was recorded. By comparing the relationship between the maximum value of the collision force sensor and the test value, the collision force of the castor capsule would be obtained, as shown in Eq.(1).

$$F = k\frac{F_{\max}v_{real}}{v_{\max}} \tag{1}$$

Where: *F* is the maximum collision force received by the castor, [N]. *K* is the amplification factor of the amplifier circuit, *k*=470. F_{max} is the maximum range of the collision sensor, [N]. V_{real} is the actual measured output voltage, [mv]. V_{max} is the maximum output voltage of the amplifier, [mv].$V_{\max}$ = 2 [mv].

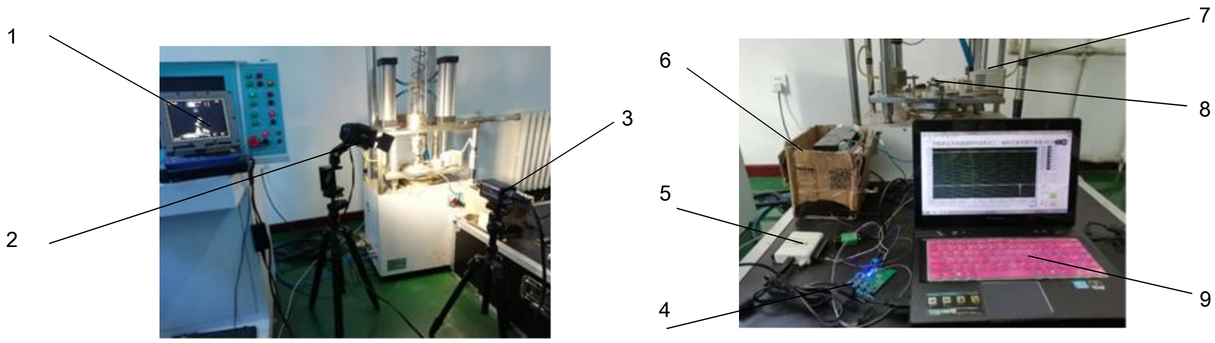


Fig. 2 - Castor capsule impact test device

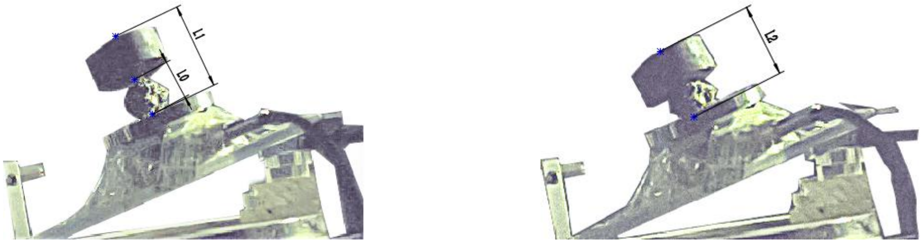
1. display panel; 2. camera; 3 light sources; 4.USB transmission line; 5. collection card; 6. battery; 7. dart impact load test bench; 8. sensor; 9. signal analysis system

The impact process of the castor capsule was recorded by high-speed photographic equipment. Through image and video processing, the changes in normal deformation of castor fruit were analysed. The normal deformation of castor fruit was obtained through the conversion of pixel distance and actual distance. The impact test device of castor fruit is shown in Fig.2.

Based on the change of reasonable deformation amount of castor capsule, the deformation amount is:

$$u_z = \frac{|L_2 - L_1|}{|L_0|} \quad (2)$$

Where: u_z is the normal deformation quantity [mm]. L_0 is the large diameter of the castor capsule. L_1 and L_2 are the pixel distances initiation and end of the collision respectively [mm].



(a) (b)

Fig. 3 - Variation of normal deformation before and after the collision of castor

(a) Initiation of the collision contact *(b) End of the collision contact*

Test methods

The main factors affecting the impact of breaking shells include impact force, moisture content, impact angle, material parameters (thickness, elastic modulus), variety, etc. Considering the limitations of the TLB-30B falling impact load test bench, the moisture content, impact height, and the angle were selected as experimental factors. The maximum impact force and normal deformation of castor capsule were selected as experimental indexes. The impact experiment was carried out by using the standard ternary quadratic general rotation combination regression test, which is shown in Table 1.

In the experiment, the castor capsules of different varieties were gradually dried and evenly divided into five parts to measure the moisture content, which was 4.01%, 9.26%, 16.97%, 24.67%, and 29.92%, respectively. With the increase of impact angle, its maximum impact force and normal deformation are smaller. Therefore, the collision angle was selected as 4°-15°. According to the secondary general rotation combination regression test, the voltage peak data and video of each test data acquisition were recorded. The sampling frequency of the data acquisition system is 1024Hz, and the sampling time is 0.5s.

Table 1

Castor capsule collision test factor level coding

Coding space	Factor levels		
	Moisture content	Fall height	Collision Angle
	[%]	[mm]	[°]
-1.682	4.01	160	4
- 1	9.26	237	6
0	16.97	350	9
1	24.67	463	12
1.682	29.92	540	14

RESULTS

Castor TongBi 17 collision test

Based on the standard ternary quadratic universal rotating combination regression test scheme, an impact test was conducted on the castor TongBi 17. The maximum collision force y_1 and normal deformation y_2 were obtained, as shown in table 2.

Table 2

TongBi 17 castor experiment design plan and results

Water content x_1	Collision height x_2	Collision Angle x_3	The maximum collision force y_1	The normal deformation y_2
[%]	[m]	[°]	[N]	[mm]
1	1	1	370.692	2.246
1	1	- 1	383.245	2.405
1	- 1	1	332.766	0.981
1	- 1	- 1	344.202	1.035

Water content x_1	Collision height x_2	Collision Angle x_3	The maximum collision force y_1	The normal deformation y_2
- 1	1	1	410.021	1.935
- 1	1	- 1	413.521	2.147
- 1	- 1	1	310.734	0.904
- 1	- 1	- 1	350.523	1.121
1.682	0	0	365.585	1.785
1.682	0	0	325.479	1.805
0	1.682	0	313.617	0.627
0	1.682	0	459.575	2.548
0	0	1.682	371.021	1.681
0	0	1.682	345.473	1.402
0	0	0	366.223	1.532
0	0	0	369.787	1.427
0	0	0	351.649	1.498
0	0	0	353.457	1.544
0	0	0	356.543	1.475
0	0	0	364.202	1.526

According to the results in table 2, the regression model of the maximum impact force y_1, moisture content x_1, impact height x_2 and impact angle x_3 were obtained based on the principle of the least square method, as equation (3):

$$y_1 = 297.95 - 6.34x_1 + 38.89x_2 - 6.42x_3 - 9.87x_1x_2 + 8.05x_2^2 \tag{3}$$

To study the significant relationship between the maximum impact force and the indicators, variance analysis was performed on the test data in table 2. The significance level α was 0.05. The analysis results are shown in Table 3. It can be seen that F=33.19>$F_{0.01}$(9,10)=4.95 and P<0.0001, which indicates that the proxy model is very significant. The impact height has an extremely significant effect on the maximum impact force, while moisture content and collision angle have a significant effect on the maximum impact force. The interaction between moisture content and collision height has a significant effect on the maximum impact force.

Table 3

Analysis of maximum collision force variance for TongBi 17

Source	Sum of squares	Degrees of freedom	The mean square	The F value	P values
model	23538.4	9	2615.38	33.19	0.0001 * *
x_1	549.41	1	549.41	6.97	0.0247 *
x_2	20653.9	1	20653.9	262.1	< 0.0001 * *
x_3	563.38	1	563.38	7.15	0.0233 *
x_1x_2	765.23	1	765.23	9.71	0.0109 *
x_1x_3	0.53	1	0.53	0.006	0.9365
x_2x_3	23.06	1	23.06	0.29	0.6004
x_1^2	95.93	1	95.53	1.22	0.2957
x_2^2	934.91	1	934.91	11.86	0.0063 * *
x_3^2	24.91	1	24.91	0.32	0.5864
Residual item	788.06	10	78.81		
Loss of quasi item	651.94	5	130.39	4.79	0.0553
Error term	136.12	5	27.22		
Total error	24326.5	19			

Note: R=0.96, correction R=0.93. Extremely significant level (p<0.01, significant level (p<0.05), not significant (p>0.05).

To further study the fitting accuracy of the agent model, the residual distribution curve of the maximum striking force test value, and the distribution diagram of the test value are shown in Fig.4. The predicted value obtained is shown in Fig.5. Among them, the biggest maximum residual value is 2.607, and the minimum residual value is 0.046. The biggest collision force of experiment and predicted values are on a straight line, which shows that the agent regression model can well reflect on the relationship of the factors.

According to the test data in table 2 and based on the principle of the least square method, the standard ternary-quadratic polynomial regression proxy model of castor TongBi 17 normal deformation was established as follows:

$$y_2 = 1.70 + 0.04x_1 + 0.6x_2 + 0.08x_3 + 0.068x_1x_2 + 0.093x_1^2 \tag{4}$$

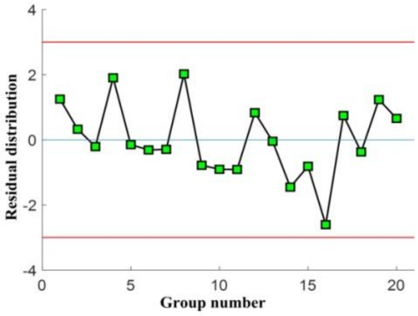


Fig. 4 - Maximum collision residual distribution of TongBi 17

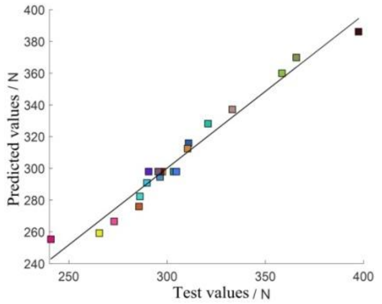


Fig. 5 - Distribution of test values and predicted values for TongBi 17

To study the significant relationship between the normal deformation y_2 and various test factors, variance analysis was conducted on the test data of castor TongBi 17. The significance level α was 0.05. The results are shown in Table 4.

Table 4

Analysis of the normal deformation variance of castor TongBi 17

Source	Sum of squares	Degrees of freedom	The mean square value	The *F* value	*P* values
model	5.25	9	0.58	147.4	< 0.001 * *
x_1	0.023	1	0.023	5.84	0.0363 *
x_2	4.96	1	4.96	1254	< 0.001 * *
x_3	0.091	1	0.091	22.93	0.0007 * *
X_1x_2	0.037	1	0.037	9.42	0.0118 *
X_1x_3	0.0075	1	0.0075	1.91	0.1967
X_2x_3	0.0005	1	0.0005	0.15	0.7102
x_1^2	0.12	1	0.12	31.47	0.0002 * *
x_2^2	0.0055	1	0.0055	1.39	0.2650
x_3^2	8×10^{-7}	1	8.2×10^{-7}	2×10^{-4}	0.9888
Residual item	0.04	10	0.0039		
Loss of quasi item	0.03	5	0.0059	3.12	0.1185
Error term	0.0095	5	0.0019		
Total error	5.28	19			

Note: R=0.98, correction R=0.96, Extremely significant level (p<0.01), significant level (p<0.05). not significant (p>0.05).

Analysis of the normal deformation variance of castor TongBi 17 is shown in Table 4. The regression proxy model F=147.38 >F(9,10)=4.95, P<0.0001, which indicated that the proxy model is very significant. The correlation coefficient R=0.98 and the misfit term P=0.1185>0.05 indicate that the agent model had high fitting accuracy. The influence of impact height and angle on the normal deformation of castor ZheBi 17 is very significant. The influence of moisture content on the normal deformation of castor TongBi 17 is significant. The interaction of moisture content and impact height on the normal deformation is significant.

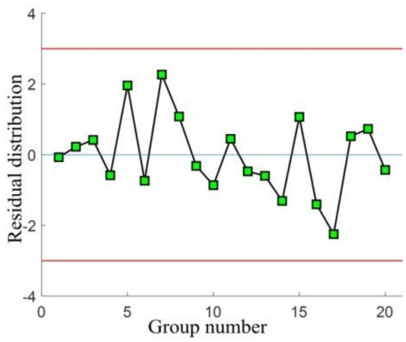


Fig. 6 - Residual distribution of normal deformation of Tongbi 17

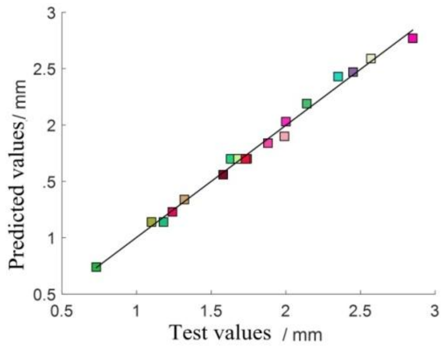


Fig. 7 - Distribution of the test value and the predicted value of the TongBi 17 deformation

The residual distribution curve of the standard deformation test value is shown in Fig.6. The distribution diagram of the test value and the predicted value are shown in Fig.7. It can be seen that the maximum residual is 2.266, and the minimum residual is 0.021. The experimental value and predicted value of the normal deformation are distributed on a straight line, which indicates that the regression agent model can well reflect the relationship between the normal deformation and the test factors.

Based on the same experimental scheme, the test factors of the castor ZheBi 4 castor fruit were at the same level as those of castor TongBi 17. The test factors of castor ZheBi 4 and castor TongBi 17 were the same. Among them, the test results of the maximum impact force y_3 and the normal deformation y_4 of castor ZheBi 4 are shown in Table 5.

Table 5

Castor TongBi 4 impact experiment design and results

Water content x_1 [%]	Collision height x_2 [m]	Collision Angle x_3 [°]	Maximum collision y_3 [N]	Normal deformation y_4 [mm]
1	1	1	350.732	2.331
1	1	- 1	367.136	2.474
1	- 1	1	300.031	1.083
1	- 1	- 1	316.104	1.149
- 1	1	1	380.426	2.033
- 1	1	- 1	390.734	2.255
- 1	- 1	1	300.484	1.047
- 1	- 1	- 1	310.695	1.258
1.682	0	0	345.866	1.186
1.682	0	0	315.732	1.984
0	1.682	0	275.819	0.627
0	1.682	0	430.214	2.748
0	0	1.682	343.381	1.802
0	0	1.682	323.692	1.202
0	0	0	330.293	1.632
0	0	0	325.764	1.567
0	0	0	320.466	1.705
0	0	0	336.047	1.655
0	0	0	320.732	1.579
0	0	0	326.415	1.603

Based on the principle of the least square method, the standard ternary quadratic polynomial regression model between the maximum impact force and water content, impact height and impact angle of castor capsule was established in equation (5)

$$y_4 = 1.62 + 0.053x_1 + 0.59x_2 - 0.12x_3 + 0.07x_1x_2 + 0.098x_1^2 \tag{5}$$

To study the significant relationship between the maximum impact force and the test factors, variance analysis was carried out for the test data of the maximum impact force in Table 5. The significance level α is 0.05, and the analysis result is shown in Table 6.

Table 6

Analysis of the variance for castor ZheBi 4

Source	Sum of squares	Degrees of freedom	The mean square value	The *F* value	*P values*
model	22876.3	9	2541.81	32.48	< 0.001 * *
x_1	717.88	1	717.88	9.17	0.0127 *
x_2	19904.4	1	19904.4	254.4	< 0.001 * *
x_3	542.93	1	542.93	6.94	0.0250 *
x_1x_2	424.10	1	424.10	5.42	0.0422 *
x_1x_3	17.87	1	17.87	0.23	0.6430
x_2x_3	0.023	1	0.023	0.002	0.9867
x_1^2	28.55	1	28.55	0.36	0.5593
x_2^2	1236.41	1	1236.41	15.80	0.0026 * *
x_3^2	81.31	1	81.31	1.04	0.3321
Residual item	782.50	10	78.25		
Loss of quasi item	606.83	5	121.37	3.45	0.0999
Error term	175.67	5	35.13		
Total error	23658.8	19			

Note: R=0.96, correction R=0.93, extremely significant level (p<0.01). 22 significant level (p<0.05). not significant (p>0.05).*

It can be seen in Table 6 that the regression model F=32.48 >$F_{0.01}$(9,10)=4.95, P<0.0001. It suggested that the agent model is very significant. The influence of impact height on the maximum impact force of castor ZheBi 4 is very significant. The influence of moisture content on the maximum impact force of castor Zheri 4 is significant. The influence of impact angle on the maximum impact force is significant, and the interaction of moisture content and impact height on the maximum impact force is significant.

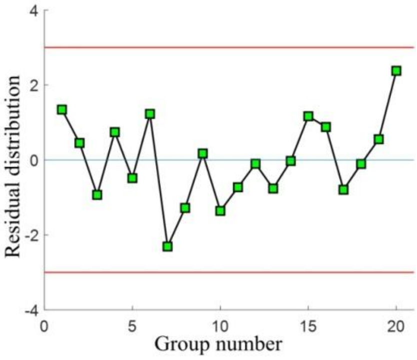


Fig. 8 - Distribution of the maximum residual of ZheBi 4

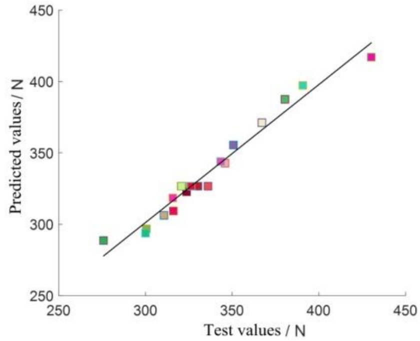


Fig. 9 - Distribution of the maximum collision force test value and the predicted value of ZheBi 4

To further study the fitting accuracy of the agent model, the residual distribution curve of the maximum striking force test value and the distribution diagram of the test value and the predicted value were obtained as shown in Fig.8 and Fig.9. The results indicated that the regression agent model could well reflect the relationship of the factors. Based on the principle of the least square method, the regression model of the standard ternary quadratic polynomial between the normal deformation y_2 and the moisture content x_1, the collision height x_2 and the collision angle x_3 are obtained as equation (6):

$$y_4 = 1.62 + 0.053x_1 + 0.59x_2 - 0.12x_3 + 0.07x_1x_2 + 0.028x_1x_3 - 0.011x_2x_3 + 0.098x_1^2 + 0.023x_2^2 - 0.042x_3^2 \tag{6}$$

The significant relationship between the normal deformation and the experimental factors was studied. Analysis of normal deformation variance is shown in table 7.

Analysis of normal deformation variance for castor ZheBi 4 **Table 7**

Source	Sum of squares	Degrees of freedom	The mean square value	The *F* value	*P values*
model	5.30	9	0.59	101.9	< 0.0001 **
x_1	0.039	1	0.039	6.64	0.0276*
x_2	4.83	1	4.83	829.6	< 0.0001 **
x_3	0.20	1	0.20	34.27	0.0002 **
x_1x_2	0.044	1	0.044	7.47	0.0211*
x_1x_3	6×10^{-3}	1	6.2×10^{-3}	1.08	0.3238
x_2x_3	9×10^{-4}	1	9.6×10^{-4}	0.17	0.6921
x_1^2	0.14	1	0.14	23.93	0.0006**
x_2^2	7×10^{-3}	1	7.7×10^{-3}	1.33	0.2749
x_3^2	0.026	1	0.026	4.44	0.0613
Residual item	0.058	10	5.8×10^{-3}		
Loss of quasi item	0.045	5	8.9×10^{-3}	3.38	0.1038
Error term	0.013	5	2.6×10^{-3}		
Total error	5.36	19			

Note: R=0.98, correction R=0.97, extremely significant level (p<0.01);22Significant level (p<0.05); not significant (p>0.05).

It can be seen that F=101.9 >$F_{0.01}$(9,10)=4.95, P<0.0001, which suggested that the agent model is very significant. The correlation coefficient R^2=0.98 and lost quasi item P=0.1038>0.05, which shows that the fitting accuracy is higher. The influence of impact height on the normal deformation is very significant, the influence of impact angle and moisture content on the normal deformation is very significant, and the interaction of water content and impact height on the normal deformation is significant.

Effect of interaction on collision damage of castor fruit

Based on experiment results, it can be seen that the interaction of water content and falling height had a significant effect on the maximum impact force and normal deformation. The interaction of moisture content and angle had no significant effect on the maximum impact force and deformation, while the interaction of impact height and impact angle has no significant effect on the maximum impact force and normal deformation. Therefore, the response surface of the interaction of water content and impact height of castor TongBi 17 and castor ZheBi 4 on their maximum impact force and normal deformation is shown in Fig.12 and Fig.13.

In the process of impacting, the interaction between moisture content and impact height affected the maximum impact force and normal deformation.

When the impact height was constant, with the increase of moisture content, the maximum impact force increased first and then decreased, and the normal deformation increased slightly. It is because the impact force increases before the shell is broken. When the shell is broken, the impact force becomes smaller. When the water content was constant, the maximum impact force and normal deformation increased significantly with the increase of impact height. Therefore, reasonable control of the maximum impact force can improve the shelling result. It is of considerable significance to reduce the shelling damage rate.

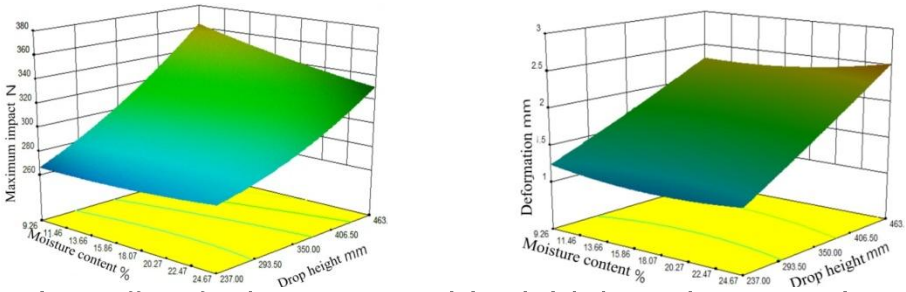


Fig.12- Effect of moisture content and drop height interaction on TongBi 17

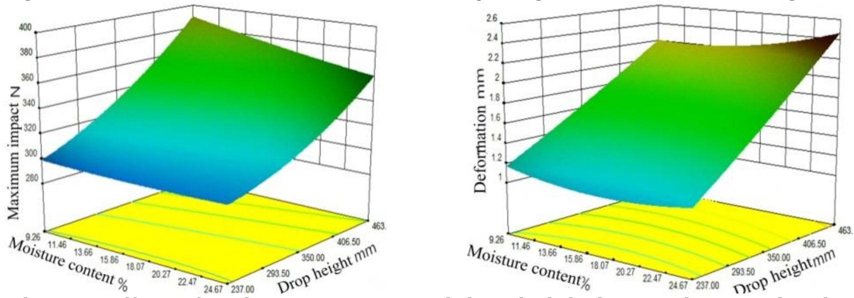


Fig. 13 - Effect of moisture content and drop height interaction on ZheBi 4

Evaluation of collision damage and multi-objective optimization

To study the sensitivity of parameters to break the shell, the optimal ratio of shelling parameters was determined. The moisture content x_1, impact height x_2 and collision angle x_3 were taken as optimization variables. The maximum impact force and normal deformation were carried for optimization, and the multi-objective genetic algorithm was used to calculate the optimal value. The multi-objective optimization model is shown in equation 7.

$$\begin{gathered} \max Y_1=f_1(x) \\ \min Y_2=f_2(x) \\ S.t.\ \ l_b \le x_i \le u_b \ \ i=1....n \\ S.t.\ l_b\ x \text{ or less } u_b \text{ or less } I = 1..._i\, n \end{gathered} \tag{7}$$

where: Y_1-normal deformation amount [mm]. Y_2- maximum collision force [N], l_b-parameter lower bound;
u_b - upper bound of parameters. n - parameter dimension.

Evaluation index of castor capsule collision damage

The damage degree of castor under different experimental conditions was used as the damage index to make the classification. Then the best parameters of the breaking shell of castor capsule were found. The classification of damage degree is shown in Table 8, and the actual impact results are shown in Fig.14.

Evaluation criteria for collision damage of castor **Table 8**

Varieties	Collision force [N]	Normal deformation [mm]	Damage index	Damage level number
TongBi 17	[0, 290]	[0,1.1]	Undamaged (elastic deformation)	I
	[290, 350]	[1.1, 2.3]	Moderate injury (three ventricular ruptures)	II
	[350 ~]	[2.3 ~]	Severe injury (complete rupture)	III
ZheBi 4	[0, 310]	[0,1.2]	Undamaged (elastic deformation)	I
	[310, 360]	[1.2, 2.1]	Moderate injury (three ventricular ruptures)	II
	[360 ~]	[2.1 ~]	Severe injury (complete rupture)	III

(a) Damage level Ⅰ *(b) Damage level Ⅱ* *(c) Damage degree Ⅲ*

Fig. 14 - Classification of collision damage levels of castor

Multi-objective genetic algorithm optimization

In the actual collision of the castor capsule, the collision of falling height on the maximum collision force and deformation of castor fruit is very significant. To improve the efficiency of the castor shelling machine, reduce the damage rate, the maximum collision force of castor fruit must be smaller. Based on the strategy of elitist rapid nondominated sorting genetic algorithm (NSGA-II), the maximum collision force and deformation of combination optimization is the following.

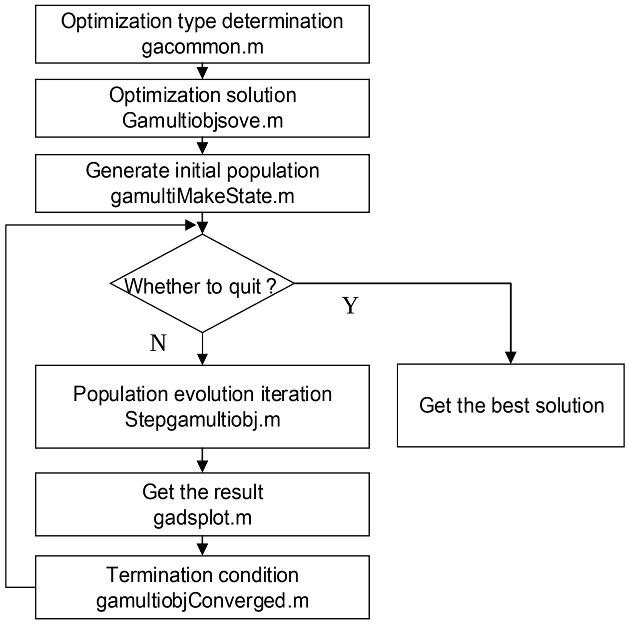


Fig. 15 - Multi-objective genetic algorithm optimization process

The optimal front-end individual coefficient ParetoFraction is 0.3, the Population size is 100, the maximum evolutionary algebra is 200, the stop algebra is 200, and the deviation of the fitness function is 1e-100.

Table 9

Optimal combination of the parameters for collapsing and shelling of castor

Varieties	The moisture content	Collision height	Collision Angle	Maximum collision force	Normal deformation
	[%]	[mm]	[°]	[N]	[mm]
ZheBi 4	4.2494	361.72	5.9906	351.0137	1.9627
TongBi17	4.3006	353.51	0.2433	347.9855	2.2786

The multi-objective optimization results are shown in Table 9. Under the optimum condition of castor capsule breaking, the difference between the maximum impact force of TongBi 17 and ZheBi 4 is 1.67% and 0.86% respectively. When the water content, collision height, and collision angle are similar, the maximum impact force of TongBi 17 is smaller, and the normal deformation is the larger. Therefore, castor ZheBi 4 is more difficult to shell than castor TongBi 17.

CONCLUSIONS

From the analysis of the experiment, it can be seen that the impact height has a significant impact on the maximum deformation($p<=0.05$), and the moisture content and impact angle have a significant impact on the force($p<=0.05$). The influence of impact height and angle on deformation is very significant($p<=0.01$), and the influence of moisture content on deformation is significant($p<=0.01$).

According to the response surface analysis, when the impact height is constant, with the increase of moisture content, the maximum impact force increases first. It then decreases, and the normal deformation rises slightly. When the moisture content is constant, the maximum impact force and normal deformation increase significantly with the increase of impact height. The difference between the maximum impact force of the castor capsule between castor TongBi 17 and castor ZheBi 4 was 7.63%, and the difference between the maximum normal variation was 3.51%.

The difference between the maximum impact forces of castor Tongli 17 and castor ZheBi 4 was 1.67% and 0.86% respectively. In the case of similar water content, collision height, and collision angle, the impact force of TongBi 17 is the smallest, and the normal deformation is the largest. Therefore, castor ZheBi 4 is more accessible to shell than castor TongBi 17.

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