DESIGN AND TEST OF APRICOT STONE SHELL BREAKING MACHINE
/
杏核破壳机的设计与试验

Zhaoshuai ZHU[1], Jie LI[2], Wulan MAO[1], Liling YANG[1], Kuanbo CUI[1], Zhanjiang ZHU[1]
[1] Research Institute of Agricultural Mechanization, Xinjiang Academy of Agricultural Sciences, Urumqi 830091, China;
[2] Xinjiang Agricultural University, College of Horticulture, Urumqi/China;
Tel: 8618509911862; E-mail: 731961221@qq.com
DOI: https://doi.org/10.35633/inmateh-67-45

***Keywords:** agricultural machinery; apricot; breaking machine; orthogonal test; design; optimization*

ABSTRACT
Low productivity and high price are considered problems of the apricot stone shell breaking machine, which is widely used in current apricot production. In this paper an apricot stone shell breaking machine was designed, the mechanical properties of apricot stone by a shell breaking machine were analyzed, and the key working parts of this machine were designed. The structure and the working parameters of the shell breaking machine are the key factors affecting the shell breaking performance determined. In this paper, the effect of shell breaking was investigated by using shell breaking clearance, feeding speed and differential speed ratio of rollers as test factors and shell breaking rate and kernel damage rate as evaluation indicators. The results of the test showed that the effects of all factors on the shell breaking rate and kernel damage rate were: shell breaking clearance > feeding speed > differential speed ratio; according to the results of single factor test and orthogonal test, the machine could achieve a better shell breaking performance and work efficiency when the shell breaking clearance was 8.5 mm, the feeding speed was 350 kg/h and the differential speed ratio was 1.75. The validation experiment was carried out with the optimal parameters' combination. The shell breaking rate and kernel damage rate were 99.04 % and 2.28 %, respectively, which provided a theoretical basis for the design and optimization of the apricot stone shell breaking machine.

摘要
针对目前新疆生产中普遍使用的的杏核破壳机械存在效率低、价格高的问题，本文研制了一种杏核破壳机通过对杏核力学特性进行分析以及设计其关键工作部件,关键工作部件结构和工作参数是影响破壳效果的关键因素。文中以破壳间隙、喂料速度和对辊差速比为试验因素，破壳率和杏仁损伤率为评价指标对破壳效果进行了试验研究，结试验果表明：各因素对破壳率、杏仁损伤率的影响均为：破壳间隙 > 喂料速度 > 差速比；综合单因素试验和正交试验结果可知，破壳间隙为 8.5 mm，喂料速度为 350 kg/h，差速比为 1.75 时杏核破壳机能够取得较好的破壳效果和工作效率。以优化后参数组合进行试验验证，结果为：杏核破壳率为 99.04 %，杏仁损伤率为 2.28 %，研究结果为杏核破壳机的设计和优化提供了理论依据。

INTRODUCTION
Xinjiang is very suitable for planting apricots with superior quality by virtue of unique geographical location and climate conditions. According to China Statistical Yearbook, the apricot planting area in Xinjiang has been more than 0.1126 million hm^2 and an annual output of 0.93 million tons by the end of 2019 was obtained, ranking first in China *(Liu et al., 2018)*. With the adjustment of agricultural planting structure, the apricot planting area is still increasing in Xinjiang. The apricot industry has become an essential pillar for rural economic development in southern regions of Xinjiang *(Yu, 2003)*. Apricot kernel is widely used as an ideal plant protein crop for forage, which is rich in nutrients such as protein and lysine and the kernel is a kind of traditional Chinese medicine, with multiple pharmacological activities such as lowering blood fat, detoxification, antiviral and bacteriostasis *(Zheng, 2019; Zhao et al., 2005)*. In recent years, with the increase of people's health awareness, the planting area of apricot in China increases year by year *(Sun, 2003)*. Apricot shells and apricot kernels grow synchronously, so it is necessary to avoid damaging kernels during shell breaking. At present, the apricot stone shell breaking mainly depends on manual breaking, which costs a large amount of labor and has low efficiency and it is difficult to control the force of manual breaking shells resulting in damaged kernels *(Tang et al., 2015; Zhang et al, 2010; Xiang et al., 2021)*. Therefore, it is important to achieve the mechanization of the apricot stone breaking operation in order to improve the efficiency of apricot production in Xinjiang.

Since 1960s, relevant studies of apricot stone shell breaking machine had been developed overseas *(Altuntas et al., 2010; Ebubekir et al., 2009; Sunmou et al., 2015; Xue et al, 2014)*. An apricot kernel sheller was designed. It can complete shell breaking operations simultaneously, and the apricot kernel yield was increased compared to that of manual breaking *(Feiling et al., 1967)*. An apricot kernel sheller was developed which can be adjusted according to apricot kernel type and other conditions; although it is more effective in apricot kernel shell breaking and offers greater applicability, the machine still needs to be improved as a result of its poor stability and reliability *(Thomson, 1998)*. An apricot kernel and soft shell nut sheller was developed with high working efficiency and high working performance *(Borrell, 2015)*. However, it cannot meet the requirements on the shell breaking of apricot in China. In order to improve the apricot shell breaking efficiency, domestic scholars have done a lot of meaningful exploration, which is a promising solution to kernel mechanical harvest *(Liu, 2016)*. A breaking machine for breaking apricot kernels was designed, and it has various problems, such as high cost, low efficiency, poor breaking quality *(Li, 1990)*. The 5XJC-350 almond breaking machine was developed. Before that the key working parts of the shell-breaking operation were designed and calculated, and the shell-breaking effect of different working parts was tested several times *(Su et al., 1993)*. A new type of apricot kernel crushing machine has been developed, but there are problems such as low efficiency and poor breaking effect *(Guo et al., 2004)*. A roller-rolling plate type ginkgo hulling machine was designed, the crush board was improved, the shell breaking rate of which can reach 70% and the smashed nut rate is less than 12% *(Zhu et al., 2008)*. A household type small apricot kernel hulling machine was designed, but it is quite expensive and unsuitable for the planting mode in Xinjiang, and it is difficult to be widely promoted in Xinjiang *(Yin et al., 2015).*

Therefore, this paper launches the study and development of apricot stone shell breaking machine duly by combining the present planting state of apricot in Xinjiang, based on the digestion and assimilation of domestic and foreign advanced technology. The improvement of shell breaking efficiency and reduction of labor costs is of great realistic significance for the development of the apricot industry. Apricot stone shell breaking machine is characterized by a compact structure, flexible operation, transfer convenience, low price, etc. thus being able to adapt to the small-farmer and widely-distributed apricot planting mode, and conform to the demands of era development and the market.

MATERIALS AND METHODS

Overall structure and working principle

Aiming at the apricot planting mode in Xinjiang regions and meeting the design principles of shell breaking, an apricot stone breaking machine is studied and designed. It mainly consists of a frame, a pressing roller, a vibrating screen, a swing arm device, an eccentric transmission device, etc. The overall structure is shown in Figure 1, while the main performance indexes and technical parameters are shown in Table 1.

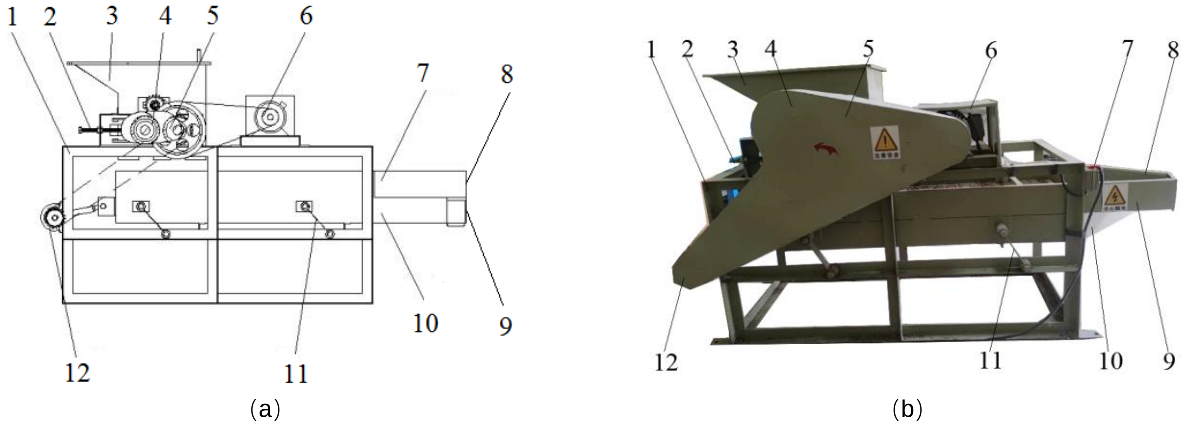

Fig. 1 - Structure diagram of apricot stone shell breaking machine
(a) Schematic diagram of sample machine; (b) General structure of sample machine;

1 – Frame; 2 – Roller pitch adjustment device; 3 – Feeding device; 4 – Adjustable roller; 5 – Fixed roller; 6 – Motor; 7 – Upper vibrating screen; 8 – Upper discharge port; 9 – Lower discharge port; 10 – Lower vibrating screen; 11 – Swing arm device; 12 – Eccentric vibration mechanism

Table 1

Main technical parameters

Parameter	Value	Units
Overall dimension (length × width ×height)	1950×850×1200	mm
Productivity	300~500	kg/h
Whole kernel rate	≥95	%
Auxiliary power	1.5	kW
Mating rotation speed	1 400	r/min

The apricot stone shell breaking machine is driven by a motor through a V-belt, and the material can be crushed at different feeding speeds. Its main working parts are a pair of parallel crushing rollers. Before shell breaking, adjust the gap of shelling roller according to the size of apricot stones. When the apricot stone shell breaking machine is working, the apricot stone enters the crushing roller through the feeding hopper in which the shell breaking roller rotates at a high speed. The apricot stone is first ground by the crushing roller and then further ground by the impact between the feed and sieve. When the apricot stones enter the crushing roller and flow through the gap between the crushing rollers, they are crushed under the friction, extrusion and collision of the crushing roller, and finally the mixture of kernels, crushed shells and dust is obtained. When the apricot kernel size is smaller than the sieve hole diameter, the kernel is discharged from the outlet.

Design of shell crushing device

The shell crushing device is the core component of the apricot stone shell breaking machine, which is used in conjunction with the feeding device to finish the crushing of the apricot stone shell. The structure and performance will directly influence the apricot stone shell breaking quality and working efficiency. The design of the shell crushing device meets various technical requirements, like simple structure, compact structure, little vibration and low power consumption. Considering the apricot planting mode in southern Xinjiang regions, and meeting the design requirements of a simple and strong reliability, a pair of parallel shell breaking rollers is employed. The shell breaking roller mainly crush the apricot stone shell, and it consists of a fixed pressure roller and an adjustable pressure roller. Its structure is shown in Figure 2. One of the pressure rollers is set up as an adjustable roller, and the shell-breaking gap can be adjusted according to the different sizes of apricot stones by means of adjusting bolts. The shell breaking roller can improve the ability of the shell crushing device to enter and break apricot stone. According to the size of the apricot stone and the actual shelling effect, the length of the shelling roller is 700 mm, the diameter is 160 mm, the width of the groove is 1.5 mm and the depth is 1 mm, in order to increase the friction force to prevent the bad rolling of the apricot stone.

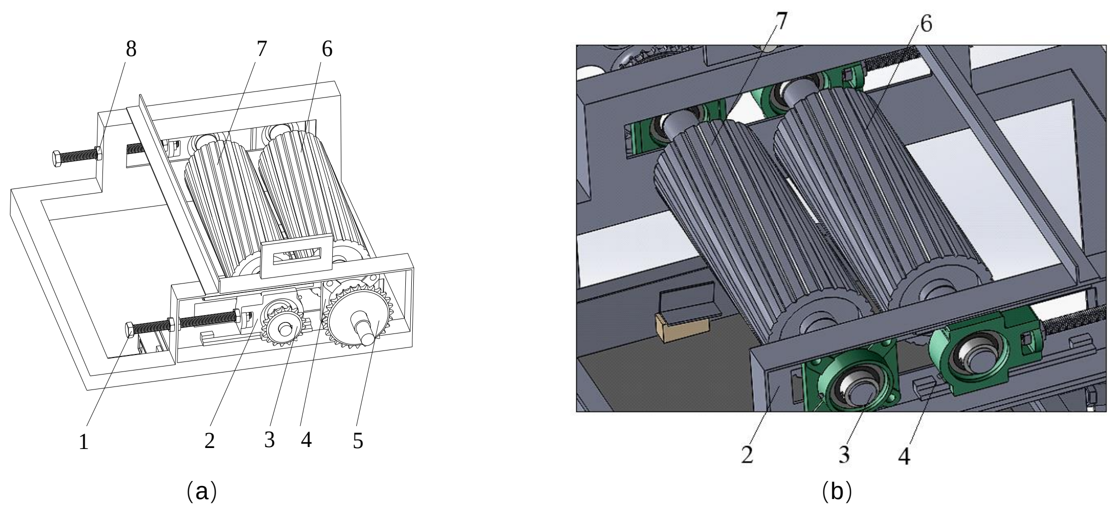

Fig. 2 - Schematic diagram of shell crushing device
(a) Two-dimensional model diagram;(b) 3D model diagram

1 – Adjusting bolt; 2 – Adjusting plate; 3 – Shell breaking roller gear 1; 4 – Bearing seat;
5 – Shell breaking roller gear 2; 6 – Fixed pressure roller; 7 – Adjustable pressure roller; 8 – Locking nut

Analysis of shell breaking process

The roller spacing of the changes can be adjusted consequently through moving the spacing of the adjusting bolt. When the crushing device spacing is smaller than the diameter of the apricot stone, the apricot stone cannot pass through the crushing device and is crushed by the rollers. When the crushing device spacing is bigger than the apricot stone diameter, the apricot stone can pass through the roller clearance all the time. Force analysis diagram between the apricot stone and rollers is shown in Figure 3(a). At the contact points of the shell breaking roller and apricot stone, there is positive pressure N_1 and N_2 and force of friction f_1 and f_2. The resultant force of the positive pressure and friction force is expressed by F_1 and F_2 respectively. The combined force of pressure N_1 and shell breaking roller *1* friction f_1 is the active force F_1 between the apricot stone and the shell breaking roller. The combined force of pressure N_2 and shell breaking roller *2* friction f_2 is the active force F_2 between the apricot stone and the shell breaking roller. The active force F_1 and F_2 are decomposed along the x and y axes to obtain F_{1x}, F_{1y} and F_{2x}, F_{2y} respectively, the condition for the shell breaking roller to crush apricot stone is that the force F_{1x} and F_{2x} acting on the two contact points are in the same straight line namely $F_{1x}=F_{2x}$. If $F_{1y}= F_{2y}$ the two forces have the same direction, which can only make the apricot stone enter the shell breaking area and the apricot stone can be crushed, but it is difficult to make the broken shells move and slip relatively, and the shell kernel cannot be separated effectively.

If the angular velocities of the two shell breaking rollers are different, namely $\omega_1>\omega_2$, the active force F_1 and F_2 on apricot stone are also different, as shown in Figure 3(b).

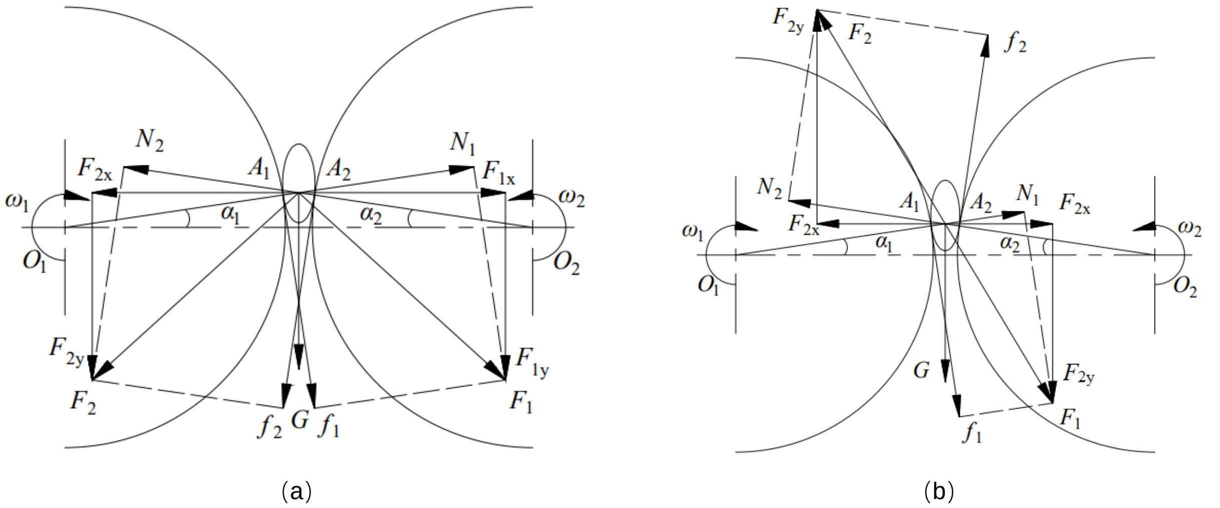

Fig. 3 - Force analysis diagram between the apricot stone and shell breaking rollers;
(a) $\omega_1=\omega_2$; (b) $\omega_1>\omega_2$

A Cartesian coordinate system is established, where the rotation center of the shell breaking roller is considered as the coordinate origin. The direction of the X-axis is the horizontal direction of the machine, and the direction of the Y-axis is vertical. The friction force F_1 of shell breaking roller 1 and the apricot stone in the horizontal and vertical directions is as F_{1x} and F_{1y}. In the same way, F_{2x} and F_{2y} can be obtained. Because the gap between the two rollers is less than the thickness of the apricot stone, the apricot stone will not move along the X-axis in the working area of the shell breaking roller, that is, $F_{1x} =F_{2x}$, and act on the same straight line. However, F_{1y} and F_{2y} are a group of variable forces with opposite directions, different sizes and not acting on the same straight line, which can be represented as follows:

$$\begin{cases} F_{1y}=F_{1x}\tan(\theta-\alpha) \\ F_{2y}=F_{2x}\tan(\theta-\alpha) \end{cases} \tag{7}$$

Where:

F_{1x} - is the decomposition force of resultant force F_1 along the X-axis, N;
F_{1y} - is the decomposition force of resultant force F_1 along the Y-axis, N;
F_{2x} - is the decomposition forces of resultant force F_2 along X-axis, N;
F_{2y} - is the decomposition forces of resultant force F_2 along Y-axis, N;
α - is the extrusion angle, which varies in the working area, (°);
N_1 - is the positive pressure of the shell breaking roller 1 on the apricot stone, N;
N_2 - is the positive pressure of shell breaking roller 2 on apricot stone, N;

F_1 - is the friction force between the shell breaking roller 1 and the apricot stone, N;
F_2 - is the friction force between the shell breaking roller 2 and the apricot stone, N.

The apricot stone is extruded by the horizontal force of F_1 and F_2 to produce deformation and cracks, and the apricot stone is torn by the friction force of f_1 and f_2, so that the cracks on the apricot stone shell continue to expand and the relative misalignment and slippage between the broken shells occur, thus realizing the extrusion and tearing of the apricot stone to crush the shell. Therefore, in order to break the shell of apricot stone, the rollers need to maintain a certain differential speed.

By analyzing the shell breaking process of the machine, it is found that if the shell breaking roller clearance is too large, the apricot stone will fall easily, resulting in leakage of apricot stone and affecting the quality of shell breaking. If the shell breaking roller clearance is too small, it is easy to damage the kernels, causing problems such as kernel injuries and plugging. In addition, the feeding speed is also an important test factor. If the feeding speed is too high, it will lead to power consumption and plugging. If the feeding speed is too low, it will lead to low efficiency. Therefore, the main factors affecting the operation effect of the shell breaker are determined as follows: shell breaking clearance *A*, feeding speed *B*, and differential speed ratio *C*. The above three factors are selected as the test influencing factors.

Test conditions

In this study, the test material apricot variety selected Saibati which is produced in Ingisha County of Xinjiang Autonomous Region. It was harvested artificially in June 2021, and then dried and stored naturally after harvest, with the residual pulp removed from the apricot stone surface, and the average moisture content of the stones was measured to be 6.2% as the original material for the test. According to the preliminary test, the thickness of Saibati apricot stones was divided into three grades, *A*1 (9-10 mm), *A*2 (10-11 mm) and *A*3 (11-12 mm), the apricot stones concentrated in *A*2 accounting for 60%, and apricot stones of 10-11 mm thickness size were graded before the test and selected as test materials after removing pulp from the surface.

The experimental instruments and equipment were as follows: apricot stone shell breaking machine, vernier caliper, Changzhou lucky XY-105MW halogen rapid moisture tester, electronic balance HC10002, AC1501000 speed meter, etc.

Fig. 4 - Experiment effects

Test method and test index

The orthogonal tests and single factor breaking tests were carried out with different shell breaking clearance, feeding speed and differential speed ratio, and the influence of various factors on the shell breaking effect and efficiency were obtained *(Zhang et al., 2020; Chen, 2005)*. Before the test, the gap of the shell breaking roller was calibrated according to the test requirements. Then, the clearance of the shell breaking roller was measured and the required clearance was repeatedly adjusted. The shell breaking rate represents the percentage of apricot stone crushed. The weight of apricot stones in the test area was counted before breaking. After the breaking test was completed, the weights of crushed and non-crushed apricot stones were counted and the weight of crushed kernels in the test area was counted after breaking. Each group of data was collected five times, and the average was calculated.

To intuitively reflect the working effect and energy consumption of the apricot stone shell breaking machine, the shell breaking rate and kernel damage rate were used as indicators to determine the performance of the shell breaking machine.

The apricot kernel shell breaking rate P_1 and kernel damage rate P_2 can be defined as follows:

$$P_1 = 1 - \frac{Z_1}{Z_2} \times 100\% \tag{8}$$

Where:

P_1 - is the apricot stone shell breaking rate, %;

Z_1 - is the total weight of unbroken apricot stones in the test area, kg;

Z_2 - is the total weight of apricot stones in the test area, kg.

$$P_2 = \frac{Z_3}{Z_4} \times 100\% \tag{9}$$

Where:

P_2 – is the kernel damage rate, %;

Z_3 - is the total weight of crushed kernels in the test area;

Z_4 - is the total weight of kernels in the test area, kg.

RESULTS

Single factor test

Effect of shell breaking clearance on the performance of the shell breaking machine

The apricot stone feeding speed was set at 350 kg/h; the differential speed ratio was 1.75, and the shell breaking gap was adjusted to 7.75, 8.0, 8.25, 8.50, 8.75, 9.0 and 9.25 mm. The relationship between the shell breaking clearance and apricot stone shell breaking rate and kernel damage rate is shown in Fig. 5.

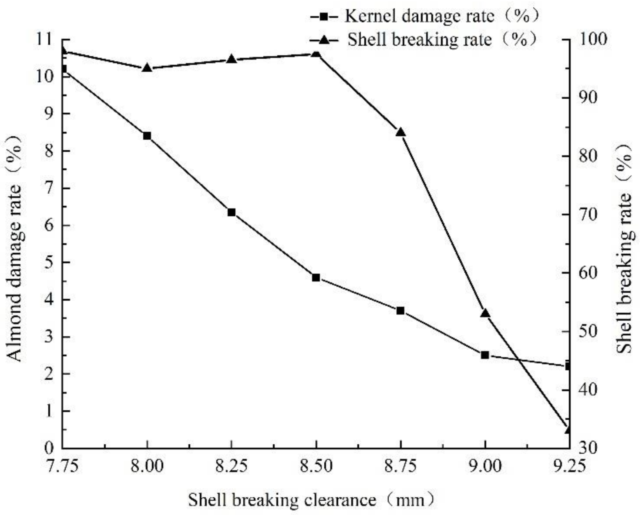

Fig. 5 - Influence of shell breaking clearance on the machine performance

It can be seen from Fig. 5 that when the shell breaking gap was 7.75-9.25 mm, the kernel damage rate decreased with the increase in shell breaking clearance, and the shell breaking rate increased first and then decreased with the increase in shell breaking clearance. However, when the shell breaking clearance was 8.75-9.25 mm, there is a big drop, and the kernel damage rate was low. Taking all test results into comprehensive consideration, the best shell breaking clearance range for the apricot stone shell breaking machine was 8.25-8.75 mm.

Effect of differential speed ratio on the performance of the shell breaking machine

The differential speed ratio was set at 1.5; the shell breaking clearance was 8.5 mm; and the apricot stone feeding speed was adjusted to 200, 250, 300, 350, 400, 450 and 500 kg/h.

The relationship between the feeding speed and apricot stone shell breaking rate and kernel damage rate was obtained, as shown in Fig. 6.

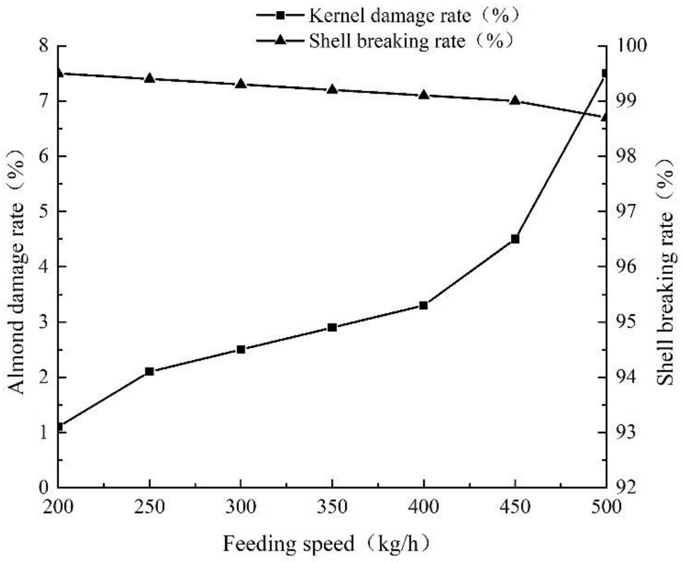

Fig. 6 - **Influence of feeding speed on the machine performance**

It can also be seen from Figure 6 that, when the feeding speed was 200-400 kg/h, the kernel damage rate increased slowly with the increase in the feeding speed. The shell breaking rate tended to be stable when the feeding speed was 200 kg/h to 500 kg/h, showing an insignificant change and the shell breaking rate decreased with the increase in the feeding speed. When the feeding speed was 400-500 kg/h, the kernel damage rate increased rapidly with the increase in the feeding speed, and the shell breaking rate decreased with the increase in the feeding speed. Taking all test results into comprehensive consideration, when the feeding speed was 300-400 kg/h, the comprehensive performance of the apricot stone shell breaking machine was the best.

Effect of differential speed ratio on the performance of the shell breaking machine

The feeding speed was set at 350 kg/h; the shell breaking clearance was 8.5 mm; and the differential speed ratio was adjusted to 1, 1.25, 1.5, 1.75, 2.0, 2.25 and 2.5. The relationship between differential speed ratio and apricot stone shell breaking rate and kernel damage rate was obtained, as shown in Fig. 7.

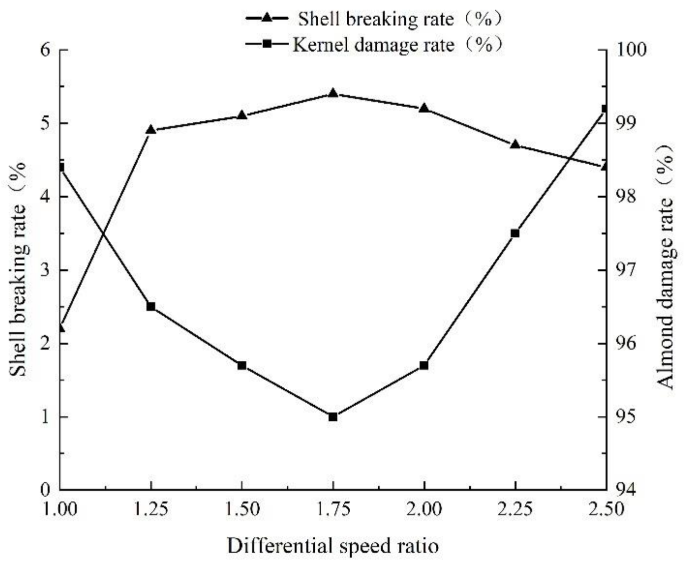

Fig. 7 - **Influence of differential ratio on the machine performance**

As shown in Fig. 7, the shell breaking rate increased first and then decreased slowly with the increase in the differential speed ratio and the kernel damage rate decreased first and then increased with the differential speed ratio. When the differential speed ratio increased from 1 to 1.75, apricot kernel damage rate showed a significant decreasing trend. When the differential speed ratio was 1.75-2.5, the apricot kernel damage rate showed a significant increasing trend. Taking all test results into comprehensive consideration, when the differential speed ratio was 1.5-2, the comprehensive performance of the apricot stone shell breaking machine was the best.

Orthogonal test and results

After the single factor levels were initially selected and reduced through a large number of single-factor tests in the early stage, part of the representative factor levels was selected to carry out orthogonal tests. Temporarily disregarding the interaction between various factors, orthogonal tests of three factors and three levels were carried out. By using the orthogonal table $L_9(3^3)$, a test plan consisting of nine horizontal combinations was designed to find out better production conditions.

The feeding speed, shell breaking clearance, and differential speed ratio were taken as the three factors to design the orthogonal test. The factors and levels are shown in Table 2, and the orthogonal test design is shown in Table 3.

Table 2

Factor level coding of orthogonal tests of four factors and three-level

Level	Experimental factors		
	Broken shell clearance A (mm)	Feeding speed B (kg/h)	Differential ratio C
1	8.25	300	1.5
0	8.5	350	1.75
1	8.75	400	2

Table 3

Result of orthogonal test

Number	Factors			Experimental index	
	A	B	C	Shell breaking rate (%)	Kernel damage rate (%)
1	-1	-1	-1	95.73	6.36
2	-1	0	0	97.42	5.56
3	-1	1	1	95.86	6.92
4	0	-1	0	97.96	4.15
5	0	0	1	98.89	3.93
6	0	1	-1	98.21	4.77
7	1	-1	1	90.98	6.11
8	1	0	-1	93.42	5.57
9	1	1	0	92.37	5.84

After the test data were sorted by office software, the orthogonal test method, variance analysis method and comprehensive balance method were used to analyze the data and optimize the optimal working conditions. In order to further explore the impact of various factors on the evaluation indicators, the test data were sorted with SPSS 20.0 data software, and then the data were analyzed through the orthogonal experiment method and comprehensive analysis method, and the results are shown in Table 4.

Table 4

Factor level table for orthogonal test

Analysis item	Shell breaking rate			Kernel damage rate		
	A	B	C	A	B	C
K_1	289.01	284.67	287.36	18.84	16.62	16.70
K_2	295.06	289.73	287.75	12.85	15.06	15.55
K_3	276.77	286.44	285.73	17.52	17.53	16.96
R	18.29	5.06	2.02	5.99	2.47	1.41
Primary and secondary factors		A > B > C			A > B > C	
Optimal combination		$A_2B_2C_2$			$A_2B_2C_2$	
SS	57.883	4.396	0.765	6.603	1.040	0.375
df	2	22		2	2	2
MS	28.941	65.519	11.410	3.302	0.520	0.188
F	862.776	65.519	11.410	150.004	23.631	8.527
P	0.001	0.015	0.081	0.007	0.0041	0.105
Significance	**	*		**	**	

Note: p<0.01 is extremely significant; 0.01<p<0.05 is significant; P> 0.05 is not significant, k1, k2, k3 represent the sum of indicators at each level of each factor; R is the measure of variation

According to the result analysis in Table 4, when the working conditions are fixed, the shell breaking clearance has the greatest influence on the apricot stone shell breaking rate and kernel damage rate, followed by the feeding speed and the differential speed ratio. The influence of the shell breaking clearance of the machine on the shell breaking rate and the kernel damage rate is extremely significant ($p<0.01$), the influence of the feeding speed on the shell breaking rate is significant ($0.01<p<0.05$), the kernel damage rate is extremely significant ($p<0.01$), and the influence of differential speed ratio of the machine on the shell breaking rate and the kernel damage rate is not significant. When selecting the optimal parameters, the comprehensive balance method should be adopted. Taking the relative kernel damage rate less than 5% as the main reference and combining the actual working situation, the optimal combination of $A_2B_2C_2$ is adopted.

Test verification

Because the production conditions of $A_2B_2C_2$ had been measured in the previous test, in order to verify the accuracy of the orthogonal test results, the processing conditions of $A_2B_2C_2$ were again verified in the test, whereby the feeding speed is 350 kg/h, the shell breaking clearance is 8.5 mm, and the differential speed ratio is 1.75. Compared with other test conditions in the orthogonal test, the obtained test results showed that the shell breaking rate and kernel damage rate were optimum, as shown in table 5.

Table 5

Validation test value

Test number	Shell breaking rate / (%)	Kernel damage rate / (%)
1	98.97	2.12
2	99.23	3.04
3	98.92	1.67
Average value	99.04	2.28

It can be seen from table 5 that under the optimal parameter combination, the results indicated that the maximum shell breaking rate was 99.23%, minimum shell breaking rate was 98.92%, and average shell breaking rate was 99.04%; the maximum kernel damage rate was 3.04%, minimum kernel damage rate was 2.28%. The validation test verified that the shell breaking machine designed in this study met the design requirements for apricot stone shell breaking devices. Due to the complex apricot stone harvesting operation and the differences in planting conditions and climate in different regions, apricot stone varieties, moisture content, yield and other factors have changed, and the shell breaking clearance is slightly different. The combination of optimal operation parameters under a single condition cannot be generally applicable, so the parameters need to be adjusted according to the actual operation conditions to meet various shell breaking needs.

(a) (b) (c)

Fig. 8 - Validation test effect diagram

(a) before apricot stone shell breaking; (b) after apricot stone shell breaking; (c) apricot kernel

CONCLUSIONS

From the above test results, the following conclusions can be drawn:

(1) In this study, an apricot stone shell breaking machine was developed. The machine is composed of a shell crushing device, a transmission mechanism and a frame, etc. Key parts of apricot stone shell breaking machine are designed and optimized.

(2) The single factor test and orthogonal test is carried out with the shell breaking clearance, feeding speed and differential speed ratio as the test factors and shell breaking rate and the kernel damage rate as the evaluation indexes. Through the comprehensive balance analysis, the primary and secondary order of the three affecting factors were shell breaking clearance, feeding speed, differential speed ratio.

(3) According to the variance analysis, the influence of the shell breaking clearance of the machine on the shell breaking rate and the kernel damage rate is extremely significant, the influence of the feeding speed on the shell breaking rate is significant, the influence of the kernel damage rate is extremely significant, and the influence of the differential speed ratio of the machine on the shell breaking rate and the kernel damage rate is not significant.

(4) Under the production conditions of $A_2B_2C_2$, the shell breaking rate was 99.04%, the kernel damage rate was 2.28%. Compared with other test conditions in the orthogonal test, the obtained test results showed the best shell breaking rate, and the kernel damage rate here was slightly higher than the optimal value. The test results proved that the optimal working conditions obtained through the orthogonal test basically conformed to the actual working situation, indicating that the combination of process parameters was reliable and optimal.

(5) In this study, more internal factors and structural parameters of the sample machine had been taken into account, such as test design, factor selection and indicator setting, while external factors were not considered, since this part would be discussed in other studies.

ACKNOWLEDGEMENT

The authors acknowledge that this work was financially supported by the Scientific Research Project of Xinjiang Minority Scientific and Technological Talents Special Training Plan (2022D03007), Xinjiang Academy of Agricultural Sciences Youth Science and technology Backbone Innovation Ability Training Project (xjnkq-2021019).

REFERENCES

[1] Altuntas E, Erkol M. (2010). Physical properties of shelled and kernel walnuts as affected by the moisture content. *Czech Journal of Food Sciences*, 28(6), 547-556.

[2] Borrell J V R. (2015). *Shelling-separating machine especially for almonds and other soft-shelled nuts*: U.S. Patent 8, 943, 955 [P]. 2015-2-3.

[3] Chen Kui. (2005). *Test design and analysis*. Beijing: Tsinghua University Press, 72-97.

[4] Ebubekir A, Mehmet E. (2009). The effects of moisture content, compression speeds, and axes on mechanical properties of walnut cultivars. *Food Bioprocess Technol*, 4(2001), 1288-1295.

[5] Feiling J M. (1967). *Almond huller*: U.S. Patent 3, 347, 295 [P]. 1967-10-17.

[6] Guo Ruiqin, Liu Zhuli. (2004). A new device for shelling almonds. *Mechanical Design and Research*. 04, 83-84+9.
[7] Liu Hong, Niu Rong. (2018). Current situation and development trend of Xinjiang characteristic forest and fruit industry. *Shanxi Agricultural Economics*, 09, 29-30.
[8] Liu Xiangdong. (2016). *Studies on mechanism and equipment of orientating and halving and pitting of fresh apricots*. Shenyang: Shenyang Agricultural University, 27-30.
[9] Li Shifeng. (1990). Experimental study on work part of apricot nucleus. *Journal of Hebei Agricultural Teachers College*, 4(02), 66-71+76.
[10] Sun Lanfeng. (2009). *Research on Xinjiang features fruit trees from the perspective of sustainable development*. Urumqi: Xinjiang University, 30-36.
[11] Su Yingchen, Huang Xingguo, Sun Ming. (1993). Research and development of 5xjc-350 almond processing equipment. *Grain and Oil Processing and Food Machinery*, 01, 18-21.
[12] Sunmonu M O, Iyanda M O, Odewole M, et al. (2015). Determination of some mechanical properties of almond seed related to the design of food processing machines. *Nigerian Journal of Technological Development*, 12(1), 22-26.
[13] Thomson K. (1998). *Nut cracker*: U.S. Patent 5, 711, 213[P]. 1998-1-27.
[14] Tang Xiang, Xie Fangping, Li Xu et al. (2015). Experimental research of mechanics characteristics of camellia oleifera fruit cracking. *Journal of Shanxi Agricultural University (Natural Science Edition)*, 35(04), 435-440.
[15] Xiang Wei, Ma Lan, Liu Jiajie, et al. (2021). Research and development of continuous clamping and delivering ramie decorticator. *Transactions of the Chinese Society of Agricultural Engineering*, 37 (01), 19-27.
[16] Xue Zhong, Guo Xiangming, Huang Zhengming et al. (2014). Experimental study on multifactor compression of macadamia nuts. *Southwest China Journal of Agricultural Sciences*, 27, (03), 1269-1273.
[17] Yu Xizhi. (2003). Talk about the current situation and Countermeasures of apricot production in China. *Northern Fruits*, 05, 24-26.
[18] Yin Pengfei, Sun Jiayu. (2015). A household-type small almond hulling machine. *Technological development of enterprise*, 34 (07), 43-45.
[19] Zheng Wenzhong. (2019). Study on current situation and countermeasures about mechanization of the fruit industry in Xinjiang. X*injiang Agricultural Mechanization*, 03, 7-9+13.
[20] Zhu Lixue, Luo Xiwen, Liu Shaoda. (2008). Optimized design and experiment of roller-crush board ginkgo huller. *Transactions of the Chinese Society for Agricultural Machinery*, 08, 139-142.
[21] Zhang Xuejun, Ma Shaoteng, Zhu Xingliang, et al. (2020). Design and test of oil-sunflower threshing device with variable clearance. *Transactions of the Chinese Society of Agricultural Engineering*, 36 (04), 26-33.
[22] Zhang Lihua, Qin Wen, Ma Rongchao. (2010). Mechanical properties of apricot seeds under compression loading. *Food Science*, 31 (17), 143-147.
[23] Zhao Xiaoguang, Zong Yi. (2005). Application and development status of nut shelling technology. Xinjiang Agricultural Mechanization, 06, 29-32.