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Design and Test of an Automatic Husking and Peeling Machine for Fresh Lotus Seeds

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There are regional differences, variety and maturity differences in fresh lotus seeds. The parameters of the working parts of husking and peeling machine need to be adjusted in real time according to the processing effect. Aiming at the problems of complex transmission, difficult connection and adjustment of various working parts of the machine on the market, an automatic husking and peeling machine for fresh lotus seeds is designed with the husking module and peeling module as the core devices. Based on the kinematic analysis of fresh lotus seeds during the circulation process, a groove wheel feeding mechanism and an arc track are designed to realize the feeding and circulation of fresh lotus seeds. The effect of working parameters on the membrane removal effect and the interaction between working parameters were experimentally studied by response surface methodology, and the correctness was verified by experiments. The experiment results showed that the processing qualification rate, damage rate and processing efficiency of the machine can meet the requirements of lotus farmers. This research can provide a theoretical basis for the structural design and parameter optimization of related equipment.

Keywords: fresh lotus seed; feeding; arc track; husking; peeling; parameter matching

1 Introduction

Lotus seeds are an agricultural product with Chinese characteristics, and the planting areas are mainly concentrated in Zhejiang, Fujian, Jiangsu, Hubei, Hunan and Taiwan [1-3]. Wuyi Xuanlian, Fujian Jianlian, Hunan Xianglian and Guangchang Bailian are known as the four famous lotuses in China [4]. Generally, a lotus seed consists of three parts: lotus husk, lotus core and lotus kernel, among which lotus kernel is the most common in the market. To obtain lotus kernels, multiple processes such as selection, grading, husking and coring of lotus seeds are required [5]. After a lotus seed is taken out of the lotus seedpod, the fresh lotus seed needs to be husked and peeled [6], and the seed coat on the lotus kernel needs to be removed for peeling. Because the lotus kernel is wrapped with two layers of lotus membranes, peeling is difficult, and manual peeling takes up half of the whole process. The mechanical peeling methods of fresh lotus seeds mainly include frictional peeling and washing peeling. Frictional peeling cannot avoid the lotus kernel being damaged due to the friction between the exposed lotus kernel and the felt belt after the lotus membrane is peeled off partially. Therefore, frictional peeling is mostly used in the peeling of dry lotus seeds. As long as the water pressure is properly adjusted and the nozzle structure is reasonable, the lotus membrane can be removed efficiently and non-destructively by washing peeling.

Most of fresh lotus seed husking and peeling machines based on frictional peeling and washing peeling adopt a purely mechanical structure [7], and their working parts are driven by a main motor through a complicated mechanical transmission mechanism [8]. Moreover, the parts they use are non-standard and have the disadvantages of high production cost, poor stability and reliability, low self-adaptation and easy damage to lotus seeds during the processing [9-11]. It is easy to cause cuts or scratches on the surface of lotus kernel, dull color and luster, and obvious cutting marks of dry white lotus kernels. In view of the problems in the current husking and peeling machines, an automatic husking and peeling integrated machine for fresh lotus seeds was designed based on the washing peeling.

2 Structure and operating principle of the machine

The automatic husking and peeling integrated machine for fresh lotus seeds mainly includes feeding module, husking module, peeling module, conveying module, and auxiliary modules such as water tank. The main technical parameters of the machine are shown in Tab. 1. The feeding module is installed in front of the frame panel and cooperates with the conveying module below it to realize the continuous feeding and sequential conveying of fresh lotus seeds one by one. A cutter mechanism for circularly cutting the lotus husk in the short-diameter direction of a fresh lotus seed, a rolling and husking mechanism for separating the lotus husk after cutting, and a peeling mechanism for removing the lotus membrane using a water jet are mounted sequentially in the conveying direction of the conveying module. A chute is installed at the tail of the conveyor belt and below the peeling device to collect lotus kernels.

Tab. 1 *Main technical parameters of the machine*

No.	Part name	Power/W	Reduction ratio	Output speed/rpm
1	Main conveyor motor	90	1:10	30~140
2	Grooved wheel motor	75	1:20	10~70
3	Cam motor	60	1:1	600~1400

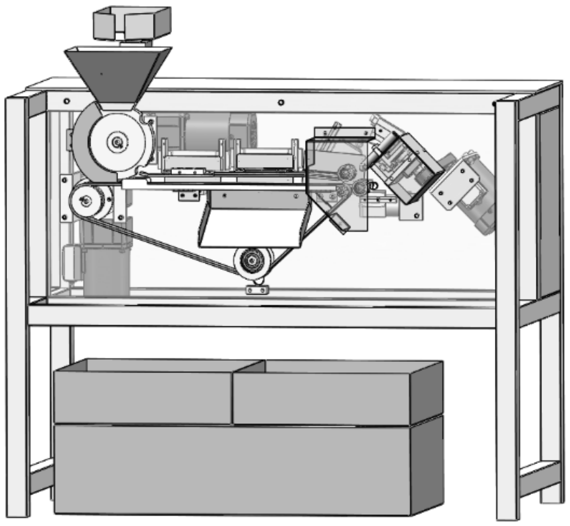

Fig. 1 *The three-dimensional structure of the fresh lotus seed husking and peeling machine*

3 Design and analysis of the key parts

3.1 Design and kinematic analysis of the feeding module

3.1.1 Design and operating principle of the feeding structure

As shown in Fig. 2, the feeding module is mainly composed of arc track, groove wheel, hopper, and drive motor. After being poured into the hopper, the fresh lotus seeds will gradually enter the chute of the vibrating tray under the action of the vibratory inline feeder. According to the measurement of the long diameter of fresh lotus seeds with husks, the chute width is designed to be 25mm. In addition, battens with arc openings are mounted on the chute to ensure the continuous arrangement of fresh lotus seeds in the chute. The front end of the chute is closed, and its lower end has an opening. When the groove wheel rotates to the lower end of the chute opening, the fresh lotus seeds fall into the groove of the wheel under the action of the vibrating propulsion force. With the rotation of the groove wheel, the fresh lotus seeds in the groove fall into the arc track. Under the action of the thrust of the groove wheel and the gravity of the fresh lotus seeds, they roll freely on the arc track to the main conveyor belt.

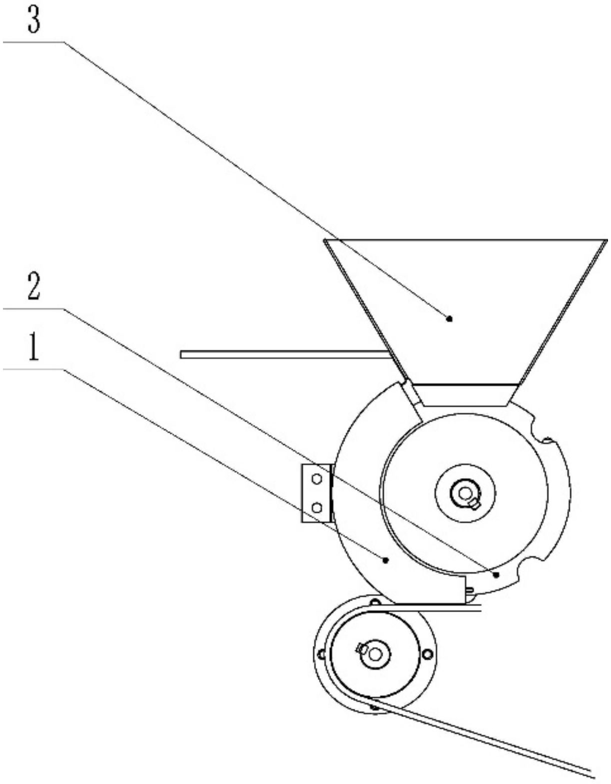

Fig. 2 *Structure of the feeding device*

Where:
1…Arc track,
2…Groove wheel,
3…Hopper.

3.1.2 Kinematic analysis of fresh lotus seeds on the arc track

The posture of fresh lotus seeds entering the husking device is one of the key factors affecting the cutting and husking of lotus husks [12]. The husking module of the device is based on the working principle of ring cutting of lotus husks and rolling husking in the short diameter direction of fresh lotus seeds. Effective husking can be performed only when the fresh lotus seeds enter the husking device, and the cutter edges make a circular cut around the short diameter circumference of fresh lotus seeds. It can be seen that before the fresh lotus seeds enter the husking device, their posture needs to be adjusted to make the long diameter in a horizontal position, and they enter the husking device in a posture perpendicular to the cutter edge.

The force analysis of fresh lotus seeds on the arc track is shown in Fig. 3. Taking the center of the groove wheel as the origin, the horizontal direction as the *X* axis, and the vertical direction as the *Y* axis, the balance equation of the plane crossing force system on the fresh lotus seeds in the groove wheel (ignoring the rolling friction force of fresh lotus seeds) is established in the plane coordinate system.

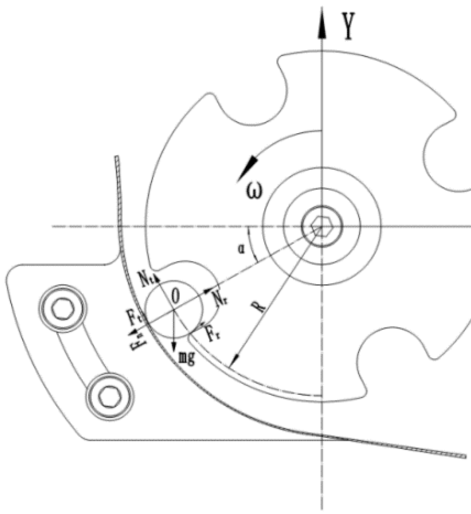

Fig. 3 *Force diagram of the fresh lotus seeds on the arc track*

Normal resultant force:

$$F_n + mg.sin\alpha_1 - N_r - F_r = 0 \quad (1)$$

Tangential resultant force:

$$N_t + F_n - mg.cos\alpha_1 = 0 \quad (2)$$

And:

$$F_r = N_t \cdot \mu = mg.\mu.cos\alpha_1 \quad (3)$$

$$N_r \cdot \mu = (F_n + mg.sin\alpha_1) \cdot \mu \quad (4)$$

Where:

F_n…Centrifugal force on the fresh lotus seeds, $F_n = m\omega^2 R$, N,

F_t…Tangential sliding friction force on the contact surface of the fresh lotus seeds, N,

F_r…Radial sliding friction force on the contact surface of the fresh lotus seeds, N,

N_t…Tangential support force on the contact surface of the fresh lotus seeds, N,

N_r…Radial support force on the contact surface of the fresh lotus seeds, N,

R…Revolution radius of the center of mass of the fresh lotus seeds, m,

ω…Angular velocity of the groove wheel, rad/s,

α…Revolution angle of the fresh lotus seeds, °,

mg…Gravity of the fresh lotus seeds, N,

μ…Sliding friction coefficient of the fresh lotus seeds.

According to the force analysis, the movement state of the fresh lotus seeds on the arc track depends on the resultant moment $T=(F_t—F_r)\cdot r$ of F_t and F_r on the central axis, where r is the short diameter of the fresh lotus seeds. When $F_t<F_r$, the fresh lotus seeds slide on the arc track; when $F_t>F_r$ and the resultant torque $T>0$, the fresh lotus seeds roll on the arc track. From the solution formulas of F_t and F_r, it can be seen that as the revolution angle α_1 of the fresh lotus seeds gradually increases, F_t increases and F_4 decreases. When $F_t=F_r$, assuming that the friction coefficient between the arc track and the contact surface of fresh lotus seeds is equal to that between the groove wheel and the contact surface, and $N_t=N_r$. Combined with formulas (1) and (2), we can obtain:

$$\alpha_1 = \frac{1}{2}\sin^{-1}(1-\frac{\omega^4 R^2}{g^2}) \quad (5)$$

The angular velocity $\omega=\pi/2$ rad/s of the feeding groove wheel, the revolution radius of the center of mass of the fresh lotus seeds R=0.053m, and the acceleration of gravity g=9.8 m/s² are substituted into formula (3) to obtain $\alpha_1=44.46°<45°$. The fresh lotus seeds start to revolute and auto rotate after the rotation angle on the arc track is greater than α_1. Therefore, the design of the arc track can ensure that the fresh lotus seeds have a certain length of rolling motion before entering the husking device.

3.2 Measurement of the fresh lotus seed parameters and design of the husking module

3.2.1 Measurement and statistics of physical parameters of fresh lotus seeds

In this study, the Xuanlian fresh lotus seeds planted in Wuyi were taken as the measuringt object, and the physical parameters of the fresh lotus seeds were measured and statistically analyzed. According to the statistical analysis result:

- (1) The distribution range of the short diameter of fresh lotus seeds (with husks) is 15.9-19.8mm, and the average short diameter is 18.25mm;
- (2) The distribution range of the long diameter of fresh lotus seeds (with husks) i20.1-24.2mm, and the average long diameter is 22.71mm;
- (3) The distribution range of the short diameter of fresh lotus seeds (without husks) is 14.5-17.8mm, and the average short diameter is 16.22mm;
- (4) The distribution range of the long diameter of fresh lotus seeds (without husks) is

16.8-20.7mm, and the average long diameter is 18.93mm;

- (5) The distribution range of the lotus husk thickness is 0.6-0.92mm, and the average thickness is 0.82mm.

3.2.2 Design of the rolling husking device

The rolling husking device is mainly composed of cutting part and rolling husking part. Both the cutting part and the rolling husking part are equipped with a tensioning mechanism to adjust the distance and pressure between the press plate and the main conveyor belt. According to the statistics of the physical parameters of fresh lotus seeds in Table 2, the distance between the press plate and the main conveyor belt is initially set to 15mm. The distance between the press plate and the main conveyor belt is adjusted to 12mm, and the pressure of the press plate is adjusted to 30N. The cutting blades are fixed by bolt pre-tightening, and the depth of the cutting blades is adjustable. Toothed battens are added at 2mm on both sides of the cutter blades to lock the fresh lotus seeds entering the press plate and ensure that the cutting blades cut lotus husks in the same circumference. In addition, the bottom surface of the press plate is glued with a flat rubber strip to prevent the press plate from pressing out the lotus kernels after husking during the rolling husking process.

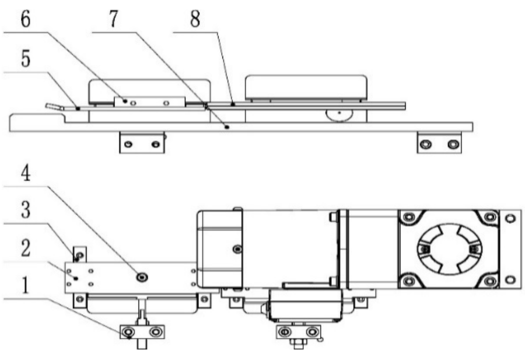

Fig. 4 *Structure diagram of the rolling husking device*

Where:
1… Tensioning mechanism,
2…Sliding mounting plate,
3…Linear slider assembly,
4…Tension spring,
5…Cutter pressing plate,
6…Cutter holder,
7…Main conveyor belt,
8…Husking pressing plate.

3.3 Design of the water washing peeling device

When using the washing peeling device, the peeled fresh lotus seeds 1 are driven by the conveyor belt 3 to pass through the detection press plate 2; the detection press plate 2 and the mounting seat 16 of the detection press plate are lifted along the linear slide rail to trigger the limit switch 15. The limit switch 15 transmits the trigger signal to the solenoid opening/closing time control relay and the spray gun water pump start/stop relay; then the solenoid opening/closing time relay starts timing, and the spray gun water pump starts. At this time, the opening/closing roller 11 installed on the solenoid telescopic rod is in a closed state; the lotus kernel is located in the center of the upper roller 4, the belt roller 5 and the opening/closing roller 11, and driven by the conveyor belt to rotate at a certain speed . When the lotus kernel rotates, the spray gun 6 and the mounting base 7 reciprocate in a straight line along the direction perpendicular to the panel. At the same time, the fan-shaped nozzle sprays a certain pressure of water flow to form a water jet, spraying the lotus membrane to achieve the purpose of removing the lotus membrane. After reaching the set time, the solenoid relay controls the suction/closing of the solenoid to drive the opening/closing roller 11 to open; then the husked lotus kernel falls into the collection frame. In this cycle, the detection pressure plate 2 and the opening/closing roller 11 are reset and then the next lotus kernel is husked.

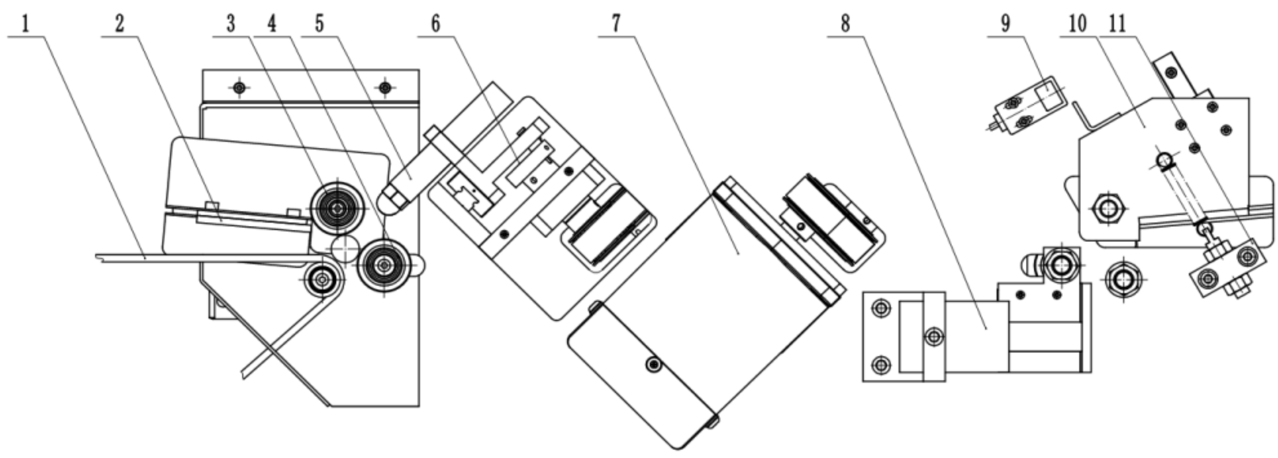

Fig. 5 *Structure diagram of the washing peeling device*

Where:
1…Main conveyor belt,
2…Press plate,
3…Upper roller,
4…Opening/closing roller,
5…Nozzle,
6…Cam mechanism,
7…Adjustable-speed motor,
8…Electromagnet,
9…Photoelectric proximity switch,
10…Sliding installation,
11…Tensioning mechanism.

4 Analysis of the influencing factors of the washing membrane removal effect

In order to explore the influence of the basic working parameters of the washing peeling device on the membrane removal effect, an experimental study was carried out by using the response surface methodology. The response surface methodology uses multiple quadratic regression equations to establish the functional relationship between the response and factors, evaluate the influencing factors and their interactions and determine the optimal value range of factors. The working parameters are taken as the experimental factors and the membrane removal rate of lotus seeds as the response. The working parameters include washing frequency, washing pressure, washing included angle and washing time of the spray gun. In order to facilitate the analysis of the influence of design variables on the film removal effect, the Box-Behnken response surface experimental design method [13-16] and Minitab were used to design the response surface experiment. $P<0.10$ was set as a significant correlation and $P<0.05$ as an extremely significant correlation. The experimental factors and levels are shown in Tab. 2.

Tab. 2 *Experimental factors and levels*

Parameters	Symbol	Levels		
		-1	0	1
Round-trip frequency of spray gun/ Hz	f	20	30	40
Nozzle pressure/MPa	P	0.8	0.9	1.0
Spray gun included angle/ °	α	13	18	23
Water washing time/s	t	0.9	1.2	1.5

An analysis of variance is performed on the experimental results of the response surface to obtain a statistically significant analysis of the influence of the working parameters on the membrane removal effect, as shown in Tab. 3. Where, f is the washing frequency; P is the washing pressure; α is the water washing angle, and t is the washing time.

Tab. 3 *Analysis of variance of response surface experiment*

Source	P-value of membrane removal rate	Source	P-value of membrane removal rate
f	0.001	f^2	0
P	0.027	P^2	0.036
α	0.337	α^2	0.003
t	0	t^2	0
f×p	0.038	p×α	0.162
f×α	0.690	p×t	0.780
f×t	0.043	α×t	0.430

According to Tab. 3, the P values of the membrane removal rate of washing frequency and washing time are 0.001 and 0, respectively, which are both less than 0.05, indicating that the above two parameters have an extremely significant influence on the membrane removal rate. The P values of membrane removal rate of washing pressure and washing angle are 0.027 and 0.337, respectively. Compared the washing frequency with the washing time, the two parameters have an insignificant influence on the membrane removal rate.

In addition to the influence of a single parameter on the membrane removal rate of fresh lotus seeds, the interaction between the working parameters also affects the film removal effect [17]. According to Table 3, the P values of both f×p and f×t are less than 0.05, indicating that the interaction between the frequency and pressure and the interaction between the frequency and time have an extremely significant influence on the removal rate. The significant or extremely significant interaction between the two factors indicates that the influence law of one factor on the response is correlated or extremely correlated to the value of the other factor.

Fig. 6 is the response surface diagram of membrane removal rate versus frequency and pressure, where the washing time t=1.2s and the washing angle α=18°. When the pressure is low, such as P=0.8MPa, the removal rate firstly increases and then decreases with the increase of frequency, and then generally tends to increase, as shown by the arrow A_1 in Fig. 6. When P=1.0MPa, the removal rate increases with the increase of frequency, and then generally tends to decrease, as shown by the arrow A_2 in Figure 6. Similarly, when the frequency is at a low level, such as f=20Hz, the removal rate increases as the pressure increases, as shown by the arrow B_1 in Fig. 6. When the frequency is at a high level, such as f=40Hz, the removal rate firstly increases and then decreases with the increase of pressure and the overall change is little, as shown by the arrow B_2 in Fig. 6.

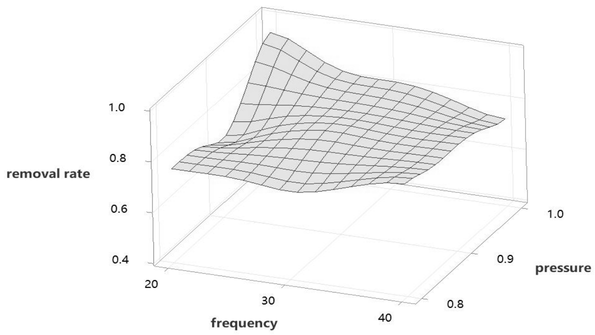

Fig. 6 *Response surface diagram of membrane removal rate versus frequency and pressure*

The P-value of membrane removal rate of the pressure is 0.027 (see Table 3), and its influence is not significant. However, due to the interaction between the washing pressure and washing frequency, the influence of pressure on the membrane removal rate cannot be represented statistically. Therefore, within the range of the working parameters studied in this experiment, the influence of the working parameters on the removal effect is different, and the interaction between the working parameters will also affect the removal effect.

According to the influences of a single parameter and its interaction on the membrane removal rate, there is no significant interaction between the angle and other working parameters. Its influence on the removal effect is minimally affected by other angles. For the operation of the reciprocating water jet peeling device, on the basis of considering the main working parameters that affect the membrane removal effect, the selection of working parameters should comprehensively consider the interaction between the working parameters from the perspective of improving the film removal effect [18]. According to the above results, on the basis of selecting the washing time and washing frequency, it is necessary to comprehensively consider the interaction between the washing frequency and washing pressure.

5 Husking and peeling experiment with the machine

5.1 Experimental scheme

The fresh lotus seeds (Xuanlian soil lotus seed) used in the experiment were all picked from Yuankou Village, Liucheng Town, Wuyi County. The lotus seeds were used for the experiment after being picked on the same day. After the experimental lotus seeds were obtained, a basket of lotus seeds were randomly selected for machine commissioning, mainly to match the frequency of the vibrating tray, the speed of the feeding groove wheel and the conveyor belt, and to adjust the pressure of the spray gun. According to the peeling and damage of lotus seeds, the reasonable range of the spray gun pressure was determined to be 0.9-1.1 MPa.

After the whole machine worked stably, 3 groups of 500 lotus seeds were randomly selected for the experiment. The processing FPY (First Pass Yield), damage rate and processing efficiency of the three groups of experiments were statistically analyzed, and the processing performance index of the husking and peeling machine was obtained. The processing FPY is the percentage of intact lotus kernels to the total number after husking of fresh lotus seeds with the machine. The damage rate is the percentage of damaged lotus kernels to the total fresh lotus seeds after husking and peeling with the machine [19-20]. The processing rate is to record the time from the first lotus seed entering the groove wheel to the last lotus kernel leaving the conveyor belt in each group of the experiment, and the unit is grains/min. The processing efficiency is calculated from the processing rate and the weight of lotus seeds per kilogram, and the unit is kg/h. In addition to intact and damaged lotus kernels, there were also lotus seeds that were not husked or incompletely husked or peeled during the experiment, all of which were regarded as processing failures.

5.2 Experimental results

The statistical data of the results obtained from the 3 groups of experiments is shown in Tab. 4. The improved automatic husking and peeling machine for fresh lotus seeds has an average processing FPY of 91.5%, a damage rate of 2.5%, a processing rate of about 58 grains/min, and a processing efficiency of about 15.4 kg/h. On the whole, the machine has good processing FPY, low damage rate and high processing efficiency, and can meet the requirements of lotus farmers.

The experimental results showed that the designed automatic fresh lotus seed husking and peeling machine had good adaptability to the size of lotus seeds, but had certain requirements for the maturity of lotus seeds. The selected lotus seeds that were not husked or incompletely husked and were not peeled or incompletely peeled during the data statistics are all lotus seeds with brown husks or clear brown stripes on the lotus membrane. The damaged lotus seeds are all lotus seeds whose maturity does not meet the processing requirements of dried lotus seeds. The first and second group of experiments indicate that in order to increase the processing rate, the working speed of each mechanism and the water pressure of the spray gun must be increased, which will lead to an increase in the damage rate. In the third experiment, the operator knew the maturity of the lotus seeds of this batch and can comprehensively consider various working parameters, which improved the processing FPY and reduced the damage rate.

Tab. 4 *Husking and peeling experiment results of the fresh lotus seeds*

Experiment group	Number of intact lotus kernels	Number of damaged lotus kernels	Time/min	FPY /%	Damage rate /%	Processing rate/(grain•min^{-1})
1	454	13	8.6	90.8	2.6	58.1
2	456	16	7.9	91.2	3.2	63.3
3	463	8	9.3	92.6	1.6	53.8
Avg.	457.7	12.3	8.6	91.5	2.5	58.1

6 Conclusion

(1) The automatic husking and peeling machine for fresh lotus seeds involved in this study includes the feeding module, husking module, peeling module and conveying module. The machine can continuously feed and convey fresh lotus seeds one by one to complete the husking and peeling processes. Based on the kinematic analysis of fresh lotus seeds during the circulation process, the paper designed an arc track and a groove wheel feeding mechanism that meet the requirements of continuous feeding and rolling of fresh lotus seeds.

(2) The influence of working parameters on the membrane removal effect and the interaction between working parameters were experimentally studied by the response surface methodology. The experimental results showed that the washing frequency and washing time had a large influence on the membrane removal effect, while the influence of washing pressure and washing angle was small. However, the washing pressure will interact with the washing frequency to indirectly affect the removal effect.

(3) According to the experimental results, the designed automatic husking and peeling machine for fresh lotus seeds had an average processing FPY of 91.5%, a damage rate of 2.5%, a processing rate of about 58 grains/min, and a processing efficiency of about 15.4 kg/h. On the whole, the machine has good processing FPY, low damage rate and high processing efficiency, and can meet the requirements of lotus farmers.

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