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MECHANICAL RESEARCH AND OPTIMIZATION OF BANANA STALK FIBER EXTRACTION

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KEYWORDS

banana stalk, fiber extraction, mechanical research, parameter optimization, orthogonal test.

ABSTRACT

Banana stalk production for fiber is an important crop activity in southern China. The fiber extraction technology used has a great impact on the effectiveness and quality of the fiber from banana stalks. A mechanical model of the process for banana stalk fiber extraction was developed through theoretical analysis. The existing problems of machines for banana stalk fiber extraction include high rates of fiber impurity and damaged fibers. A 3-factor 3-horizon orthogonal rotation combination test was established. The rates of fiber impurity and damaged fibers were the evaluation indices. The significant order of the factors determining the rate of fiber impurity, from largest to smallest, was the gap between the scraper and the holding plate, the number of scrapers, and the rotational speed of the scraping knives roller. The significant order of factors for the rate of damaged fiber was the gap between the scraper, the rotational speed of the scraping knives roller, and the number of scrapers. The optimized banana straw fiber extraction machine was tested in the field. The results show that the development of this model can provide valuable experience and references for understanding and improving other similar agricultural machinery and equipment.

INTRODUCTION

Banana is an important economic crop in the tropical region of China, mainly distributed in five provinces, namely Guangdong, Guangxi, Yunnan, Hainan, and Fujian (Zhang et al., 2010; Wei et al., 2019; Yu et al., 2024). A wealth of banana stalks are also produced when China outputs a large number of bananas. There are over 25 million tons of banana stalks produced every year in China (Zhang et al., 2024). Banana stalks are a valuable biomass energy source that can be shredded into silage for raising livestock or used as biomass fuel. Therefore, research on the comprehensive utilization of banana stalks has vitally important economic value.

Banana plants have a height of 2–5 m, a stem diameter of 20–35 cm, and a growth cycle of 6 months (Wang et al., 2017; Liu et al., 2021; Gan, 2021). A schematic cross-sectional view of a banana stalk is shown in Figure 1. The banana stalk is a thick cylindrical stem formed by multiple long, curved leaf sheaths that closely overlap each other, and the wrapped sheath is brittle and easily broken. Its growth depends largely on the lignin growing from the center of the stalk with each new leaf, whose peripheral sheath gradually pushes outward, thus swelling and growing. Banana straw fiber is mainly dispersed in the inner layer and the epidermis of the sheath, and the fiber content of the two layers is inconsistent. The fibers of the epidermis layer are more abundant and stronger than those of the inner layer. The structure between the inner layer and the epidermis is a hollow grid, and the distribution of the epidermis fibers of the banana stem is shown in Figure 2.

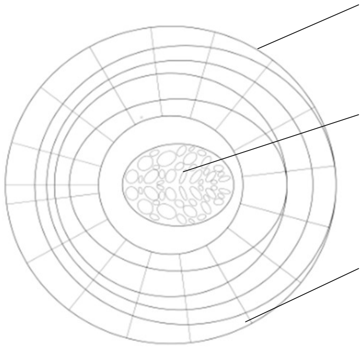

FIGURE 1. Schematic diagram of banana straw cross-section

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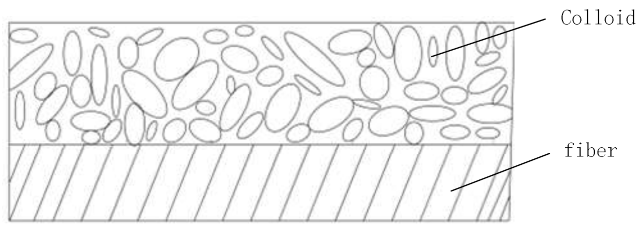


FIGURE 2. Schematic diagram of the fiber distribution in banana straw

Banana straw is rich in a large amount of fiber. The study showed that banana fiber, similar to other cellulose fibers, is mainly composed of cellulose, hemicellulose, lignin, ash, pectin, and a small amount of water solute and other substances. After being processed, banana fiber has a higher strength than cotton and can be blended or purely spun (Zhang et al., 2015b). The fabric made from banana stalk fiber is moisture-absorbing, breathable, and suitable for making various decorative objects and high-grade paper. Therefore, banana stalk fiber has a vitally important economic value, and fiber extraction technology has a wide range of applications. At present, biochemical methods and mechanical methods are adopted in China's extraction technology for banana stalk fiber. However, the biochemical extraction of banana stalk fibers has not been promoted because of the cumbersome procedures and long cycle times. The mechanical method of banana stalk fiber extraction has the advantages of speed, high efficiency, and time saving. Disadvantages such as a high impurity rate and a large fiber damage rate also exist for mechanical methods. To solve these problems, the separation of the stem fiber and impurities is key for extraction technology of banana stalk fiber (Wulantuya et al., 2020).

Many scholars in China have carried out research on crop straw separation technology. Peng et al. (2022) completed the fiber extraction of corn stover after peeling and core removal using a staged mechanical crushing method, and the extracted fibers were all under 6 mm in length, had a moisture content of 4.7%, and showed high quality. Yu & Wang (2013) used a self-designed skin separation machine test bench to study the separation mechanism of the skin and flesh during the separation process in corn. Based on the unsatisfactory peeling effect of the corn stalk skin separation mechanism and the easy breakage of the straw skin, Chen & Wang (2014) and Zhang et al. (2023) proposed the tooth-knife-type skin and flesh separation mechanism and carried out response surface analysis of the relevant working parameters. Yan et al. (2022) used a self-designed ramie stripping machine to test and optimize the basic parameters for hemp skin, cutting mechanism dynamics, and other parameters for improving the quality and efficiency of the stripping machine. Based on the analysis of the structure, growth traits, and strength characteristics of sugarcane sheath, Mou et al. (2013, 2014), Xie et al. (2020), and Qian et al. (2023) conducted a destruction test of the leaf sheath and proposed the optimal peeling method according to the sheath growth characteristics. Zhang designed a roller-scraping extractor specifically for coarse banana stalks with low fiber extraction efficiency. However, the size of the crushing device led the banana stalk fibers to become tangled during extraction, thereby compromising the machine's reliability (Zhang et al., 2013; Li et al., 2019).

In summary, in terms of crop straw separation technology, most scholars in China currently focus on corn, ramie, and sugarcane, their separation mechanism, and experimental optimization of relevant working parameters. Research on the extraction technology of banana stem fiber mainly focuses on the design and experiment of a fiber extraction prototype. The mechanism of banana stem fiber extraction and experimental optimization has not yet been performed.

Based on the analysis of the structure, growth characteristics, and strength characteristics of banana stalks, this study planned to use the method of theoretical analysis to build the mechanical model of the process for banana stalk fiber extraction and carry out kinematic analysis of the process in which banana stalk was squeezed and fed by a feeding roller and was scraped and purified by scrapers. According to this analysis, the extraction mechanism of the machine for banana stalk fiber extraction was revealed. The main influencing factors of the rates of fiber impurity and damaged fibers, namely the rotational speed of the roller with the scraping knives, the gap between the scraper and the holding plate, and the number of scrapers, were determined through response surface analysis to obtain the best working parameters. The rationality of the method of response surface analysis was verified using a prototype test.

MATERIAL AND METHODS

Machine structure and working principle

As shown in Figure 3, the machine for banana stalk fiber extraction was composed of a frame, a conveying device for the stalk, a device for extrusion and feeding, a scraping device, and a conveying device for the fiber.

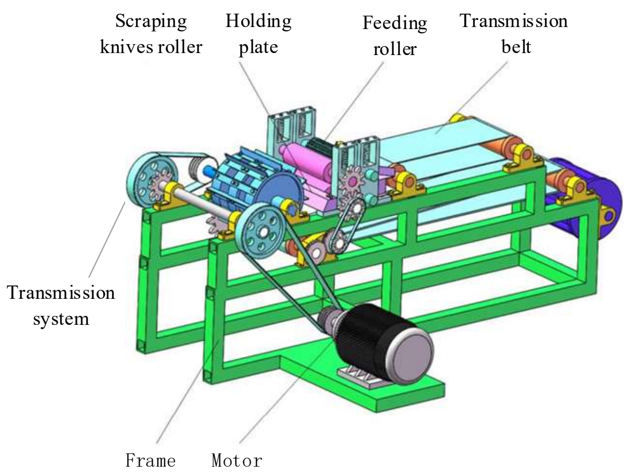


FIGURE 3. Structure of the banana stalk fiber extracting machine with scraping type

When working, the banana stalks were first broken into pieces using a banana stalk slicer and placed on a transmission belt, and then the block banana stalks were conveyed continuously and stably into the device for extrusion and feeding by the transmission belt. The banana stalks gradually became soft during the process of transiting the extrusion and feeding device and then were conveyed into the gap between the scraper and the holding plate. The motor drove the scraping knives roller to rotate at a high speed, and the banana stalks entering the gap were constantly squeezed and hit by the scraper. The colloids around the fiber were knocked into slags and separated from fibers or clamped between the fibers. Because the banana stalks experienced the dual action of squeezing and striking at this time, they lost rigidity and became relatively soft. Then, the soft banana stalks vibrated and shook off the slag stuck in the fibers. Under the action of the wind force generated by the scraping knives roller, the slags were thrown from the banana stalk fibers in the direction of the tangential movement of the scraping knife, and the remaining banana stalk fibers were outputted through the transmission belt.

The scrapers applied both striking and frictional forces to the banana stalks during the process of touching stalks, and these two forces always existed simultaneously, from touching stalks to separation from the stalks. During hitting, the scrapers rotated along the circular arc track, and the positive pressure (F_N) was perpendicular to the direction of the stalk fiber. Positive pressure was continuously applied to make the scraper stick to the surface of the stalk during sliding, which generated the pushing and scraping effect on the stalk. When scrapers slid along the surface of the stalk, the streaked stalks were scraped and pulled by the tangential force (F_t). When the maximum tangential force (F_{tmax}) occurred, damage was generated through the tangential stretch of the stalks. Throughout the destruction process, the friction of the scraper on the stalks always existed.

Mechanical modeling of the stalk fiber extraction process

As shown in Figure 4, the unit stalk volume was used as the analysis sample. The inner surface of the stalk unit was subjected to the positive pressure, tangential force, and friction of the scrapers, and the outer surface was subjected to support and friction by the holding plate.

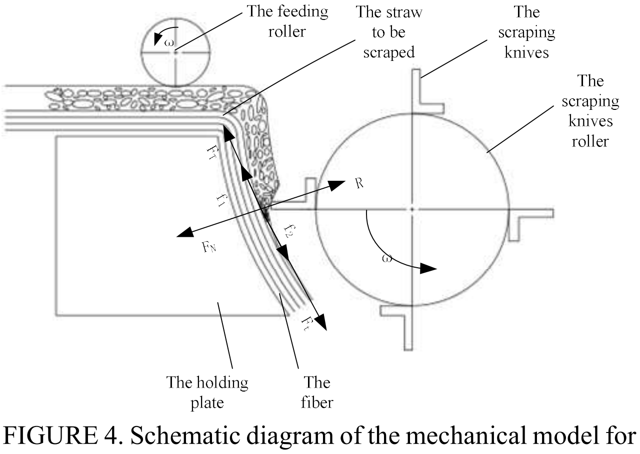


FIGURE 4. Schematic diagram of the mechanical model for extracting banana fiber

With the stalk torn and broken, the tangential force (F_t) carried out the actions of pushing and pulling. When the colloids slid, the banana stalks suffered a shearing action in the tangential direction of the trajectory, that is, the tangential force (F_t) along the tangential direction of the trajectory and the pulling force (F_T) of the squeezing roller to banana stalks backwards. As shown in Figure 5a, the shear strength of the torn stem unit in the tangential direction of the trajectory was calculated using [eq. (1)].

$$\sigma_x = \frac{F_t}{uw} \tag{1}$$

Where:

σ_x - shear strength of stalk units in the tangential direction of the trajectory, 10^6 N/m^2;

u - ratio of the culm sectional area of the torn stalk to the whole culm sectional area;

w - banana stalk cross-sectional area, m^2.

Therefore, the condition for the effective separation of the banana stalk units was $\sigma_x > \sigma_0$. σ_0 refers to the critical shear strength of the banana stem cell.

The positive pressure of the scraper (F_N) and the rebound force (R) of the holding plate generated a vertical shear effect on the banana stalk units. As shown in Figure 5b, the shear strength of the banana stalk units in the longitudinal direction was calculated using [eq. (2)].

$$\sigma_y = \frac{F_N}{S} \tag{2}$$

Where:

σ_y - shear strength of the banana stalk units in the longitudinal direction, 10^6 N/m^2;

F_N - positive pressure of the scraper, N;

S - longitudinal section area of the banana stalk unit, m^2.

The force that the banana stalk suffered when the transverse tear failure occurred under the action of the scraper was the dynamic friction, and the dynamic friction was calculated using [eq. (3)].

$$f_1 = \mu_1 F_N \tag{3}$$

Where:

f_1 - friction force generated by the stalk fiber and the scraper, which moved in the tangential direction of the trajectory, N;

F_N - positive pressure of the scraper on the stalk fiber, N;

μ_1 - kinetic friction factor between the stalk fiber and scraper, 0.36.

The force that caused the transverse rupture of the stalk fiber was f_1, and the tensile stress in the tangential direction of the trajectory was calculated using [eq. (4)].

$$\sigma_2 = \frac{f_1}{\omega} \quad (4)$$

Where:

σ_2 - tensile stress of the stalk fiber, 10^6 N/m^2;

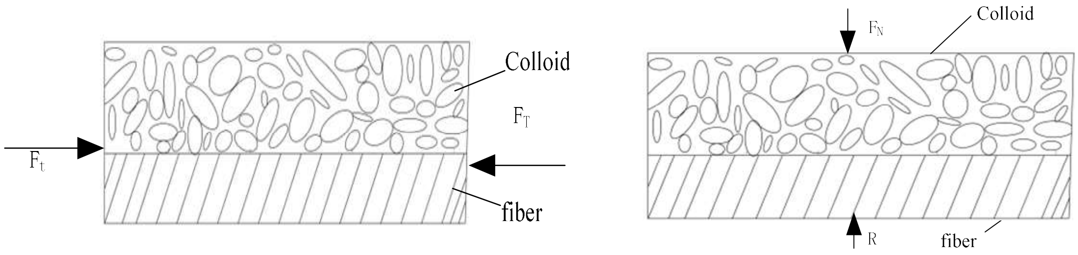
ω - cross-sectional area of the stalk fiber bundle, m^2.

Therefore, the condition that the banana stalk fiber would not be broken was $\sigma_2 < \delta$, and δ was the critical stress value. The mechanical model of which the colloids in the banana stalks were effectively separated from the stalk fibers and the stalk fibers were not broken was calculated using eqs (5) and (6).

$$F_t > \sigma_0 \cdot u \cdot w \quad (5)$$

$$F_N < \frac{\delta \cdot \omega}{\mu_1} \quad (6)$$

Equations (5) and (6) showed that the condition for the colloids separating from the stalk fibers was that the force applied by the scrapers in the tangential direction and the normal direction should satisfy $F_t > \sigma_0 \cdot u \cdot w$, and $F_N < \sigma_0 \cdot u \cdot w$.



a. Horizontal cut b. Vertical cut

FIGURE 5. Schematic diagram of banana straw unit being cut.

The banana stalks were fed into the gap between the scraper and the holding plate by the feeding roller at a constant speed, and the banana stalks were hit continuously by the high-speed rotating scrapers to remove impurities in the banana stalks. The times that banana stalks in the gap between the scraper and the holding plate were struck by scrapers determined the quality of the separated banana stalk fibers. The speed at which banana stalks were fed into the gap between the scraper and the holding plate was calculated using [eq. (7)].

$$V_f = \frac{\pi \cdot D_f n_f}{60} \quad (7)$$

Where:

V_f - linear velocity of the feeding roller, m/s;

D_f - diameter of the feeding roller, m,

n_f - rotational speed of the feeding roller, r/min.

The times (L) that banana stalks were scraped by scrapers per second was calculated using [eq. (8)].

$$L = \frac{n_0 \times Z}{60} \quad (8)$$

Where:

n_0 - rotational speed of scrapers, r/min,

Z - number of scrapers.

The banana stalks were fed into the scraping device by the feeding roller, and the time from the initial position to the terminating position of the holding plate was calculated using [eq. (9)].

$$t = \frac{\theta \cdot (R+g)}{V_f} \quad (9)$$

Where:

θ - curvature of the holding plate, rad;

R - gyroradius of scraping knives roller, m;

g - gap between the scraper and the holding plate, m,

V_f - linear velocity of the feeding roller, m/s.

Therefore, the number of times that a random banana stalk segment was scraped by the scrapers in the holding plate was calculated using [eq. (10)].

$$m = \frac{n_0 \cdot t \cdot Z}{60} \quad (10)$$

The number of times that a random banana stalk segment was scraped by the scrapers was calculated by combining eqs (7) and (9), as shown in [eq. (11)].

$$m = \frac{\theta \cdot (R + g) \cdot n_0 \cdot Z}{\pi \cdot D_f \cdot n_f} \quad (11)$$

As shown in [eq. (11)], the number of times that a random banana stalk segment was scraped by scrapers was proportional to the curvature of the holding plate, the gyroradius of the scraping knives roller, the gap between the scraper and the holding plate, the rotational speed of scrapers, and the number of scrapers and had an inverse relationship with the diameter of the feeding roller and the rotational speed of the feeding roller.

Based on previous research, an experiment with a test bench was carried out at the Agricultural Machinery Laboratory of Hainan University. The test facility mainly consisted of two inverter motors, a device for extrusion and feeding, a scraping device, and a frame. The two inverter motors provided the corresponding rotational speed of the feeding roller and the scraping knives roller. The gap between the holding plate and the scraper in the scraping device was adjusted by the thread adjusting mechanism, and the scraping knives roller and the scrapers were linked by bolts. The number of scrapers could be adjusted by removing the scraper. Other instruments, such as electronic balances, vernier calipers, and steel rulers, were included.

Through the analysis of the banana stalk fiber extraction mechanism, the main factors affecting the extraction effect of banana stalk fiber were the rotational speed of the roller with the scraping knives, the gap between the scraper and the holding plate, and the number of scrapers. Based on the previous test results and empirical data, the obtained results concluded that when the rotational speed of the roller with the scraping knives, the gap between the scraper and the holding plate, and the number of scrapers were in the range of 1400–1800 $r \cdot min^{-1}$, 2–4 mm, and 6–8, respectively, the fiber extraction rate of the fiber extraction mechanism was 90.4% or higher (Zhang et al., 2015a). Therefore, according to the Box–Behnken combination design principle, a 3-factor 3-horizon orthogonal rotation combination test was established. The rotational speed of the roller with the scraping knives, the gap between the scraper and the holding plate, the number of scrapers were the experimental factors of the orthogonal rotation combination test, and the rates of fiber impurity and damaged fibers were the evaluation index. The horizontal codes of test factors are shown in Table 1.

TABLE 1. Experimental variables and levels.

Level	Rotating speed of knives roller X_1 /(r/min)	Interval X_2 /(mm)	Number of scraping knives X_3
−1	1400	2	6
0	1600	3	7
1	1800	4	8

After machine processing for banana stalk fiber extraction, the percentage of the mass of the residual impurities (colloids) on the obtained banana stalk fibers as the total mass of the fibers obtained by the separation was referred to as the rate of fiber impurity. Each test was repeated five times, and the average value was obtained as the rate of fiber impurity, which was calculated using [eq. (12)].

$$\eta = \frac{m}{M} \times 100\% \tag{12}$$

Where:

η - rate of fiber impurity, 100%;

m - mass of the residual impurities on the obtained banana stalk fibers by the separation, g,

M – total fiber mass obtained by the separation, g.

The fibers acquired from the fiber extraction machine had a length of more than 5 cm, which could be considered qualified fiber. The percentage of the total mass of fibers less than 5 cm in length obtained and the total mass of the fibers obtained by separation was referred to as the rate of damaged fibers. Each test was repeated five times, and the average value was obtained as the rate of damaged fibers, which was calculated using [eq. (13)].

$$\varepsilon = \frac{n}{N} \times 100\% \tag{13}$$

Where:

ε - rate of damaged fibers, 100%;

n - total mass of fibers having a length of less than 5 cm, g,

n - total mass of the fibers obtained by separation.

RESULTS AND DISCUSSION

According to the above test factor level, the test was designed using a quadratic orthogonal rotation combined test. The test results are shown in Table 2.

TABLE 2 Experimental plan and results.

No.	Rotating speed of knives roller X_1	Interval X_2	Number of scraping knives X_3	Percentage of impurity in fiber Y_1 (%)	Percentage of damaged fiber Y_2 (%)
1	1800	2.0	7	13.0	13.2
2	1600	3.0	7	32.0	3.00
3	1800	3.0	6	28.5	4.90
4	1600	3.0	7	40.0	3.00
5	1800	4.0	7	39.5	2.55
6	1800	3.0	8	24.0	7.70
7	1600	2.0	6	22.5	7.60
8	1400	2.0	7	18.0	7.20
9	1400	3.0	8	27.0	4.50
10	1400	3.0	6	37.5	2.35
11	1400	4.0	7	47.0	1.35
12	1600	3.0	7	36.0	4.00
13	1600	3.0	7	35.0	4.00
14	1600	2.0	8	8.0	10.80
15	1600	4.0	6	43.5	1.85
16	1600	3.0	7	44.0	2.60
17	1600	4.0	8	42.5	2.30

The design results were analyzed using Design-Expert software. The regression equations of the coding parameters for the rates of fiber impurity and damaged fibers were obtained.

$$Y_1 = 37.40 - 3.06X_1 + 13.88X_2 - 3.81X_3 - 0.63X_1X_2 + 1.50X_1X_3 + 3.37X_2X_3 - 3.95X_1^2 - 4.08X_2^2 - 4.20X_3^2 \quad (14)$$

$$Y_2 = 3.32 + 1.62X_1 - 3.84X_2 + 1.08X_3 - 1.20X_1X_2 + 0.16X_1X_3 - 0.69X_2X_3 - 0.99X_1^2 - 1.76X_2^2 - 0.55X_3^2 \quad (15)$$

After processing using Design-Expert software, the variance analysis results of the fiber impurity rate and the damaged fiber rate are shown in Table 3.

TABLE 3. Analysis of variance.

Sources of variance	Percentage of impurity in fiber					Percentage of damaged fiber				
	Sum of squares	Degrees of freedom	Mean square	*F*	*P*	Sum of squares	Degrees of freedom	Mean square	*F*	*P*
Model	2022.12	9	224.68	18.02	0.0005**	176.34	9	19.59	49.78	<0.0001**
X_1	75.03	1	75.03	6.020	0.0439*	20.96	1	20.96	53.27	0.0002**
X_2	1540.13	1	1540.13	123.550	<0.0001**	118.20	1	118.20	300.33	<0.0001**
X_3	116.28	1	116.28	9.330	0.0185*	9.25	1	9.25	23.49	0.0019**
X_1X_2	1.56	1	1.56	0.130	0.7337	5.76	1	5.76	14.64	0.0065*
X_1X_3	9.00	1	9.00	0.720	0.4236	0.11	1	0.11	0.27	0.6245
X_2X_3	45.56	1	45.56	3.650	0.0975	1.89	1	1.89	4.80	0.0645
X^2_1	65.69	1	65.69	5.270	0.0553	4.13	1	4.13	10.49	0.0143*
X^2_2	69.92	1	69.92	5.610	0.0497*	13.12	1	13.12	33.33	0.0007**
X^2_3	74.27	1	74.27	5.960	0.0447*	1.29	1	1.29	3.27	0.1137
Residual	87.26	7	12.47			2.75	7	0.39		
Sum	2109.38	16				1779.09	16			

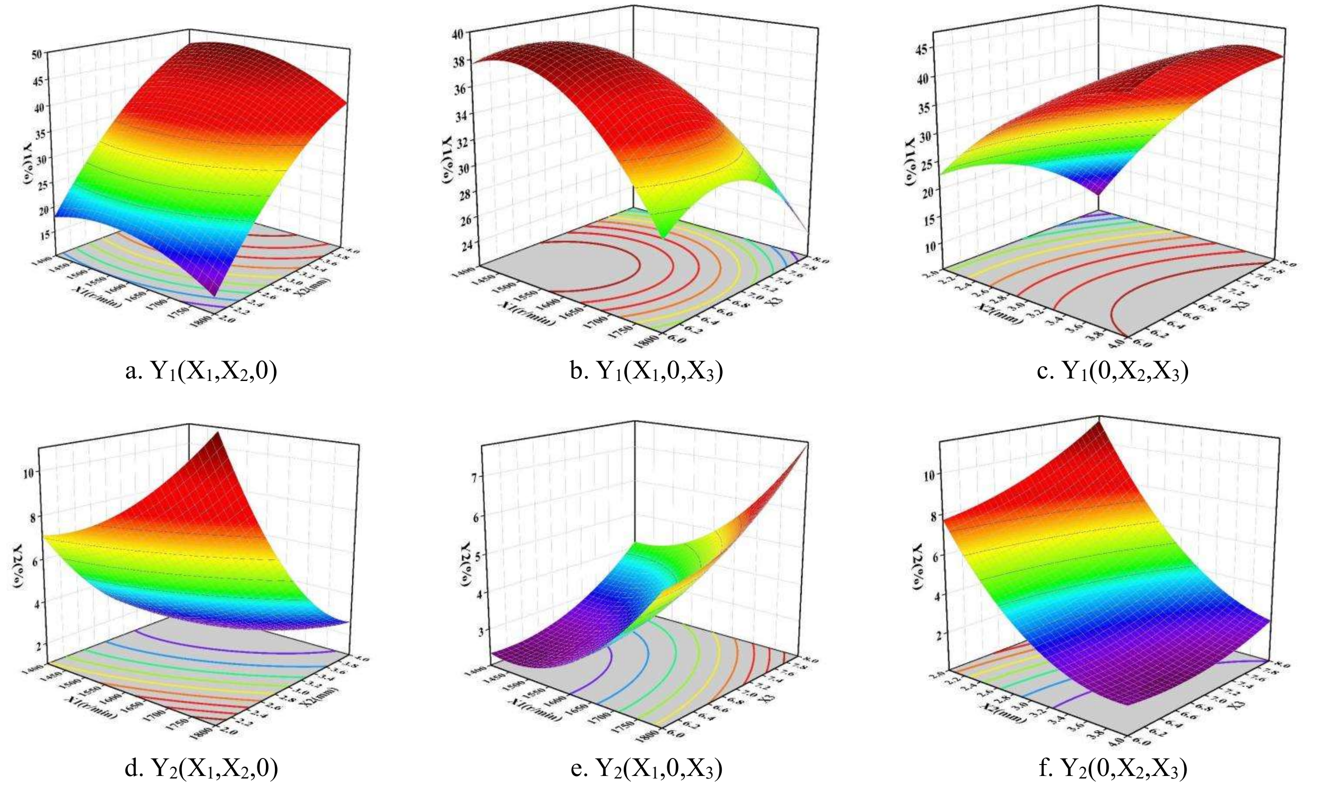
Note: When P is less than 0.05, the test is significant, which is symbolized as "*", when P is less than 0.01, the test is highly significant, which is symbolized as "**".

As shown in Table 3, the model of the fiber impurity rate and the damaged fiber rate was significant (P<0.05). For the objective function, Y_1, factor X_2 was extremely significant, and factors X_1, X_3, X_2^2, and X_3^2 were significant at P=0.05, and the other factors were not. Based on the analysis, the significant order of the factors determining the rate of fiber impurity, from largest to smallest, was the gap between the scraper and the holding plate, the number of scrapers, and the rotational speed of the roller with the scraping knives. For the objective function, Y_2, factors X_1, X_2, X_3, and X_2^2 were extremely significant, factors X_1X_2 and X_1^2 were significant at P=0.05, and other factors were not. The significant order of factors for the rate of damaged fibers, from largest to smallest, was the gap between the scraper, the rotational speed of the roller with the scraping knives, and the number of scrapers.

Based on the data analysis of Design-Expert 8.0.6 software, the graph of the response surface analysis for the rotational speed of the roller with the scraping knives, the gap between the scraper and the holding plate, and the number of scrapers on the rates of fiber impurity and damaged fibers is shown in Figure 6. As shown in Table 3 and Figure 6, the primary and secondary order of influence factors on the fiber impurity rate was the gap between the scraper and the holding plate, the number of scrapers, and the rotational speed of the roller with the scraping knives. Moreover, the influencing factors had an interactive effect on the fiber impurity rate. As shown in Figure 6a, the rate of fiber impurity increased with the increase in the gap between the scraper and the holding plate, while the rate of fiber impurity increased first and then decreased with the increase in the rotational speed of the roller with the scraping knives. As shown in Figure 6b, the rate of fiber impurity increased first and then decreased with the increase in the number of scrapers and the rotational speed of the roller with the scraping knives, and the decreasing trend increased gradually. As shown in Figure 6c, the rate of fiber impurity increased with the increase in the gap between the scraper and the holding plate, and the growth gradually slowed down. The rate of fiber impurity decreased with an increase in the number of scrapers.

The primary and secondary order of influencing factors on the rate of damaged fibers were the gap between the scraper and the holding plate, the rotational speed of the roller with the scraping knives, and the number of scrapers. Moreover, the influencing factors had an interactive effect on the rate of damaged fibers. As shown in Figure 6d, the rate of damaged fibers decreased with the increase in the gap between the scraper and the holding plate. The rate of damaged fibers increased with the increase in the rotational speed of the roller with the scraping knives. As shown in Figure 6e, the rate of damaged fibers increased with the increase in the rotational speed of the roller with the scraping knives and the number of scrapers. As shown in Figure 6f, the rate of damaged fibers decreased with the increase in the gap between the scraper and the holding plate. The rate of damaged fibers increased slowly with the increase in the number of scrapers.

By utilizing the optimization function and Design-Expert software, optimization analysis was carried out to obtain the optimal parameter combination of the machine for banana stalk fiber extraction. The optimal working parameters were as follows: rotational speed of the roller with the scraping knives, 1400 r/min; gap between the scraper and the holding plate, 2.5 mm; and 8 scrapers. Under optimal conditions, the rates of fiber impurity and damaged fibers were 17.082 and 6.254%, respectively.



a. $Y_1(X_1,X_2,0)$ b. $Y_1(X_1,0,X_3)$ c. $Y_1(0,X_2,X_3)$

d. $Y_2(X_1,X_2,0)$ e. $Y_2(X_1,0,X_3)$ f. $Y_2(0,X_2,X_3)$

FIGURE 6. Influence of factors on the percentage of fiber impurity and damaged fibers.

Operational performance of the fiber extractor after parameter optimization

By creating a mechanism model of the banana fiber extraction process and addressing a number of issues, including high impurity and high fiber loss rates in current banana stalk fiber extraction in China, the three primary factors influencing the quality of fiber extraction were shown to be the gap between the scraper and the holding plate, the number of scrapers, and the rotational speed of the roller with scraping knives. This agrees with the results of a previous study (Liu et al., 2017). To determine the best combination of parameters to guarantee the quality of fiber extraction, this study optimized the parameters based on the findings of the original study.

As shown in Figure 7, the optimal working parameters found in the results—1400 r/min for the scraper roller rotational speed, 2.5 mm for the gap between the holding plate and the scraper, and 8 scrapers—were used to experimentally verify the fiber extraction machine's operational performance. With these parameters combined, the rate of damaged fibers was 6.83%, and the rate of fiber impurity was 17.98%, both within allowable bounds. Following parameter optimization, the machine's operating performance surpassed that of the first machine. First, the efficiency of the current machine in extracting fiber was increased, indicating that the increased roll speed of the doctor blade contributed to the machinery's good performance in extracting fiber. Furthermore, the spacing between the clamping plate and the doctor blade, both before and after parameter optimization, has a big influence on the fiber extraction quality; if the gap is too narrow, it can easily lead to fiber damage and clogging issues. It is challenging to scrape the stalk fiber efficiently if the gap is too large. The number of scrapers also had a big impact on the quality of the fiber extraction process. Too few blades can lead to a high impurity content after fiber extraction, and too many blades can make banana fiber tissues very vulnerable to damage over time. Furthermore, compared to the original machine, the impurity content and damage rate of banana stalk fiber after fiber extraction were lower under the ideal parameter combination. These outcomes align with the results of previous studies (Zhang et al., 2013; Ran et al., 2024).

FIGURE 7. Experimental diagram of the banana stalk fiber extracting machine.

Limitations of this study and possible future work

While testing and theoretical analyses have demonstrated significant advantages in terms of increasing metrics through parameter optimization, whether this combination of parameters would have the same benefits for feeding different stalk flake types was not investigated. In the future, experiments on various stalk flake types should be used to identify the ideal conditions for accommodating fiber extraction from various stalk blades. Furthermore, it is imperative to optimize the machine's structure to minimize its size and consequently lower its overall power consumption. This will also enhance the fiber extractor's operational efficiency.

CONCLUSIONS

This study establishes a mechanical model for the banana stalk fiber extraction process as well as the mathematical model for the number of times necessary for scraping any section of the banana stalk based on the number of scrapers, the rotational speed of the roller with the scraping knives, and the gap between the scraper and the holding plate to solve the various problems of banana fiber extractors in the process of stalk fiber extraction with high impurity and fiber loss rates. Theoretical analysis and experimental results showed that by optimizing the original working parameters, the machine's overall operational performance improved under the following parameters: scraper roller speed, 1400 r/min; gap between the clamping plate and the scraper, 2.5 mm; and 8 scrapers. The fiber impurity and damage rates after fiber extraction were also significantly reduced.

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