OPTIMIZATION OF THE WORKING PERFORMANCE OF HALF-FEEDING PEANUT PICKING DEVICE BASED ON RESPONSE SURFACE METHODOLOGY
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基于响应曲面法的半喂入式花生摘果装置作业性能优化

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ABSTRACT

The paper researches the effect of structure and operation parameters of the self-developed half-feeding peanut picking device on the picking performance by response surface methodology. Through the response surface optimization test and design principle of Box-Behnken, the cylinder length, roller diameter, the overlap distance of outlet end, the roller speed and the clamping conveying speed are taken as factors; the synthetic weighted mark method is used to obtain the response value that taking the comprehensive index determined by the picking rate of the peanut pods as the test. The paper also makes response surface analysis to the effect of different factor level on the comprehensive index. The quadratic polynomial regression model of each factor to the effect of the comprehensive index is established. The factors are optimized and the optimization results are tested through the picking experiment. The experiment results show that when the picking roller length is 875mm, the roller diameter is 158mm, the overlap distance of roller outlet is 5.6mm, the rotational speed of picking is 302rpm and the clamping conveying speed is 1.1m/s, which is the optimal parameter combination. The quadratic polynomial regression model established can reflect the effect of each index on the working performance optimally. The optimization results based on the quadratic polynomial regression model are consistent with the actual operation. The research provides a technical basis for the improvement of peanut harvesting machinery.

摘要

采用响应曲面法，对自行研制的半喂入式花生摘果装置的结构及作业参数对摘果性能的影响进行了研究。通过响应曲面优化试验，根据Box-Behnken 试验设计原理，以摘果筒长度、滚筒直径、出口端重叠距离、滚筒转速以及夹持输送速度为因素，采用综合加权评分法获得的由花生荚果摘净率、破碎率确定的综合指标为试验的响应值，对各因素不同水平对综合指标的影响进行响应面试验分析，建立了各因素对综合指标影响的二次多项式回归模型，并对各因素进行了优化，通过摘果试验对优化结果进行了检验。试验结果表明：当摘果辊长度875mm，辊筒直径158mm，辊筒出口端重叠距离5.6mm，摘果辊转速302rpm，夹持输送速度1.1m/s 为各因素的最佳参数组合。建立的二次多项式回归模型能较好地反映各参数对作业性能的影响，基于二次多项式回归模型的优化结果与实际作业效果相符，研究为花生收获机械的改进提供了技术依据。

INTRODUCTION

The overall level of peanut harvesting mechanization is low in China. How to improve the level of peanut harvesting mechanization is a big problem faced by the peanut industry in China *(Lü X.L. et al, 2012)*. The half-feeding picking is suitable for dry and wet peanuts, which effectively promotes the marketing time of fresh peanuts in advance. At present, the half-feeding peanut picking device is in the development stage, there are still many problems in the operation process *(Lü X.L. et al, 2014; Hu Z.C. et al, 2012; Xu J.K. et al, 2014; Nuti R.C. et al, 2010; Guan M. et al, 2015)*. Response surface methodology (RSM) is a global function relationship synthesizing test design and mathematical modeling through local experiment to return fitting factor and results. Compared with the traditional optimization test methods, the test group needed by RSM is relatively small, which can use the most economical way and least time to study the experiment comprehensively. It has been widely used in various industries now *(Ambati P. and Ayyanna C., 2001; Hu Z.W. et al, 2016; Lee W.C. et al, 2006; Arzu Y. and Adnan D., 2007; Hou X.M. et al, 2013; Zhao H.M. et al, 2011)*.

The paper uses the Box-Behnken pattern of RSM in the Design-Expert to study the effect of half-feeding picking device structure and operation parameters on the picking performance.

MATERIALS AND METHODS

- **Test materials and methods**

The test selects self-developed half-feeding peanut picking device to test the picking performance, as shown in Fig.1. The picking object is spring planting peanuts and the variety is "TaiHua four". In the experiment, the peanut vines are dug artificially. Twenty plants are fed continuously and uniformly in each test, repeating three times to take the average value of the results. The paper refers to Peanut picker operation quality of Agricultural Industry Standard of the People's Republic of China *(NY/T 993-2006)* to calculate picking rate and damage rate. The calculation method of each detection index is as follows:

Picking rate=100%×(1- weight of unpicking)/(weight of unpicking+ weight of damage+ weight of good)

Damage rate＝100%×weight of damage/(weight of unpicking+ weight of damage+ weight of good)

Fig.1 - Structure diagram of the peanut picking device

- **Test plan design**

According to the design principle of Box-Behnken *(GUO Y et al, 2017)*, the paper makes response surface test analysis on the picking roller length L, the roller diameter D, the overlap distance of outlet end C, the roller speed n and clamping conveying speed V in five factors and three levels. These factors are marked as X_1- X_5, and the test factor codes and level is shown in Table 1. The independent variable coding is calculated according to the following transformation formula:

$$x_i = (X_i - X_{i0}) / \Delta X_i \quad (1)$$

Where, x_i is the code value of independent variable X_i; X_{i0} is the value of the independent variable X_i in the centre; $\triangle X_i$ is the change step of independent variable.

Table 1

Factors level and code of response surface analysis

Factor	coding	Non- coding	Coding value	level
L/mm	x_1	X_1	-1	600
			0	900
			1	1200
D/mm	x_2	X_2	-1	150
			0	200
			1	250
C/mm	x_3	X_3	-1	5
			0	10
			1	15

Factor	coding	Non- coding	Coding value	level
n/rpm	x_4	X_4	-1	200
			0	350
			1	500
V/ m·s^{-1}	x_5	X_5	-1	0.5
			0	1.0
			1	1.5

In order to balance the impact of picking rate and damage rate, the comprehensive indicator determined by synthetic weighted mark method is adopted as the response value of the response surface test. When the comprehensive indexes are determined, according to the importance of each indicator, the total "weight" number is 1 *(Wang X.Y. et al, 2008)*, the damage rate is 50% and the picking rate is 50%. On account of the opposite effect of the damage rate and picking rate on picking quality, the damage rate is negative when the comprehensive indicators are calculated. Additionally, in order to eliminate the effect of difference data measurement scale when the comprehensive marking index is calculated, the calculation is introduced into the average value of each unit data. The comprehensive indicator of each group is expressed as:

$$y_i = \sum_{j=1}^{r} W_j \frac{y_{ij}}{\overline{y_j}} \tag{2}$$

Where, y_i is the calculation value (weighted score index) obtained by the *i* test; W_j is the "weight" of the *j* index; y_{ij} is the *j* index of the *i* test; *r* is the number of factors affecting comprehensive index; $\overline{y_j}$ is the average value the *j* index in the group of tests.

RESULTS

- **Analysis scheme and test results of the response surface**

The test is made on the picking test bed according to the response surface. The multiple quadratic regression equation between the factors and response value is established through multiple quadratic regression method. The response surface between response value and variable is used for function analysis. The correlation between the factor and response surface, and the relationship between factors are studied. The response value is optimized for achieving the optimal value with factors combination in the whole region. This test consists of six central point repeat and needs 46 tests, experiment scheme and test results of the response surface are shown in Table 2.

Table 2

Design and results of RSM experimental schemes

Test groups	Variable coding					Response values
	X_1	X_2	X_3	X_4	X_5	Composite index Y
1	0	0	-1	-1	0	0.35
2	0	-1	0	1	0	-0.59
3	0	0	0	0	0	0.17
4	0	0	-1	0	1	0.22
5	-1	0	1	0	0	-0.03
6	-1	0	0	-1	0	0.29
7	0	0	0	1	-1	-0.81
8	-1	0	-1	0	0	0.19
9	0	1	1	0	0	0.08
10	1	0	-1	0	0	0.25

Test groups	Variable coding					Response values
	X_1	X_2	X_3	X_4	X_5	Composite index Y
11	0	1	0	0	-1	0.17
12	0	0	1	0	1	0.05
13	1	0	0	0	1	0.22
14	-1	-1	0	0	0	0.22
15	0	0	0	0	0	0.17
16	0	0	-1	0	-1	0.14
17	0	0	0	1	1	-0.73
18	0	1	0	0	1	0.14
19	0	0	-1	1	0	-0.64
20	0	0	0	0	0	0.19
21	0	-1	1	0	0	-0.08
22	0	-1	0	-1	0	0.37
23	1	0	1	0	0	0.14
24	1	-1	0	0	0	0.25
25	0	-1	-1	0	0	0.25
26	-1	1	0	0	0	0.08
27	0	1	-1	0	0	0.19
28	0	0	0	-1	-1	0.32
29	0	1	0	-1	0	0.19
30	0	-1	0	0	-1	0.22
31	-1	0	0	0	1	0.11
32	0	1	0	1	0	-1.56
33	0	0	1	-1	0	0.26
34	1	0	0	-1	0	0.33
35	0	0	1	1	0	-1.20
36	1	1	0	0	0	0.11
37	-1	0	0	0	-1	0.14
38	0	0	0	-1	1	0.28
39	0	0	0	0	0	0.17
40	0	0	0	0	0	0.17
41	-1	0	0	1	0	-0.78
42	1	0	0	1	0	-0.75
43	0	-1	0	0	1	0.25
44	0	0	1	0	-1	0.08
45	0	0	0	0	0	0.22
46	1	0	0	0	-1	0.17

- **Picking performance test analysis and the establishment of regression equations**

Design-Expert is used to obtain the response surface model of comprehensive index Y through multiple regressions fitting for the test results, and makes variance analysis on the quadratic equation of the response surface model; it also makes significant testing to the regression equation coefficient. Making regression analysis on the test data in Tab.2, the full-factor quadratic regression model of the comprehensive indicator coding space of the picking is specific to:

$$\begin{aligned} Y = {} & 0.1806 - 0.0316X_1 - 0.0929X_2 - 0.1031X_3 - 0.5905X_4 + 0.0068X_5 - 0.0006X_1X_2 \\ & + 0.0277X_1X_3 - 0.0029X_1X_4 + 0.0215X_1X_5 + 0.0551X_2X_3 - 0.1969X_2X_4 \\ & - 0.0138X_2X_5 - 0.1181X_3X_4 - 0.0278X_3X_5 + 0.0302X_4X_5 + 0.0101X_1^2 \\ & - 0.0428X_2^2 - 0.0453X_3^2 - 0.4558X_4^2 + 0.0145X_5^2 \end{aligned} \tag{3}$$

The variance analysis of quadratic regression equation model of the comprehensive index for picking (shown in Table 3) shows that the response surface model is significant (P<0.001) with optimal fitting degree. The determination coefficient R^2 of the model is 0.957; the adjustment determination coefficient R_{adj}^2 is 0.9227, which indicates that the credibility and precision of the model is high. From the significance test and analysis of regression coefficient (shown in Table 4), it is known that one degree term X_4 and quadratic term X_4^2 of the roller speed n has an extremely significant influence on the comprehensive indicator of picking. The effect of roller diameter D, the overlap distance C of outlet end and the interactive items （X_2, X_3, X_2X_4） between the roller diameter D and roller speed n on the comprehensive index of picking is quite significant. Picking roller length L and clamping conveying speed V has little influence on the comprehensive index of picking.

Table 3

Variance analysis of quadratic regression equation model Y

source of variation	Sum of squares	degree of freedom	mean square	Value of F	significance
Model	8.2598	20	0.4130	27.8479	< 0.0001
residual	0.3708	25	0.0148		
error	0.0027	5	0.0005		
total	8.6305	45			
R^2=95.70%					
R_{adj}^2=92.27%					

Table 4

Regression coefficient Y and its significant test

No.	source of variation	regression coefficient	standard error	Value of F	Value of significance P
1	constant term	0.1806	0.0497		
2	X_1	0.0316	0.0304	1.0773	0.3092
3	X_2	-0.0929	0.0304	9.3032	0.0054
4	X_3	-0.1031	0.0304	11.4580	0.0024
5	X_4	-0.5905	0.0304	376.1623	< 0.0001
6	X_5	0.0068	0.0304	0.0494	0.8260
7	$X_1 X_2$	-0.0006	0.0609	0.0001	0.9918
8	$X_1 X_3$	0.0277	0.0609	0.2068	0.6532
9	$X_1 X_4$	-0.0029	0.0609	0.0023	0.9621
10	$X_1 X_5$	0.0215	0.0609	0.1243	0.7274
11	$X_2 X_3$	0.0551	0.0609	0.8198	0.3739
12	$X_2 X_4$	-0.1969	0.0609	10.4570	0.0034
13	$X_2 X_5$	-0.0138	0.0609	0.0517	0.8220
14	$X_3 X_4$	-0.1181	0.0609	3.7645	0.0637
15	$X_3 X_5$	-0.0278	0.0609	0.2088	0.6517
16	$X_4 X_5$	0.0302	0.0609	0.2466	0.6238

17	X_1^2	0.0101	0.0412	0.0599	0.8087
18	X_2^2	-0.0428	0.0412	1.0780	0.3091
19	X_3^2	-0.0453	0.0412	1.2075	0.2823
20	X_4^2	-0.4558	0.0412	122.2492	< 0.0001
21	X_5^2	0.0145	0.0412	0.1236	0.7281

Note: $p<0.001$ (extremely significant), $p<0.01$ (quite significant), $p<0.05$ (significant)

- **Response surface interaction analysis**

The multiple quadratic regression equation can obtain the response surface of picking factors on the interaction of comprehensive index, as shown in Fig.2.

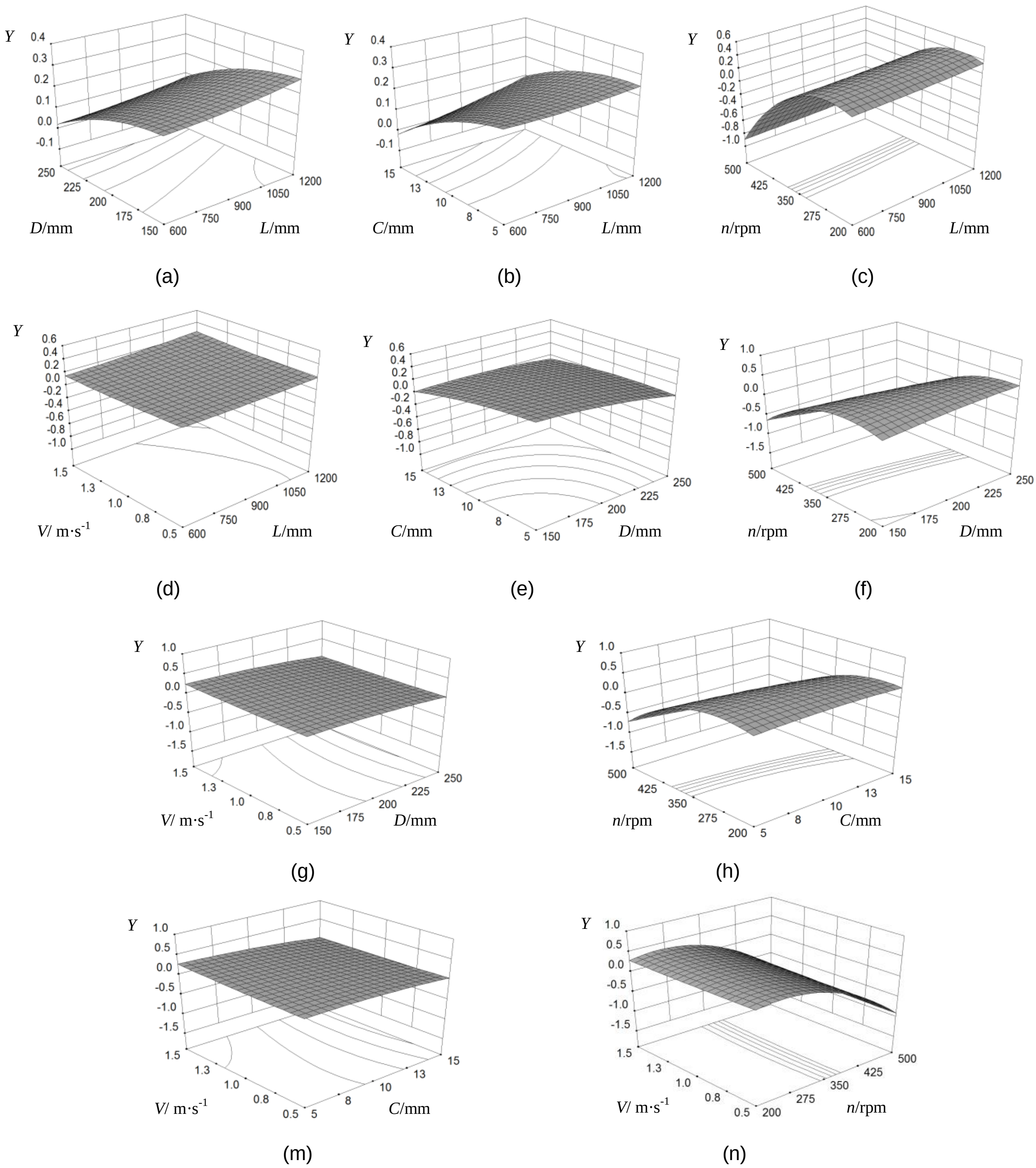

Fig.2 - The response surface of the interaction of various factors to the comprehensive index

It can be known from Fig.2 and combining the p value of each coefficient that the influence of each factor on picking effect is respectively as the roller speed, the overlap distance of outlet end, the roller diameter, the picking roller length and clamping conveying speed. Improvement of the roller speed increases the picking force and frequency, the larger of picking revolving speed *n* and the quicker of picking leaf speed, the higher of the picking strength and the higher of picking frequency; the hitting number of picking leave on the peanut pods is more frequently in the same time. The picking rate is gradually increasing with improvement of the roller speed; the growth rate form fast to slow, and the damage rate is also increasing. The growth rate is from slow to fast; the picking rate reaches the maximum without change when the roller speed exceeds a certain limit value and the damage rate increases significantly, reflecting the comprehensive that it increases first and then decreases. With the increase of the roller diameter D and the overlap distance C of outlet end, the larger of the volume of empty picking area, in the whole channel trip from the entrance end to the outlet end, the volume of empty picking area crossed by peanuts. The larger is the available picking area, the better is the effect of picking. The residual space of the blades with staggered configurations of two roller decreases; the damage rate increases and the comprehensive index decreases. With the increase of picking roller length L, the staying time of peanuts in picking is longer, and the hitting time increases. Picking rate and damage rate are both increased, and the comprehensive index has a certain increase and the impact is not obvious. With the increase of clamping conveying speed V, the smaller the time of peanut staying in the picking is, the lower is the picking frequency, and the picking rate and damage rate both decrease. The comprehensive index c has certain decrease, but not an obvious one. In the model, the interaction of the two groups on the comprehensive index is shown in Fig.2. With the increase of roller speed and diameter, the picking rate and damage rate both increase significantly, and the comprehensive index shows a downward trend. As the overlap distance of outlet end and the roller speed is greater, the picking rate and damage rate both increase significantly. The smaller of the comprehensive index, the effect of other interactions on the comprehensive index is small. From the optimized regression model, the interaction of X_2X_4 is quite significant in the model, which indicates that there is interaction between the roller speed and the roller diameter.

- **Optimization of the picking condition and test of the regression model**

The optimization solver of Design Expert is to optimize and solve the above established multiple quadratic regression models, determining the optimal value of the corresponding factors when the comprehensive index Y is the maximum. Where, the selection of clamping conveying speed area needs to consider the productivity of the combined harvester. The suitable walking speed is 0.8-1m/s and the clamping conveying speed is 0.9-1.2m/s when the machine harvests in the field. The optimal parameter combination obtained by optimizing is that the picking roller length is 875mm, the roller diameter is 158mm, the overlap distance of outlet end is 5.6mm, the roller speed is 302rpm, the clamping conveying speed is 1.1m/s, and the comprehensive index is 0.3731 at this moment. Because the optimal parameter combination obtained by optimizing does not present in the test of the response surface design scheme, the optimization result and prediction model is verified. Three repeated experiments for the optimized parameters combination on the picking test bed are made and the comprehensive index is measured as 0.3238. On account of the small theoretical optimal value and the verification value of Y solved by quadratic regression model, the difference can be ignored in practice. Thus, it is feasible to adopt the optimal combination in the design of machine tool.

CONCLUSIONS

The paper uses Box–Behnken model of the response surface method utilizing Design-Expert software to test the performance of the developed picking device. The weighted mark method is adopted to determine the comprehensive index of damage rate and picking rate. The multiple quadratic polynomial model is established. The paper also uses the response surface of the model to discuss the key factors and its interaction affecting picking performance. The research results show that the influence of each factor on picking effect is respectively as the roller speed, the overlap distance of outlet end, the roller diameter, the picking roller length and clamping conveying speed. With the increase of roller speed and roller diameter, the comprehensive index shows a downward trend. The larger is the roller speed and the overlap distance of outlet end, the smaller is the comprehensive index. The influence of other interactions on the comprehensive index is little. It can be seen from the optimization regression model that there is a significant interaction effect between the roller speed and roller diameter. By optimizing the combination parameters of the picking factors, the optimal combination obtained is that the picking roller length is 875 mm, the roller diameter is 158 mm, the overlap distance of outlet end is 5.6 mm, the roller speed is 302 rpm and the clamping conveying speed is 1.1m/s. The experimental results show that the theoretical optimization value is consistent with the verification value basically and it is feasible to design the test scheme and optimize its structure and operation parameters using the response surface method. It has a guiding role for the development of peanut harvesting machinery.

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