OPTIMIZATION OF PROCESS PARAMETERS OF PELLETIZER FOR AGROPYRON SEEDS UNDER VIBRATION FORCE FIELD
/
振动力场作用下冰草种子丸粒化包衣机工艺参数优化

***Zhanfeng* Hou, *Yi* Qiu, *Zhi* Chen*), *Haiyang* Liu, *Fang* Guo, *Longkai* Mi**
Inner Mongolia Agricultural University, College of Mechanical and Electrical Engineering, Inner Mongolia, China
Tel: 04714309215; Corresponding author E-mail address: sgchenzhi@imau.edu.cn
DOI*: https://doi.org/10.35633/inmateh-60-17*

Keywords: *Pelleting; Agropyron seed; Coating machine; Single seed rate; Design-Expert*

ABSTRACT
In order to solve the poor pelleting quality of Agropyron seeds, this paper designs a novel pelleting experimental platform. A regression mathematical model of pelleting qualified rate and single seed rate was established and analysed by variance. The results showed that vibration had significant effect on pelleting quality. The order of influence is as follows: rotating speed>vibration frequency> tilt angle of coater. When the speed is 41.7 r/min, the vibration frequency is 20.28 Hz, and the tilt angle is 34.89 °, the pelleting qualified rate and the single seed rate are the highest, 83.1% and 94.9% respectively.

摘要
针对冰草种子丸化包衣品质较差等问题，该文设计了新型丸化包衣实验平台。建立冰草种子丸化合格率、单籽率的回归数学模型并进行方差分析。结果表明：振动对冰草种子的的丸化合格率和单籽率有显著效果，影响冰草种子丸化合格率和单籽率的主次要因素为: 包衣锅转速>包衣锅振动频率>包衣锅倾角；当包衣锅转速为 41.7 r/min、包衣锅振动频率 20.28 Hz、包衣锅倾角 34.89°时，丸化合格率和单籽率达到最高，分别为 83.1%和 94.9%。

INTRODUCTION
In recent years, the area of degraded grassland in the Inner Mongolia has accounted for 31.77% of the total grassland area. The degradation of grassland results in a significant reduction of production and ecological functions, which affects the normal growth of vegetation (*Gui, 2012; Hang, 2012*). Seed pelleting is the key technique to guarantee the germination rate and survival rate of the seeds after sowing (*Andrew, 2016*). Therefore, it is of great significance to study the pelleting equipment and technology for the restoration and reconstruction of degraded grassland vegetation (*Shen, 2016*). American scientists Thornton and Ganulee first put forward the problem of seed coating in 1926, until the 1980s, the technology of pelleted seed coating in developed countries was basically mature (*Ge, 2016; Masoume, 2012*). However, the research on pelleting technology in China started late. Since 1990s, the pelleting of tobacco seeds was studied (*Han, 2018*). *Junhao Mei* et al. studied pelleting of rice seeds in 2000 (*Wu, 2017*). Although China's pelleting technology has made some progress, there is still a big gap compared with developed countries, especially in forage grass seed pelleting technology where there are more problems. In this paper, the two-regression orthogonal test and response surface methodology are used to study the pelleting technology and optimize the parameters of the novel pelleting equipment. The results can provide technical reference for solving the problem of poor pelleting quality of Agropyron seeds.

MATERIALS AND METHODS
Pelleting machine and working principle
The pelletizer for Agropyron seed is shown in Fig. 1. When the machine is working, seeds and powder are lifted up to the seed hopper *18* and the powder hopper *1* respectively. The seed coating agent is mixed in a certain proportion, and is pumped to the atomizer by the high-pressure pump *8*. When seeds pass through the seed diffuser plate *16*, they are arranged in sequence. It is preliminarily mixed with seed coating agent to make the liquid film form on the surface of the seed. The seeds after film formation fall into the coater *14*, and the powder is sprayed into the coater *14*. The coater *14* starts to rotate under the drive of the motor *11*. Meanwhile, the electric vibrator *13* changes the magnitude of the exciting force by adjusting the frequency of the converter, and applies the exciting force to the spindle of the coater *14*, and then transfers the vibration to the coater *14*. After pelleting, the seeds are poured into the discharge port *12* to complete the whole process.

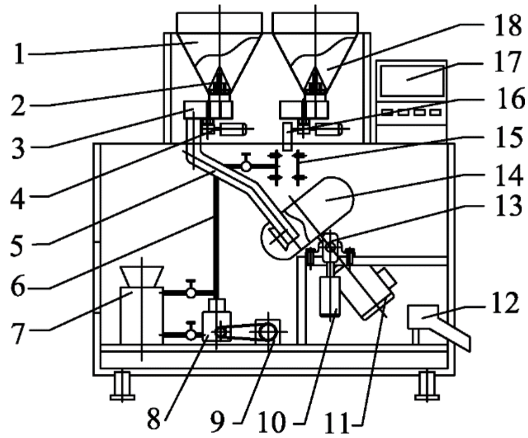


Fig. 1 - Schematic diagram of overall structure of pelletizer for Agropyron seeds

1. Powder feed inlet 2. Feed inlet valve 3. Weighing system 4. Step motor 5. Powder conveying pipeline 6. Liquid medicine pipe 7. Liquid medicine storage tank 8. High pressure pump 9. Motor 10. Rotary stepper motor 11. Coater motor 12. Outlet port 13. Electric vibration exciter 14. Coater 15. Nozzles 16. Seed diffuser plate 17. Controller 18. Seed feed inlet

Experiment materials

Agropyron seeds grown under natural conditions were selected as test objects. The shape is shuttle shape, the length is 6~7 mm and the 1000 grain mass was 2.4 g. Carboxymethyl cellulose and polyvinyl alcohol were used as seed coating agents. The blend of diatomite, bentonite and talcum powder were used as coating powder (*Liu, 2020*).

The Agropyron seed mass was 200 g and the powder mass was 1000 g (diatomite 400 g, bentonite 400 g, talcum powder 200 g). The adhesive mass was 60 g (Carboxymethyl cellulose 6 g, polyvinyl alcohol 3 g, water 51 g).

Test response parameters

According to People's Republic of China industry standard (*JB/T 7730-2011*) on seed coating machine test method (*Wang, 2017*). The percentage of seed coating agent completely covered on the surface of Agropyron seeds in the total number of pelleted seeds as pelleting qualified rate (*J*). The percentage of single pelleted seed in the total number of pelleted seeds is called single seed rate (*P*). The formula is as follows:

$$J = \frac{Z_h}{Z_b + Z_h} \times 100\% \tag{1}$$

$$P = \frac{D_d}{D_d + D_f} \times 100\% \tag{2}$$

where: J is the pelleting qualified rate, [%];

Z_h - the number of particles fully coated for Agropyron seeds, [-];

Z_b - the number of particles that are not fully coated on the seed surface, [-];

P - single seed rate, [%];

D_d - the number of single seed in the total of pelleted seeds, [-];

D_f - the number of Multi-seeds in the total of pelleted seeds, [-].

Single factor test results and discussion

Effect of vibration frequency on the pelleting quality

The coater speed is set at 30 r/min, the tilt angle of the coater is adjusted to 45° and the amplitude of the coater is 2 mm. The vibration frequencies are set at 10, 15, 20, 25, and 30 Hz, respectively, and pelleting experiment is performed. The relation between vibration frequency of coater and pelleting qualified rate and single seed rate was obtained, see Fig. 2.

In Fig. 2, when the vibration frequency is 10-30 Hz, the qualified rate and the single seed rate of the pelleting seeds are increased first and then decreased with the increase of vibration frequency. When the vibration frequency is 20 Hz, the qualified rate and the single seed rate of Agropyron seed pellets are the highest. Therefore, when the vibration frequency is 20Hz, it is the best frequency of the coating machine.

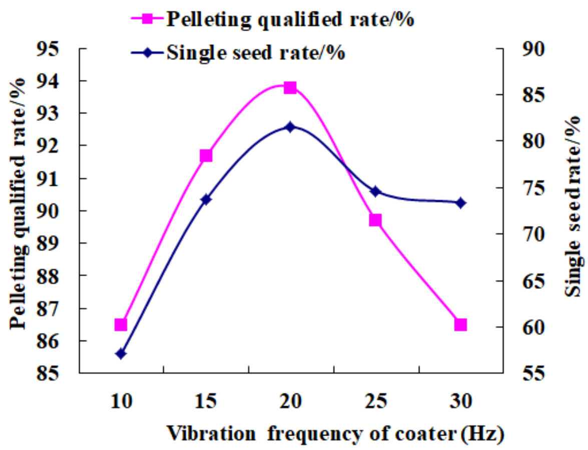


Fig. 2 - Effect of vibration frequency on the pelleting quality

The effect of coater rotating speed on the pelleting quality

When the vibration frequencies are set at 0 and 20 Hz, the tilt angle of coater is 45°, the amplitude is 2 mm, the rotating speed is adjusted to 30, 35, 40, 45, 50 r/min respectively, the seed pelleting qualified rate and single seed rate test are conducted. The relation between rotating speed and pelleting qualified rate and single seed rate was obtained under the action of vibration or no vibration, see Fig. 3.

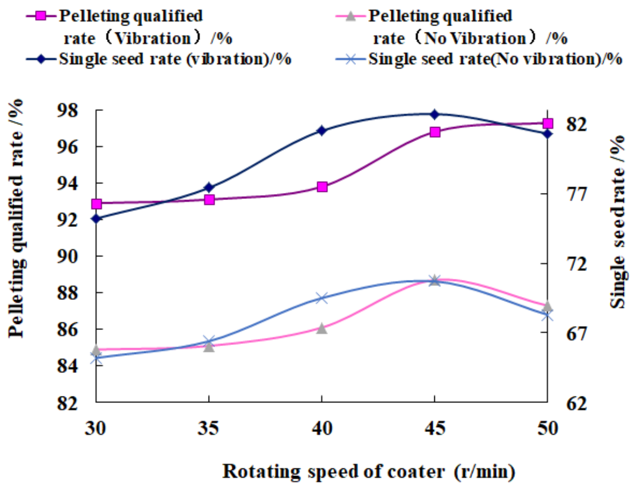


Fig. 3 - Effect of coater rotating speed on the quality of pelleting

The pelleting qualified rate and single seed rate under no vibration were significantly lower than with vibration. Therefore, this paper only discussed the pelleting qualified rate and single seed rate under vibration. When the rotating speed of the coater was 30~45 r/min, pelleting qualified rate and single seed rate gradually increased with the increase of rotating speed. As the rotating speed was 45~50 r/min, the pelleting qualified rate and single seed rate gradually decreased with the increase of rotating speed. It can be concluded that when the rotating speed of the coater is 45 r/min, the single seed rate and the qualified rate of pelleting were the highest.

The effect of coater tilt angle on the pelleting quality

The vibration frequency was set at 0 and 20 Hz respectively, the speed was 40 r/min, the amplitude was 2 mm, and the tilt angle was adjusted to 25, 30, 35, 40 and 45 ° respectively. Experimental study on pelletization of Agropyron seeds was conducted. The relation between coater tilt angle and the pelleting qualified rate and the single seed rate was obtained under the action of vibration or no vibration (Fig. 4).

In Fig.4, the pelleting qualified rate and single seed rate without vibration are significantly lower than with vibration. When the tilt angle is 25~35°, the single seed rate increases with the increase of the tilt angle. When the coater tilt angle is 35~45°, the single seed rate decreases with the increase of the tilt angle. When the coater tilt angle is 25~40°, with the increase of the tilt angle, the qualified rate increases. When the tilt angle of coater is 40~45°, with the increase of the tilt angle, the qualified rate increases. It can be concluded that the best single seed rate can be obtained when the tilt angle of the coater is 35°, and the best pelleting qualified rate can be obtained when the tilt angle of the coater is 40° under vibration.

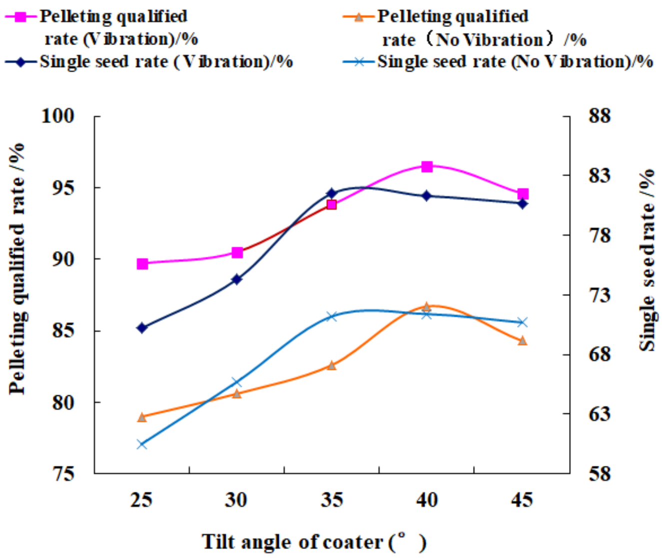


Fig. 4 - Effect of coater tilt angle on the pelleting quality

Orthogonal test results and discussion

The pelleting qualified rate and single seed rate were taken as the test performance index. Taking rotating speed, vibration frequency and coater tilt angle as experimental factors, 3 factors and 3 level orthogonal experiments were conducted (*Chi, 2015*). According to the single factor test results, the best parameter was selected by two-regression orthogonal test coding, and the factor level encoding was shown in Table 1. Two-regression orthogonal statistical results were shown in Table 2.

Table 1

Factors and levels encoding table

Level	Coater rotating speed	Coater vibration frequency	Coater tilt angle
	A [r•min^{-1}]	B [Hz]	C [°]
1	30	15	30
0	40	20	35
-1	50	25	40

Table 2

Two-regression orthogonal test scheme and experimental results

Test No.	Coater rotating speed	Coater vibration frequency	Coater tilt angle	Single seed rate	Pelleting qualified rate
	A [r•min^{-1}]	B [Hz]	C [°]	[%]	[%]
1	1	-1	0	73.9	93.4
2	0	1	1	83.2	95.8
3	1	0	1	74.1	93.5
4	-1	0	-1	72.1	92.3
5	0	0	0	84.1	96.1
6	1	0	-1	74.2	92.2
7	0	0	0	78.5	93.1
8	0	-1	1	77.2	92.5
9	-1	-1	0	82.5	95.1
10	0	1	-1	72.4	92.4
11	0	-1	-1	83.6	96.5
12	0	0	0	72.6	92.5
13	-1	1	0	74.8	92.8
14	0	0	0	82.8	95.8
15	0	0	0	72.2	92.3
16	1	1	0	74.1	92.1
17	-1	0	1	73.1	92.1

Analysis of pelleting qualified rate

Variance analysis of pelleting qualified rate

According to table 2, two-regression method was applied to analyse pelleting qualified rate. At the same time, Design-Expert was used to analyse variance (see Table 3), and regression mathematical model was established.

$$J = 95.86 + 0.43A + 0.16B - 0.14C + 0.075AB - 0.025AC - 0.05BC - 1.43A^2 - 1.91B^2 - 1.55C^2 \quad (3)$$

where: *A* is the coater rotating speed, [r/min]; *B* is coater vibrational frequency, [Hz];
C is the coater tilt angle, [°].

The absolute value of each factor in the model determines the influence degree on the pelleting qualified rate. Therefore, the influence of each factor on the pelleting qualified rate is: *A*, *B*, *C*, that is, the coater rotating speed > the coater vibration frequency > the coater tilt angle.

Table 3

Variance analysis of test result of pelleting qualified rate

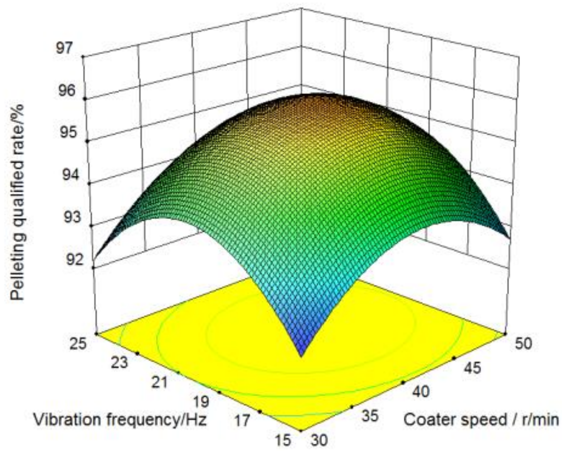
Origin	Squares	Df	SD	F Value	P Value
Mode	39.837	9	4.426	22.70	0.0002
A	1.445	1	1.445	7.413	0.0297
B	0.211	1	0.211	1.084	0.3325
C	0.151	1	0.151	0.776	0.4076
A•B	0.022	1	0.022	0.115	0.7440
A•C	0.002	1	0.002	0.013	0.9130
B•C	0.010	1	0.010	0.051	0.8273
A^2	8.610	1	8.610	44.17	0.0003
B^2	15.280	1	15.280	78.38	< 0.0001
C^2	10.181	1	10.181	52.23	0.0002
Residual	1.365	7	0.195		
Lack of Fit	0.313	3	0.104	0.396	0.7636
Pure Error	1.052	4	0.263		
R^2	0.9669				
Adequate Precision	11.362				

Note: *DF is degree of freedom. SD is standard deviation. F value is the statistical verification value. P value is a parameter used to determine the result of hypothesis test.*

From table 3, it can be seen that the *F* value of the model is 22.71 and the *P* value is less than 0.01. The *P* value of the model is very significant and the Lack of fit is not obvious. It is proved that the regression equation (3) has high accuracy with the actual results. Therefore, this model can be used to analyse and predict pelleting qualified rate.

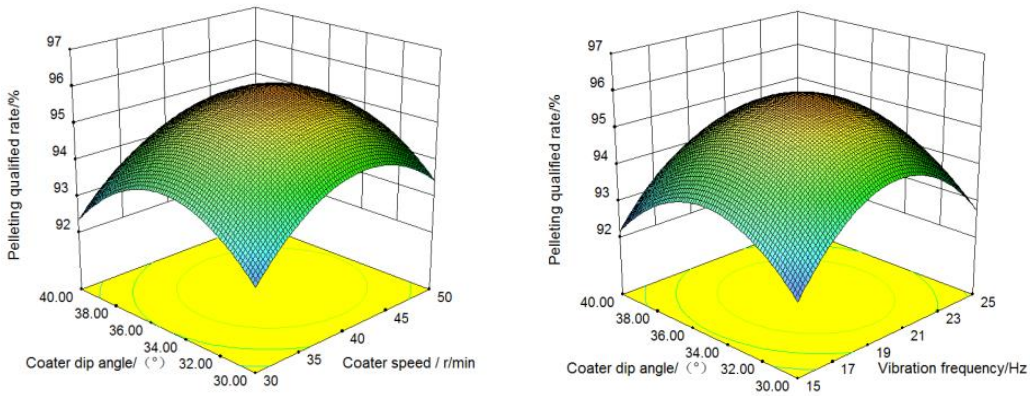
Surface analysis of pelleting qualified rate

According to the regression mathematical model (3), the response surface of the rotating speed, the tilt angle and the vibration frequency of the coater to pelleting qualified rate is obtained (Fig. 5).



J=(A,B,0)

Fig. 5 - Response surface of coater rotating speed to pelleting qualified rate



a) $J=(A,0,C)$ b) $J=(0,B,C)$

Fig. 6 - Response surface of vibration frequency and coater tilt angle to pelleting qualified rate

Fig. 5 and fig. 6 show that with the increase of each factor, the pelleting qualified rate increases first and then decreases. As the rotating speed increases, seed peristalsis in coater increases. When the speed increases to a certain extent, the seed is stationary with respect to the coater under the action of friction, thereby affecting the pelleting qualified rate. However, when the coater tilt angle is too large, the seed rotates with the coater, resulting in poor pelleting quality. Because the coater tilt angle is too large, most of the seeds basically fall at the bottom of the coater. The seed peristalsis effect is not good, resulting in a low pelleting qualified rate. In addition, vibration can increase the peristalsis of the seed in the coater, but the vibration intensity is too large, and the impact between the seeds is too large, resulting in a decrease in the pelleting qualified rate.

Single seed rate analysis

Analysis of single seed rate variance

According to the two-regression orthogonal test scheme and experimental data in Table 2, the single seed rate was analysed by two-regression methods (see Table 4) and the regression mathematical model was established simultaneously.

$$P=83.24+1.61A+0.36B-0.025C+0.75AB-0.075AC-0.27BC-4.14A^2-3.55B^2-6.02C^2 \quad (4)$$

where: *A* is the coater rotating speed, [r/min]; *B* is the vibrational frequency of coater, [Hz];
C is the tilt angle of coater, [°].

Table 4

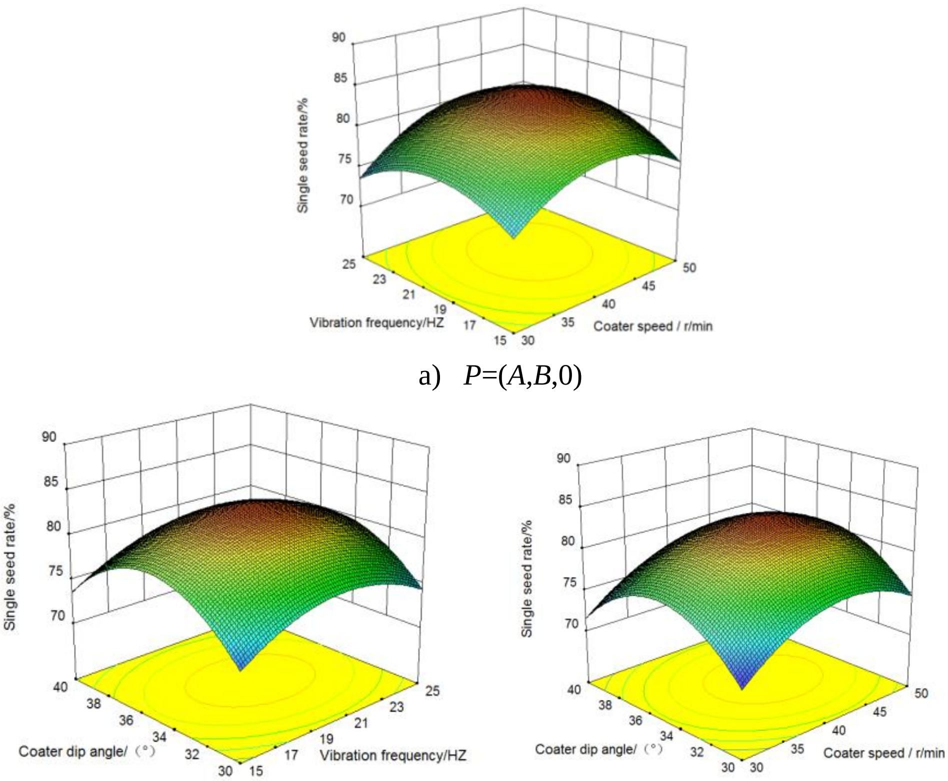
Variance analysis of test results of single seed rate

Origin	Squares	Df	SD	F Value	P Value
Mode	332.613	9.000	36.9570	36.41	< 0.0001
A	20.801	1.000	20.801	20.49	0.0027
B	1.051	1.000	1.051	1.036	0.3427
C	0.005	1.000	0.005	0.005	0.9460
A•B	2.250	1.000	2.250	2.217	0.1801
A•C	0.022	1	0.022	0.022	0.8858
B•C	0.303	1	0.303	0.298	0.6021
A^2	72.341	1	72.341	71.27	< 0.0001
B^2	52.914	1	52.914	52.13	0.0002
C^2	152.591	1	152.591	150.3	< 0.0001
Residual	7.1045	7	1.01492		
Lack of Fit	5.493	3	1.831	4.543	0.0889
Pure Error	1.612	4	0.403		
R^2	0.9791				
Adequate Precision	15.307				

The absolute value of each factor in the model determines the influence degree on the single seed rate. Therefore, the influence of each factor on the pelleting qualified rate is: *A*, *B*, *C*, that is, coater rotating speed > coater vibration frequency > coater tilt angle.

Single seed rate surface analysis

According to the regression mathematical model (4), the response surface of rotating speed, tilt angle and vibration frequency of the coater to the single seed rate can be obtained, as shown in Fig. 7.



a) $P=(A,B,0)$

b) $P=(0,B,C)$ c) $(P=A,0,C)$

Fig. 7 - Response surface of coater rotating speed, vibration frequency and tilt angle to single seed rate

Fig. 7 shows the response surface of each of the two factors to the single seed rate. The analysis shows that with the increase of each factor, the single seed rate increases first and then decreases. As the coater rotating speed increases, the peristalsis of the seed in the coater increases, so the probability of mixing the multi-seeds is reduced. When the rotating speed continues to increase, the peristaltic effect of the seed is reduced by the centrifugal force. The single seed rate was reduced. Besides, when the vibration is added, the single seed rate can be increased. However, when the vibration frequency is too large, the powder wrapped on the surface of the seed easily falls off and settles at the bottom of the coater, resulting in a decrease of single seed rate. As the tilt angle of coater increases, the pelleting qualified rate increases first and then decreases. When the coater angle is too small, the path of the seed rotating with the coater is long, and falls when reaching a higher height in the coater. Since the coater tilt angle is too small, the seed movement path is long, and the seed falls directly from the top to the bottom of the coater to generate a large collision force, so that the powder coated on the surface of the seed falls off under the action of the collision force. The seeds are re-bonded together under the action of the agent, resulting in a decrease in the single seed rate. When the tilt angle of coater is too large, the trajectory of the seed along the coater is small, basically at the bottom of coater, the seed peristalsis effect is not good, and the powder cannot uniformly enter the seed group, resulting in a low single seed rate.

Optimization and test verification

According to the multivariate two-regression equation fitting factor and response value, Design-Expert software was used to get the best parameters.

$$\begin{cases} MaxJ \\ MaxP \\ 30 \le A \le 50 \\ 15 \le B \le 25 \\ 30 \le C \le 40 \end{cases} \tag{4}$$

After the analysis of Design-Expert software, when A=41.74, B=20.28, C=34.89, the optimum value is obtained. That is, when the rotating speed of coating is 41.7 r/min, the vibration frequency of coater is 20.28 Hz, and the coater tilt angle is 34.89°, the pelleting qualified rate is 95.8% and the single seed rate is 83.4%.

CONCLUSIONS

1) Pelleting qualified rate and the single seed rate of Agropyron seeds were significantly increased by introducing vibration.

2) Response surface methodology was applied to analyse the test results. The primary and secondary factors affecting the qualified rate and single seed rate of Agropyron seed pellets were determined as follows: coater rotating speed, coater vibration frequency and coater tilt angle. When coater rotating speed is 41.7 r/min, coater vibration frequency is 20.28 Hz and the coater tilt angle is 34.89°, the pelleting effect and the single seed rate are the best.

3) The optimization results are verified by experiments, and they are basically consistent with the experimental results. The single seed rate and pelleting qualified rate were 83.1% and 94.9% respectively.

ACKNOWLEDGEMENTS

We acknowledge that this work was financially supported by National Natural Science Foundation Project "Research on soil wind erosion monitoring system based on wireless sensor network and its key technologies (41361058)" and "Research on seed pelleting parameters and coating mechanism under the vibration force field (2018MS05023)".

REFERENCES

[1] Andrew L., Todd E., King Y., Kingsley W., David J., (2016), Flash flaming effectively removes appendages and improves the seed coating potential of grass florets. *Restoration Ecology*, Vol. 24, Issue S2, pp. S98-S105, University of Western Australia / Australia;

[2] Chi Q., (2015), Experimental design and statistical analysis[M]. *Chongqing University press*, pp. 280-282, Chongqing / China;

[3] Ge J., Gan D., Meng S., (2016), The research status of seed coating and the necessity of implementing good agricultural practices. *Seed*, Vol 35, Issue 2, pp. 45-49, Beijing/China;

[4] Gui H., Wuren Q., (2012), Characteristics of Leymus chinensis community under different extent of degradation in Hulun Buir Grassland. *Journal of Southern Agriculture*, Vol.43, Issue 12, pp.2035-2039, Inner Mongolia / China;

[5] Han B., Chen K., Lv X., Lu D., Tang Y., (2018), Development status and existing problems of seed pelletizing coating equipment at home and abroad. *Journal of Chinese agricultural mechanization*, Vol. 39, Issue 11, pp.51-55, Jiangsu / China;

[6] Hang Y., Sun J., (2012), Leymus Chinensis grassland improvements (Review). *Acta Agrestia Sinica*, Vol.20, Issue 4, pp.603-608, Hulun Buir/China;

[7] Liu J., Zhang X., Jin X., Yang X., Yang L., (2020), Effects of fertilization and seed coating formula on the growth of grass seedlings in sandy land. *Resources and environment in arid area*, Vol. 34, Issue 2, pp.148-153, Hulunbuir / China;

[8] Masoume A.， Anil N. Huang W.， Taylor A.G., (2016), Investigation of Soy Protein–based Biostimulant Seed Coating for Broccoli Seedling and Plant Growth Enhancement. *HortScience*, Vol. 51, Issue 9, pp.1121-1126, Cornell University / USA;

[9] Shen H., Zhu Y., Zhao X., Geng X., Gao S., Fang J., (2016), Analysis of current grassland resources in China (in Chinese). *Chin Sci Bull*, Vol 61, Issue 2, pp.139–154, Inner Mongolia/China;

[10] Wang J., Xie H., Hu Z., Hu L., Peng B., Liu M., (2017), Parameter optimization on mechanical coating processing of rotary table-roller coating machine for peanut seeds. *Transactions of the Chinese Society of Agricultural Engineering*, Vol 33, Issue 7, pp. 43 − 50, Jiangsu / China;

[11] Wu F., Zhang H., Xie H., Wang J., Qiu C., (2017), Overview and development of seed coating machine in China [J]. *China Journal of agricultural machinery chemistry*, Vol. 38, Issue 10, pp.116-120, Nanjing / Jiangsu.