DESIGN AND EXPERIMENTAL STUDY OF A RAPESEED BROADCAST SPREADER OF SCREW-DROP TYPE
/
螺旋排种式油菜籽撒播机设计及试验

Prof. Ph.D. Eng. Xie S.Y., Ms. Stud. Eng. Yu T., Ms. Stud. Eng. Chen T.H., Ms. Stud. Eng. Yang Z.R., Prof. Ph.D. Eng. Yang L., Prof. Ph.D. Eng. Yang M.J.*

Southwest University, College of Engineering and Technology, Chongqing Key Laboratory
of Agricultural Equipment for Hilly and Mountainous Regions / P. R. China
Tel: 8613883002509; E-mail: ymingjin@swu.edu.cn

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ABSTRACT

A small-scale rapeseed broadcast spreader of screw-drop type was developed in this study. The effect of process parameters on broadcast sowing performance of rapeseed was tested and investigated. The metering rate and spreading width of the broadcast spreader were adjustable. The metering rate linearly increased with the increase of screw auger revolution and the spreading width logarithmically increased with the increase of rotary disk revolution and height. Rotary disk revolution had the highest significant level of impact on distribution uniformity of rapeseed broadcast sowing of the broadcast spreader, and it was followed by screw auger revolution, rotary disk height and the spreader forward speed, sequentially. The optimal process parameters for distribution uniformity of rapeseed broadcast sowing were the rotary disk revolution 180 rpm, rotary blade height 800 mm, forward speed 2 km/h, and screw auger revolution 40 rpm.

摘要

本研究开发了一套小型螺旋排种式油菜籽撒播机，并测试和验证了工艺参数对油菜籽撒播性能的影响。研究表明，撒播机的排种速率和撒播幅宽可调，排种速率随着螺旋排种搅龙转速的增加而呈线性增加，撒播幅宽随着圆盘转速和圆盘高度的增加而呈对数关系增加。圆盘转速对油菜籽撒播均匀性的影响最显著，其次是螺旋排种搅龙转速和圆盘高度，前进速度影响最小。对于撒播均匀性而言，最优的工艺参数是：圆盘转速 180 rpm，圆盘高度 800 mm，前进速度 2 km/h，排种搅龙转速 40 rpm。

INTRODUCTION

Rape is a bright-yellow flowering member of the family *Brassicaceae* (mustard or cabbage family), cultivated mainly for its oil-rich seed. Rapeseed is the third-largest source of vegetable oil in the world *(Yang et al., 2017)*. China is one of the top rapeseed producers and accounts for about 20% of world production. Rapeseed is more likely to achieve increased yield in high-density plantings since high-density planting can increase index of plant leaf area, improve efficiency of light energy use and nitrogen use, and promote transformation of nitrogen to grain *(Hu et al., 2017)*.

Direct drilling is an effect method of rapeseed planting in high-density planting model and greatly reduces labour cost and improves soil structure. By means of direct drilling, rapeseed is metered and dropped into farming lands, namely mechanical seedling nursery is not required, which simplifies the planting process and benefits its mechanization of rapeseed production *(Zhang et al., 2012)*. Direct drilling falls into 4 categories: broadcast sowing, strip sowing, dibble sowing and precision sowing, and their sowing precision increases sequentially. No-till farming of rape is newly encouraged in Southern China. Broadcast sowing is one of the key links of no-till farming of rape. Compared to traditional transplanting method, broadcast sowing shows good performance of high efficiency and low labour cost. The main obstacles for advocating broadcast sowing are high amount of seed use and low distribution uniformity of sowing *(Sun et al., 2017)*.

The application of broadcast spreader to broadcast sowing gave direct reference to fertilizer spreader. Centrifugal spreader was the main type of broadcast spreader used in fertilizer broadcasting, and as a result, the corresponding study, design, optimization, and improvement matured a lot. Theoretical studies on centrifugal spreader dated back to the 60s of last century. While neglecting particle bounce, motion and force of a single spherical particle on a flat rotary disk equipped with radial straight vanes were examined, particle trajectories escaping from the disk were investigated. According to these theoretical studies, many centrifugal spreaders for fertilizer use were developed and their broadcasting performances were examined *(Wu, 2007; Zhang et al., 2012; Dong et al., 2013; Kobets et al., 2017)*. To optimize spreading process and improve broadcasting performance, innovative image-based techniques were employed to measure the spread pattern and identify the particle dispersion, and showed good agreement with experiments *(Cool et al., 2017; Chen et al., 2017)*.

Nevertheless, as for centrifugal spreader for rapeseed broadcast purpose, few reports or literatures were available. The main objectives of this study were to develop a small-scale rapeseed broadcast spreader, investigate the effect of process parameters on rapeseed broadcast sowing performance, and optimize process parameters of the broadcast spreader.

MATERIALS AND METHODS

Mature and dry rapeseed was bought from market in Beibei, Chongqing, China. The impurities, cracked, germinated, mouldy seed and seed of small size were manually removed to obtain test samples of a uniform size.

Design of broadcast spreader

A schematic diagram of the broadcast spreader designed for rapeseed broadcast sowing was presented, as shown in Fig.1. The main components of the spreader were seed hopper, screw auger for metering rapeseed, seed chute, and rotary disk for spreading rapeseed. Rapeseed in seed hopper was screw-dropped onto the flat rotary disk of diameter 200 mm, through a screw auger of diameter 100 mm and seed chute. The rotary disk was evenly equipped with 6 radial straight vanes. Rapeseed on the rotary disk was accelerated by the resultant of forces such as gravity, inertia transfer, Coriolis' inertia, frictional forces interaction with disk and vane edge, disk reaction *(Kobets et al., 2017)*. An initial throw velocity off the rotary disk was obtained, with rapeseed passing through a 120° exit. Other rapeseed, blocked by the shield, was dropped into the seed collector for later sowing. The screw auger and rotary disk were driven by different motors to obtain revolutions of ω_1 and ω_2. The screw auger rotated counter-clockwise on the top view.

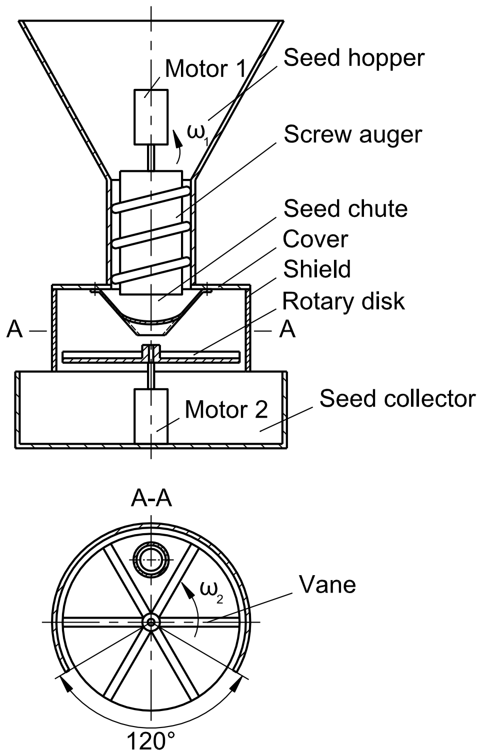


Fig. 1 – Structure diagram of broadcast spreader of screw-drop type

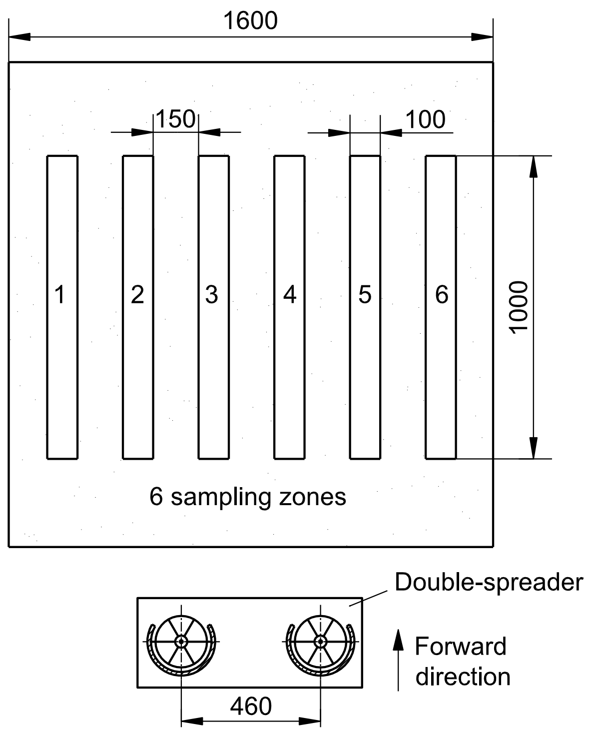


Fig. 2 – Outline of experiments on double-spreader

Experiments on single-spreader

(1) Metering rate with revolution of screw auger. In order to obtain a defined constant broadcast sowing rate of rapeseed, it is necessary to examine the metering rate of screw auger. The revolution of screw auger was controlled by motor *1* with Pulse Width Modulation (PWM) method, and it was tested by a portable tachometer. The rapeseed was metered under constant revolution of screw auger. Seven revolutions were adopted for the experiment, at an increasing revolution of 10 rpm from 10 rpm to 70 rpm. To reduce errors of metering test, only rapeseed in the medium stage was sampled by a container. The sampling time was from 0.5 min to 1.5min.

(2) Spreading width with revolution of rotary disk. A flannelette cloth of dimensions 1.6 m width and 10.0 m length was covered on a flat field for the spreading width test. The height of rotary disk above the flat field was set as 160 mm, and revolution of screw auger was set as 40 rpm. Seventeen revolutions of rotary disk were adopted for the experiment. The rotary disk minimum revolution was set as 118 rpm, and the maximum revolution was set as 584 rpm. Five grams of rapeseed were used for each test. The revolution of rotary disk was controlled by motor *2* with PWM method.

(3) Spreading width with height of rotary disk. The revolutions of screw auger and rotary disk were set as 40 rpm and 417 rpm, separately. Eight heights of rotary disk were set for the experiment. The minimum height was set as 160 mm, and the maximum height was set as 1500 mm. Five grams of rapeseed were used for each test as well.

Experiments on double-spreader

(1) Experimental setup. To improve efficiency and distribution uniformity of rapeseed broadcast sowing, an overall design of double-spreader was adopted for the rapeseed broadcast spreader. The span of the two spreaders was set as 460 mm, an approximate span of an adult's shoulders. Six sampling zones were marked on the flannelette, with dimensions of 1000 mm length and 100 mm width, and there were spaces of 150 mm between neighbour zones, as shown in Fig. 2. Five grams of rapeseed per spreader, namely 10 g of rapeseed altogether, were used for each test.

(2) Experimental procedures. Experiments of distribution uniformity of single-factor sowing were initially conducted to obtain an overall performance of the double-spreader. According to the tested distribution uniformity, control factors and their levels of multi-factor sowing for distribution uniformity could be defined. Parameters of the single-factor sowing for distribution uniformity were listed in Table 1.

Table 1

Parameters of single-factor sowing for distribution uniformity

Experiment Item	Fixed parameters				
	Revolution of rotary disk	Height of rotary disk	Span of spreaders	Revolution of screw auger	Forward speed
	[rpm]	[mm]	[mm]	[rpm]	[km/h]
Effect of revolution of rotary disk on distribution uniformity	/	160	460	40	0
Effect of height of rotary disk on distribution uniformity	435	/	460	40	0
Effect of span of spreaders on distribution uniformity	435	160	/	40	0
Effect of forward speed on distribution uniformity	435	410	460	40	/

For experiments on distribution uniformity of multi-factor sowing, orthogonal Factorial Experiment Design technique based on Taguchi methodology was employed to arrange experiments. Taking revolution of rotary disk, height of rotary disk, forward speed of broadcast spreader, and revolution of screw auger as control factors, and sowing distribution uniformity as evaluation index, levels of control factors were defined, as shown in Table 2. Experiments were designed in accordance with appropriate orthogonal array $L_9(3^4)$, a 3-level 4-factor array with 9 runs, and their arrangement was shown in Table 3. The span of spreaders was set as 460 mm for the multi-factor sowing.

Table 2

Levels of control factor

Level	Revolution of rotary disk A	Height of rotary disk B	Forward speed C	Revolution of screw auger D
	[rpm]	[mm]	[km/h]	[rpm]
1	180	400	1	10
2	360	800	2	40
3	540	1200	3	70

Table 3

Experiment arrangements and results of distribution uniformity

No.	Factor A	Factor B	Factor C	Factor D	Distribution uniformity
1	1	1	1	1	0.713
2	1	2	2	2	0.761
3	1	3	3	3	0.656
4	2	1	2	3	0.556
5	2	2	3	1	0.657
6	2	3	1	2	0.669
7	3	1	3	2	0.688
8	3	2	1	3	0.697
9	3	3	2	1	0.701

The experiments of distribution uniformity of broadcast sowing were conducted according to standard of American Society of Agricultural and Biological Engineers ASAE S341.3, namely "Procedure for measuring distribution uniformity and calibrating granular broadcast spreaders" *(American Society of Agricultural and Biological Engineers, 2005)*. Distribution uniformity was calculated by the following expression:

$$D = 1 - CV \tag{1}$$

where:

D is distribution uniformity, [dimensionless];

CV – coefficient of variation, [dimensionless].

Coefficient of variation was calculated as follows:

$$CV = \frac{s}{\mu} \tag{2}$$

where:

s is standard deviation of samples;

μ – mean accumulated sample per sampling zone, [particles].

RESULTS

Performance of Single-spreader

Metering rate with revolution of screw auger, at an increasing revolution of 10 rpm from 10 rpm to 70 rpm, was obtained and depicted. As shown in Fig. 3, metering rate of the broadcast spreader linearly increases with the increase of screw auger revolution. A regression equation, with coefficient of determination R^2 0.9820, was obtained by means of software SPSS as:

$$M = 0.1293R_a + 2.5571, \text{ [g/min]} \tag{3}$$

where:

M is metering rate, [g/min];

R_a – auger revolution, [rpm].

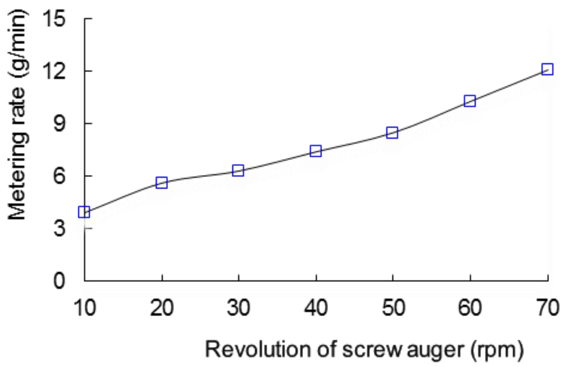


Fig. 3 – Metering rate with screw auger revolution

Spreading width with rotary disk revolution, starting from 118 rpm to 584 rpm, was obtained and depicted. As shown in Fig. 4, spreading width of the broadcast spreader logarithmically increases with the increase of rotary disk revolution. A regression equation, with coefficient of determination R^2 0.9830, was obtained as:

$$W = 768.87\ln\left(R_{\mathrm{d}}\right) - 3489.7\text{, [mm]} \tag{4}$$

where:

W is spreading width, [mm];

R_{d} – rotary disk revolution, [rpm].

Similarly, spreading width with the height of rotary disk, starting from 160 mm to 1500 mm, was obtain and depicted. As shown in Fig. 5, spreading width of the broadcast spreader logarithmically increases with the increase of rotary disk height. A regression equation, with coefficient of determination R^2 0.9840, was obtained as:

$$W = 600.7\ln\left(H\right) - 2001.3\text{, [mm]} \tag{5}$$

where:

H is rotary disk height, [mm].

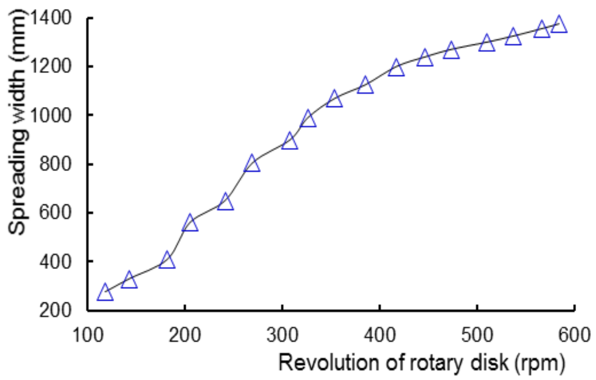


Fig. 4 – Spreading width with revolution of rotary disk

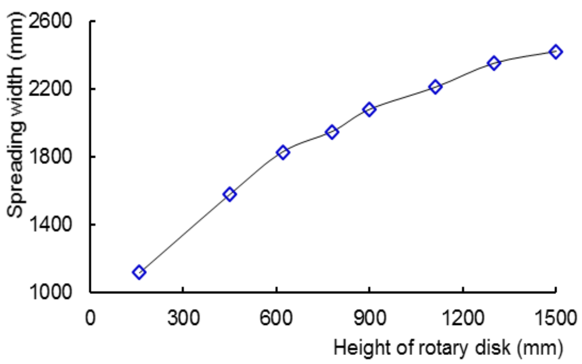


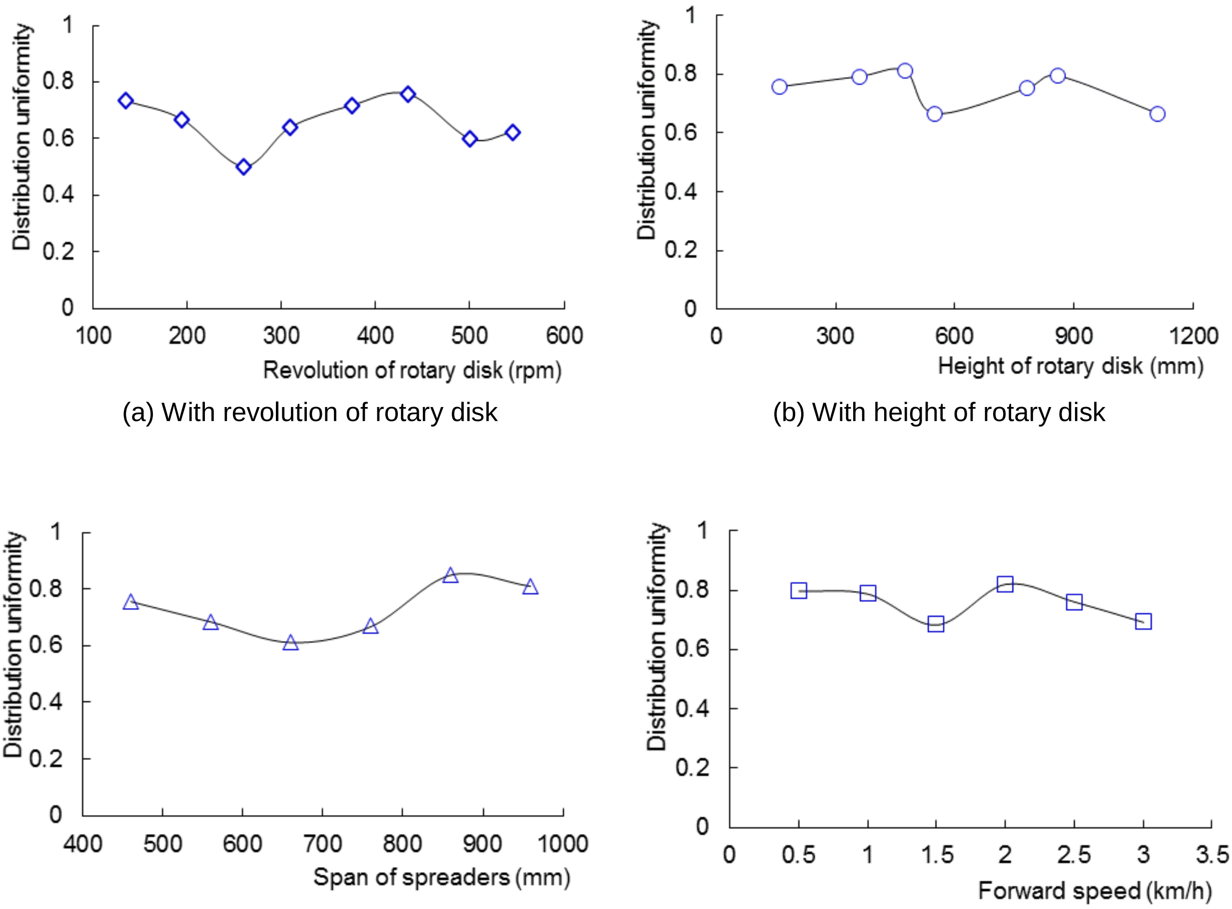
Fig. 5 – Spreading width with height of rotary disk

Performance of Double-spreader

Distribution uniformity of single-factor sowing

Distribution uniformity of single-factor sowing was obtained and depicted, as shown in Fig. 6. While keeping height of rotary disk 160 mm, span of spreaders 460 mm, revolution of screw auger 40 rpm, and forward speed of the double-spreader 0 km/h constant, the maximum distribution uniformity obtained was 0.757 at rotary disk revolution 435 rpm, and the minimum was 0.502 at 260 rpm, with a difference of 0.255 (Fig. 6 (a)). While keeping rotary disk revolution 435 rpm, span of spreaders 460 mm, screw auger revolution 40 rpm, and forward speed of the double-spreader 0 km/h constant, the maximum distribution uniformity obtained was 0.812 at rotary disk height 475 mm, and the minimum was 0.665 at 550 mm, with a difference of 0.147 (Fig. 6 (b)). While keeping rotary disk revolution 435 rpm, rotary disk height 160 mm, screw auger revolution 40 rpm, and forward speed of the double-spreader 0 km/h constant, the maximum distribution uniformity obtained was 0.851 at span of spreaders 860 mm, and the minimum was 0.613 at 660 mm, with a difference of 0.238 (Fig. 6 (c)). While keeping rotary disk revolution 435 rpm, rotary disk height 160 mm, span of spreaders 460 mm, and screw auger revolution 40 rpm constant, the maximum distribution uniformity obtained was 0.820 at forward speed of the double-spreader 2 km/h, and the minimum was 0.684 at 1.5 km/h, with a difference of 0.136 (Fig. 6 (d)).

According to Chinese standard JB/T 6274.1-2013, namely "Grain drill - Part 1: Specifications", the distribution uniformity of a grain drill should be higher than 0.55 *(Ministry of Industry and Information Technology of the P. R. China, 2013)*. The overall performance of the double-spreader is good, especially for application of rapeseed broadcast sowing in hilly and mountainous regions of Chongqing, China. But for practical promotion of the broadcast spreader, some parameters or specifications should be adjusted, so as to obtain convenience, easy-operation and portability of the rapeseed broadcast sowing.



(a) With revolution of rotary disk (b) With height of rotary disk

(c) With span of spreaders (d) With forward speed

Fig. 6 – Distribution uniformity of single-factor sowing

Distribution uniformity of multi-factor sowing

Experimental results of distribution uniformity of multi-factor sowing were obtained, as listed in Table 3. Statistical analyses of range and variance were performed to obtain the impacts and their significance of each control factor on distribution uniformity of rapeseed broadcast sowing. Range analysis results were listed in Table 3, and variance analysis results were listed in Table 4. The values in cells of each level of the control factors in Table 3 represented mean values of distribution uniformity of the corresponding levels and factors. The delta values of each factor represented the biggest change of mean distribution uniformity of the factor, namely the impact level of each factor. The numbers in the rank row indicated the impact significance of the control factors.

Table 4

Range analysis

Level	Factor A	Factor B	Factor C	Factor D
1	0.7100	0.6523	0.6930	0.6903
2	0.6273	0.7050	0.6727	0.7060
3	0.6953	0.6.53	0.6670	0.6363
Delta	0.0827	0.0527	0.0260	0.0697
Rank	1	3	4	2

Table 5

Variance analysis

Source of variance	Degree of freedom	Sum of squares	Mean sum of squares	*F*-ratio	Critical *F*-ratio
Factor A	2	0.011673	0.005836	10.41	$F_{0.088}(2,2)=10.41$
Factor B	2	0.004183	0.002091	3.73	$F_{0.211}(2,2)=3.73$
Factor C	2	0.001122	0.000561	Error	/
Factor D	2	0.008015	0.004007	7.15	$F_{0.123}(2,2)=7.15$
Total	8	/	/	/	/

Range analysis and variance analysis showed that: factor of rotary disk revolution had the highest significant level of impact on distribution of rapeseed broadcast sowing of the double-spreader, and it was followed by factors of screw auger revolution, rotary disk height and forward speed of the double-spreader, sequentially. By taking the column of control factor with the minimum sum of squares, namely factor of forward speed, as the error column of orthogonal array, the *F*-ratio of each control factor was compared to a critical value corresponding to a certain pre-selected probability. Then, there were probabilities of 91.2 %, 87.7 %, and 78.9 % that control factors were in fact due to chance because of rotary disk revolution, screw auger revolution and rotary disk height, respectively. The probabilities were quite high for the outdoor experiments. $A_1B_2C_2D_2$ was the optimal level combination for good performance of distribution uniformity, namely rotary disk revolution 180 rpm, rotary blade height 800 mm, forward speed 2 km/h, and screw auger revolution 40 rpm.

CONCLUSIONS

A rapeseed broadcast spreader of screw-drop type was developed. The metering rate with screw auger revolution, spreading width with rotary disk revolution and rotary disk height were examined for the single-spreader. The performance of distribution uniformity of single-factor sowing and multi-factor sowing was investigated for the double-spreader.

The main conclusions are as follows:

- The metering rate of the broadcast spreader was adjustable with Pulse Width Modulation method, and it linearly increased with the increase of screw auger revolution. Spreading width of the broadcast spreader was also adjustable by means of altering rotary disk revolution or rotary disk height, and it logarithmically increased with the increase of rotary disk revolution and rotary disk height.
- Factor of rotary disk revolution had the highest significant level of impact on distribution uniformity of rapeseed broadcast sowing of the double-spreader, and it was followed by factors of screw auger revolution, rotary disk height and forward speed of the double-spreader, sequentially. There were probabilities of 91.2 %, 87.7 % and 78.9 % that control factors were in fact due to chance because of rotary disk revolution, screw auger revolution and rotary disk height, respectively.
- The optimal process parameters for distribution uniformity of rapeseed broadcast sowing were rotary disk revolution 180 rpm, rotary blade height 800 mm, forward speed 2 km/h and screw auger revolution 40 rpm.

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