DESIGN AND EXPERIMENT OF A SINGLE-ROW SMALL GRAIN PRECISION SEEDER /

单行小籽粒精少量播种机设计与试验

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ABSTRACT

In order to meet the precision seeding of small seeds including millet and broomcorn millet in hilly and mountainous areas, a single-row small grain precision seeder was developed. Static seeding test and seeding test were carried out on the seeder. In this paper, the key parts such as socket wheel-ring groove seed metering device, transmission system and tensioning wheel are designed. The working parts such as arrow shovel furrow opener, plastic seed tube and hollow cast iron press wheel were selected to achieve seed metering. The seed metering wheel has double-row of holes. The results of static seeding test showed that rotational speed had a significant effect on the sowing quantity of millet and broomcorn millet (P < 0.001). The higher the rotational speed, the greater the sowing quantity. With the increase of rotational speed of seed metering wheel, the damage rate of millet and broomcorn millet increased. At the same rotational speed, the breakage rate of broomcorn millet is smaller than that of millet. The field sowing test showed that when the seeder is at a marching speed of about 0.5 m/s, the qualified rate of the hole spacing of millet and broomcorn millet is greater than or equal to 90%, and the qualified rate of the number of grains per hole is greater than or equal to 82%. All indicators meet the requirements of the technical conditions of single-grain (precision) seeder. The design can provide reference for the design and optimization of small grain precision seeder.

摘要

为了满足丘陵山地谷子、黍子等小籽粒种子的精少量播种，研制了单行小籽粒精少量播种机，并对播种机进行了静态排种试验和播种试验。该文设计了窝眼轮-环槽式排种器、传动系统、张紧轮等关键零部件，选用了箭铲式开沟器、塑料导种管、空心铸铁镇压轮等工作部件，排种轮具有双排型孔。静态排种试验结果表明：转速对谷子、黍子的排量有极显著影响显著（P＜0.001），转速越大，排量越大；随着排种轮转速的增大，谷子和黍子的破损率均增大；在同一转速下，黍子的破损率比谷子的破损率均小。田间播种试验表明：当播种机在0.5m/s 左右的前进速度下，谷子、黍子的穴距合格率均大于等于 90%，穴粒数合格率均大于等于 82%，各项指标均满足单粒（精密）播种机技术条件的要求。该设计可为小籽粒精量播种机设计和优化提供参考。

INTRODUCTION

Millet is one of the characteristic crops in China with drought tolerance and balanced nutrition *(Li et al., 2021; Hou et al., 2017)*. In recent years, driven by the adjustment of industrial structure and the market, *(Li et al., 2021)*, the planting area of millet is increasing, and the development prospect is broad. However, at present, millet sowing mostly uses strip sowing. If the sowing quantity is large, it needs to be artificially interplanted. It wastes seeds, time and labor *(Zhang et al., 2017)*. If the sowing quantity is small，which will appear 'broken seedlings' phenomenon, and artificial seedling replenishment is needed, which limits the rapid development of millet industry to a certain extent. Therefore, the development of a small grain precision seeder can not only save labor and sowing costs, but also promote the whole mechanization of millet.

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The precision sowing machinery in foreign developed countries started early and has perfect technology *(Nikolay et al., 2022; Pareek et al., 2023; Dylan et al., 2013).* Because of its wide sowing width and high sowing speed, the traditional mechanical sowing can't meet the sowing requirements, so it is mainly based on air suction or air blowing sowing *(Arzu et al., 2014; Sujit et al., 2022; Pareek et al., 2021).*

Karayel D studied the depth uniformity of the improved vacuum precision seeder and experimentally determined the optimum vacuum pressure *(Karayel et al., 2009).* The seeding uniformity of vacuum precision seeder was optimized by response surface method (RSM). The optimum combination of variables was obtained and verified *(Arzu et al., 2007).* Cujbescu used the mathematical model to numerically simulate the working process of the pneumatic seed-metering device, and analyzed the movement of the seeds according to the angle of detachment, the height of detachment of the seed, as well as the speed of the seed in its trajectory towards the channel opened by the coulter (*Cujbescu et al., 2022*)*.* Hoque developed a tilt-plate seeder, which has been tested to save 90 % of time and 86 % of cost compared to manual planting, with a payback period of 1.2 years *(Hoque et al., 2016).* However, foreign millet planting area is relatively small. There is not much research on millet precision metering device *(Yi et al., 2021).* Four kinds of suction holes with different structures were compared by Wang. The results showed that the suction effect of the air-suction millet seed metering device was the best when the suction hole was the four-prism platform, and the best working parameters of the seed metering device were obtained *(Wang et al., 2021)*.

In recent years, there are more and more researches on millet and other small grain precision metering device in China. Yi developed positive and negative air pressure and type hole wheel combined millet seed metering device, and obtained the best working parameters of the metering device through the combination test *(Yi et al., 2021).* Zhang designed a pressure-holding precision seed-metering device for maize, and obtained the optimal size of the parts of the seed-metering device and the rotation speed (*Zhang et al., 2023*). Wang combined EDEM discrete element software to optimize the mechanical wheat seeding device, and concluded that when the inner diameter of the seed wheel was 125 mm and the opening inclination angle was 25°, the seeding performance was the best (*Wang et al., 2021*). Zhang designed a millet fluid seed-metering device. The seed-metering device seeded the prepared suspension liquid through the pump pipe and the seed-metering pipe by the conveying pump. The field test showed that the qualified rate of hole spacing and the qualified rate of the number of holes were both above 74% *(Zhang et al., 2017*; *Zhang et al., 2012).* Zhang developed a kind of ring groove millet seed metering device. Liu designed a magnetic pickup finger seed-metering device with magnetic force to complete the opening and closing of the finger-clamp, and optimized the seed-metering device to obtain the optimal operating parameters (*Liu et al., 2021*). Chen designed a vertical disc metering device, and used the quadratic orthogonal rotation center combination design test to optimize the structural parameters of the seed agitators (*Chen et al., 2021*). Tian designed a rotary precision hill direct seeding metering device, and obtained the optimal parameters through test (*Tian et al., 2021*). Mechanical metering device has the problems of seed injury, seed sticking and complex structure*.* The air suction metering device has high processing precision, high energy consumption and high air tightness requirements *(Wang et al., 2017; Yi et al., 2021).* The fluid metering device has higher requirements for mixed suspension *(Zhang et al., 2017).*

The purpose of this paper is to design and trial-produce a single-row small grain precision seeder with simple structure, low damage rate and low cost, and carry out static seeding and seeding experiments on the seed metering device of the seeder. This study can provide reference for the development of precision sowing technology for millet and other small grains.

MATERIALS AND METHODS

Overall Design of Seeder

The single-row small grain precision seeder is shown in figure 1.

It is mainly composed of ring screw *1*, ground wheel *2*, body frame *3*, scraping blade *4*, seed metering device *5*, big sprocket *6*, chain *7,* hand-push rod *8*, small sprocket *9*, pressing wheel *10*, spring *11*, tension pulley wheel *12*, type *R* opening pin *13*, seed guide tube *14*, furrow opener *15*, butterfly nut *16* and other parts. Ground wheel, furrow opener, pressing wheel through bolts or pins installed on the body frame, adjust the opening pin installation position can adjust the ditching depth. The seed metering device and the hand putter are fixed on the opener by bolts, the big sprocket and the seed tube are installed on the seed metering device, the small sprocket is installed on the pressing wheel, and the tension pulley wheel is installed on the body frame. Adjust the tightness of the tensioning wheel by a spring mounted on the frame. The number of working rows is single, the whole machine size is: 1100mm × 400mm × 960mm.

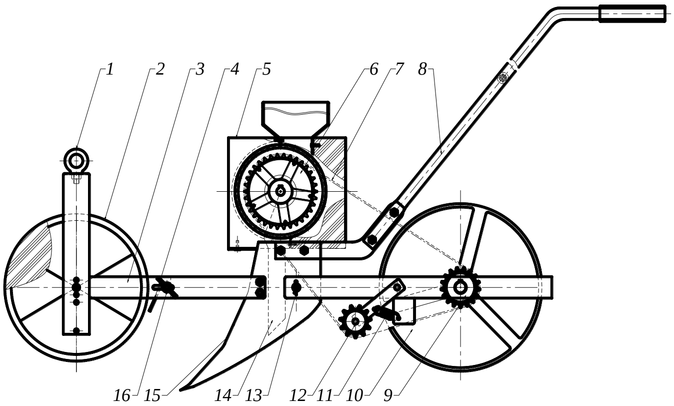


Fig. 1- Schematic diagram of the structure of a single-row small grain precision seeder
1 – Ring screw; 2 – Ground wheel; 3 – Body frame; 4 – Scraping blade; 5 – Seed metering device; 6 – Big sprocket; 7 – Chain; 8 – Hand-push rod; 9 – Small sprocket; 10 – Pressing wheel; 11 – Spring; 12 – Tension pulley wheel; 13 – Type R opening pin; 14 – Seeding guide tube; 15 – Furrow opener; 16 – Butterfly nut

Working principle

When the seeder is working, the forward power is provided by pushing the hand-push rod (*8*) and pulling the ring screw (*1*). The pressing wheel drives the seed metering device shaft to rotate through the chain drive, and the seed metering device shaft drives the seed metering wheel to rotate. The seed is introduced into the seed ditch through the seeding guide tube, and the concave pressing wheel completes the soil covering and pressing operation at the same time. The tensioning wheel can prevent the chain from unchaining under the action of spring tension.

Overall structure design and working principle of seed metering device

The radius R of the seed metering wheel is 70 mm, and the larger diameter of the seed metering wheel can prolong the filling time and filling distance, which is beneficial to improve the filling coefficient. *(Huang et al., 2019)*. The thickness of the seed metering wheel is 30 mm. In order to meet the land with different moisture conditions, the seed metering wheel is a double-row sockets. The single-row or double-row seeding can be determined according to the moisture condition of soil, which effectively improves the utilization rate of the seeding device. The number of double-row sockets of the metering device is designed to be 20, the center line of the two rows of sockets is 14mm apart, and the center of the single-row socket is 8mm from the edge of the seed metering wheel. The minimum diameter of the seeding wheel shaft can be calculated to be 12 mm according to Formulas (1) and (2).

$$d \geq A_0 \sqrt[3]{\frac{P}{n}} \quad \text{[mm]} \tag{1}$$

$$P = \frac{FV}{1000} \quad \text{[kW]} \tag{2}$$

where: d is the minimum diameter of the shaft, [mm];

A_0 is a constant (related to the material and structure of the shaft), and the value is 126;

n is the rotational speed of the metering device, [r/min];

P is power, [kW];

F is the working resistance, [N], the value is 110 N;

V is the speed of the metering device, [m/s].

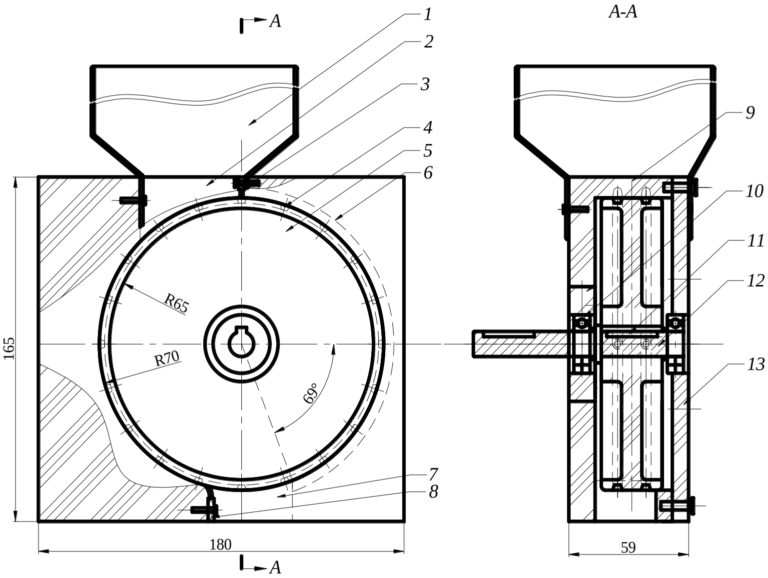
According to 'GB/T 276-2013', use a 6001 deep groove ball bearing. According to 'GB/T 1096-2003', select 5mm×5mm ordinary flat keys. The cross section of filling port is 50 mm × 8 mm, and the cross section of seeding port is 40 mm × 30 mm. Acrylic plate has the advantages of high transparency, easy processing, so the seed metering wheel, shell and end cover are made of acrylic plate processing. The processed metering device can clearly see its internal structure and the whole seeding process.

The socket wheel-ring groove metering device is mainly composed of seed box *1*, scraping seed brush *3*, seed metering wheel *5*, ring groove *6*, seed clearing brush *8*, seed metering shell *9*, metering device shaft *12*, end cover *13*, etc. the schematic diagram of the seed metering device is shown in Fig. 2.

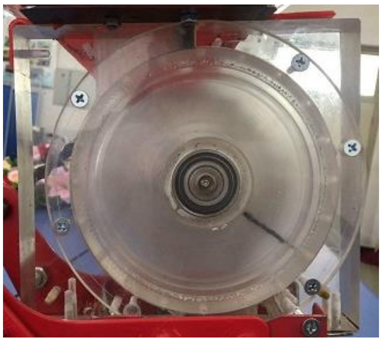
When working, the pressing wheel drives the metering shaft *12* to rotate clockwise through the chain drive, and the shaft drives the metering wheel *5* to rotate through the key connection.

The seeds in the filling room *2* are filled into socket *4* under the action of gravity. With the rotation of the seed metering wheel, the seed brush *3* removes the excess seeds. In the seed protection area, there is a ring groove *6* at the corresponding part of socket. The ring groove can effectively avoid compression and friction of the seed protection plate on seed, so as to achieve the effect of protecting the seed. After the seed metering wheel is turned about 110° from the vertical direction, seed begins to move from socket to the ring groove. In order to ensure that the seed in the socket can be completely discharged into seed furrow, a seed cleaning brush *8* was installed at the seed outlet *7*.

The conical section of the ring groove seed metering device can only accommodate one seed, which can avoid the self-locking phenomenon of two seeds. The socket wheel seed metering device has a more accurate hole spacing and the number of seeds per hole, the height of seed falling is low, and it can be designed into single and double row sockets *(Li et al., 2018).* Therefore, the seeding method of the seed metering device is the socket wheel ring groove type, that is, the seed metering wheel is socket wheel, and the seed protection plate has a 1/2 ring groove corresponding to the socket.



a) Schematic diagram of the seed metering device



b) The object diagram of the seed metering device

Fig. 2 - The seed metering device

1 – Seed box; 2 – Filling room; 3 – Scraping seed brush; 4 – Socket; 5 – Seed metering wheel; 6 – Ring groove; 7 – Seed outlet; 8 – Seed cleaning brush; 9 – Seed metering shell; 10 – Rolling bearing; 11 – Keyslot; 12 – Seed metering shaft; 13 – End cover

Design of socket section and ring groove section

In order to design the cross-sectional shape and size of the socket, it is necessary to measure the triaxial size of small grains. In this paper, the triaxial size of millet and broomcorn millet were measured by digital vernier caliper (accuracy: ± 0.01mm). The measurement results are shown in table 1.

Table 1

Measurement the triaxial size of the millet and broomcorn millet

Small grain cereal species	Triaxial size/mm	Measurement times					Average value/mm
		1	2	3	4	5	
Millet	Length	2.16	2.21	2.24	2.18	2.15	2.188
	Width	1.81	1.92	1.85	1.89	1.87	1.868
	Height	1.45	1.41	1.38	1.36	1.42	1.404
Broomcorn millet	Length	3.42	3.48	3.53	3.50	3.45	3.476
	Width	2.53	2.51	2.61	2.42	2.48	2.510
	Height	1.87	1.74	1.99	1.78	1.90	1.856

It is known from table 1 that the average size of the three axes of millet is 2.19 mm length, 1.87 mm width and 1.40 mm height. The three-axis average size of broomcorn millet is 3.48 mm in length, 2.51 mm in width and 1.86 mm in height. Therefore, the shape of the socket is designed as an inverted conical table, and the angle between the generatrix and the vertical direction is designed to be 20°.

The cross-section shape is shown in fig.3 The socket can accommodate up to 2~3 seeds. After cleaning and brushing, two seeds can be retained. The two sides of the socket are inclined, which is conducive to both filling and seeding.

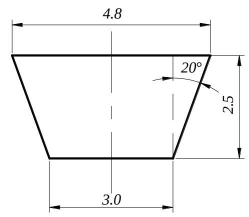


Fig. 3 - The shape of socket section

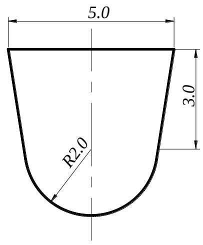


Fig. 4 - The shape of ring groove section

In order to make the ring groove shape suitable for small grains of various shapes and sizes, the cross-section design of the ring groove is shown in figure 4.

Seed metering device cleaning device and brushing device

Commonly used seed cleaning methods include rigid seed cleaning plate, elastic seed cleaning wheel, rubber scraper, brush and air flow seed cleaning. The bristle brush is harder than sponge, but softer than rubber. The cleaning effect is better than that of rubber and felt, and the rate of seed injury is lower. In order to reduce the rate of seed injury, the brush is used to scrape the excess seeds. The brush is fixed with iron sheet and bolt in the filling port and coincides with the central axis of the seed metering wheel. The cleaning device of the seed metering device is to use iron sheet and bolt to fix the brush at the end of the seed metering port, and the seeds remaining in the socket are brushed out of the socket in time and then discharged into the seed furrow, which does not affect the subsequent filling.

Body frame design

In order to reduce the weight of the whole seeder, on the premise of meeting the stiffness requirements of the seeder, the hand-push rod of the frame is connected by steel pipe and fixed by bolt, and the beam spacing of the hand-push rod is 230 mm. While meeting the seeding requirements, in order to facilitate maintenance, the ground wheel, opener, and press wheel are all connected with shafts and opening pins, and the length of the shaft is 90 mm.

In order to meet the characteristics of low cost, convenient disassembly and assembly, adjustable sowing depth, adjustable sowing amount and adjustable hand-held parts of the seeder, at the same time, the space is reserved according to the ground wheel, seed metering device, furrow opener and pressing wheel. The length of the frame is 730 mm, the width is 400 mm, and the height is 840 mm.

Transmission system design

The driving wheel generally adopts the pressing wheel or the ground wheel, and the seeder adopts the pressing wheel drive, and the transmission type is chain drive.

First, the optimal speed of the metering device is obtained by the test. The speed of the seed metering device is adjusted by adjusting the speed of a stepless variable speed motor. Taking millet and broomcorn millet as the test objects, under the static seeding performance test, the optimal speed range of the metering device was measured as: 9 r/min~15 r/min. The theoretical operating speed of the seeder is about 18 r/min~30 r/min. The average transmission ratio of the sprocket can be calculated as about 1:2 by formula (3), and the tooth number ratio of the sprocket is about 2:1.

$$i=\frac{\pi D(1+\delta)}{tz}=\frac{n_1}{n_2}=\frac{z_2}{z_1} \tag{3}$$

where: z_1 is number of teeth of the driving sprocket;

z_2 is number of teeth of the driven sprocket;

n_1 is the rotational speed of the driving sprocket, [r/min];

n_2 is the rotational speed of the driven sprocket, [r/min];

D is the diameter of the press wheel, [m];

δ is he slip rate of the press wheel, [%];

t is the hole spacing, [m];

z is the number of sockets of seeding wheel;

Generally, the number of small sprocket teeth is greater than or equal to 17*(Pu et al., 2019)*. Therefore, the number of teeth of the driving and driven sprockets is: z_1=17, z_2=34.

In order to prevent the chain from loosening and falling off, reduce the wear of the chain and sprocket, and prolong the service life of the chain and sprocket, it is necessary to install the tension wheel. The diameter of the tension wheel should be close to the diameter of the small sprocket *(Pu et al., 2019)*. The number of teeth of the tension wheel is 11. Chain tensioner adopts spring structure. The physical diagram of the single row small grain precision seeder is shown in figure 5.

Fig. 5 - Physical diagram of the single-row small grain precision seeder

Test instrument

Test instruments include: electronic balance, tape measure. SQP electronic balance parameters: Sartorius Scientific Instruments (Beijing) Co., Ltd., operating voltage:12~18V(DC)/0.4A, calibration index value of 10mg.The millet variety is 'Jingu-21', and the broomcorn millet variety is 'Jinshu-8'.

Static seeding test of the seeder

The static seeding test of the seeder is mainly to test the breaking rate and sowing quantity stability of the seed. The method is as follows: the ground wheel and opener of the seeder are fixed on the ground, the pressing wheel is suspended in the air, the pressing wheel is rotated at a constant speed, and the seeds collected in a container below the opener within 1 min are collected as a group. Test five groups, measure their weight with the electronic balance, record the test results and process them with SAS. And the experimental results were analyzed.

Effect of rotational speed on millet and broomcorn millet sowing quantity

The test is carried out according to the above method, and the test results are calculated by the following formula.

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \quad [g] \tag{4}$$

$$S_{\bar{q}} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\bar{q} - q_i\right)^2} \quad [g] \tag{5}$$

$$\alpha_i = \frac{S_{\bar{q}}}{\bar{q}} \quad [\%] \tag{6}$$

where: $\bar{q}$ is the average of five measurements, [g];

n is the total number of measurements;

$S_{\bar{q}}$ is the standard deviation of five measurements, [g];

α_i is the coefficient of variation of sowing quantity, [%];

The rotational speed of the seed metering device is 9 r/min, 10 r/min, 12 r/min, 14 r/min and 15 r/min, respectively. The measurement results are recorded in table 2.

The SAS software was used to analyze the balanced random design test of the samples, and the mean multiple comparisons were performed. The results are shown in table 3.

The test of seeds damage rate

Before the test, five samples of the same quality were randomly selected from the same batch of seeds that were not tested to determine the natural damage rate of the seeds. The test material selected for determining the seeds damage rate is the seeds discharged through the seed metering device.

Five samples of the same quality were randomly weighed, and the samples were placed on an electronic balance to measure their weight, record the data, and calculate the damage rate of the seeds.

Sowing test of the seeder

In order to observe the sowing situation and record the data of millet and broomcorn millet more accurately, this test was carried out on the sand trough. The test method is as follows: the metering device is fixed on the trolley, and the trolley is driven by the motor at a constant speed according to the designed speed. According to the rotation speed of the seed metering wheel, the field test was simulated at 9r/min, 10r/min, 12r/min, 14r/min and 15r/min respectively, and the sowing situation is observed and the hill spacing is recorded. Through comparative analysis, it is concluded that when the rotation speed of the seed metering wheel is 14 r/min, the hill spacing of millet is mostly 50 mm~70 mm, and the number of seeds per hill is mostly 2~4, and the sowing uniformity of millet is the best. The test results are shown in fig.6. When the rotation speed of the seed metering wheel is 12 r/min, the hill spacing of broomcorn millet is mostly 60 mm~90 mm, the number of seeds per hill is mostly 1~2, and the sowing uniformity of broomcorn millet is the best. The test results are shown in Fig.7.

Fig. 6 - The test of millet sowing

Fig. 7 - The test of broomcorn millet

Fig. 8 -The test of field sowing

According to the requirements of precision sowing, the best hill spacing of millet is generally 50 mm~100 mm, and the number of seeds per hill is 2~3. The best hill spacing of broomcorn millet is generally 45mm~60mm, and the number of seeds per hill is 1~2. Therefore, when the rotation speed of the seed metering wheel is 14r/min and 12r/min respectively, millet and broomcorn millet meet the requirements of precision seeding.

Field test of the seeder

According to the requirements of GB/T6973-2005 single grain (precision) seeder test method, the field test was designed and carried out. The field test included sowing uniformity test and sowing depth consistency test. The sowing length is 30 m, and the artificial sowing is carried out at a speed of about 0.5m/s. The ditching depth is set to 40 mm, as shown in Fig.8.

The soil on the seed was gently scraped with a scraper and a brush to make the seed completely leak out, and then the sowing depth was measured with a ruler. At the same time, the number of grains per hill and the distance between hills were measured. When the number of grains per hill of millet was 2-4, it was qualified, and the others were unqualified. When the number of grains per hill of broomcorn millet is 2-5, it is qualified, and the others are unqualified. The theoretical hill spacing value plus or minus 15 mm was qualified. A total of 101 grains per hill, 100 hill spacing, and 50 sowing depths were measured. Record and process the data, calculate the qualified rate of the number of grains per hill, the qualified rate of hill spacing and the average sowing depth.

RESULTS

The results obtained using the designed small grain precision seeder are presented below.

Table 2

Effect of the rotate speed on sowing quantity of millet and broomcorn millet

Small grain cereal species	Rotate speed(r/min)	Measurement times					Average value / g
		1	2	3	4	5	
Millet	9	3.66	3.63	3.59	3.61	3.64	3.626
	10	3.81	3.87	3.79	3.83	3.8	3.820
	12	4.21	4.17	4.25	4.23	4.18	4.208
	14	4.71	4.77	4.8	4.75	4.72	4.750
	15	5.08	5.12	5.14	5.09	5.11	5.108

Small grain cereal species	Rotate speed(r/min)	Measurement times					Average value / g
		1	2	3	4	5	
Broomcorn millet	9	1.91	1.97	1.96	1.89	1.94	1.934
	10	2.13	2.2	2.22	2.18	2.17	2.180
	12	2.66	2.67	2.75	2.69	2.70	2.694
	14	2.95	2.93	2.96	2.94	2.95	2.946
	15	3.19	3.21	3.22	3.2	3.21	3.206

From Table 2 and Table 3, it can be seen that the rotational speed has a very significant effect on the sowing quantity of millet and broomcorn millet ($P < 0.001$). The greater the rotational speed, the greater the sowing quantity. The sample is analyzed by a linear regression model. The regression model is as follows:

$$y_1 = 0.24254x + 1.39194 \tag{7}$$

$$y_2 = 0.20569x + 0.12369 \tag{8}$$

where: y_1 is millet sowing quantity, [g];

y_2 is broomcorn millet sowing quantity, [g];

x is rotation speed of seed metering device, [r/min]

The determination coefficients R^2 of the regression model are 0.9877 and 0.9862, respectively. It shows that the fitting accuracy of the model is high and can be used as the corresponding prediction.

Table 3

The multiple comparison of means about the rotate speed test

Small grain cereal species	Rotate speed(r/min)	Average value/g	Number of observations	Significance	
				0.05	0.01
Millet	9	3.626	5	e	E
	10	3.820	5	d	D
	12	4.208	5	c	C
	14	4.750	5	b	B
	15	5.108	5	a	A
Broomcorn millet	9	1.934	5	e	E
	10	2.180	5	d	D
	12	2.694	5	c	C
	14	2.946	5	b	B
	15	3.206	5	a	A

Table 4

The effect of rotational speed on the damage rate of millet and broomcorn millet

Damage rate	Rotate speed(r/min)				
	9	10	12	14	15
Damage rate of millet	6.83	7.05	7.44	7.78	7.92
Damage rate of broomcorn millet	6.51	6.68	7.02	7.39	7.53

The effect of rotational speed on the damage rate of millet and broomcorn millet is shown in table 4.

It can be seen from table 4 that with the increase of the rotation speed of the seed metering wheel, the damage rate of millet and broomcorn millet increases. At the same speed, the damage rate of broomcorn millet is smaller than that of millet. This is because under the same moisture content, broomcorn millet is harder than millet *(Sun et al., 2017;* Yang *et al., 2016)*, and the seed coat of broomcorn millet is harder than millet and smoother than millet.

Table 5

Field sowing test results

Grain	Marching speed ($m\cdot s^{-1}$)	Rotation speed of seed metering device ($r\cdot min^{-1}$)	Theoretical hole spacing / mm	Average hole spacing / mm	Average number of grains per hole	Qualified rate of hole spacing / %	Qualified rate of the number of grains per hole / %	Average sowing depth / mm
Millet	0.50	19	78	79	3.0	90	82	39.4
Broomcorn millet	0.44	17	91	90	2.4	91	83	41.1

It can be seen from table 5 that at the marching speed of about 0.5 m/s, the average hole spacing of millet and broomcorn millet was 79 mm and 90 mm respectively. The average number of grains per hole was 3.0 and 2.4, respectively. The qualified rate of hole spacing is greater than or equal to 90%. The qualified rate of hole number is greater than or equal to 82%, and the average sowing depth was 39.4 mm and 41.1 mm respectively. All indicators meet the technical requirements of JB/T 10293-2013 single grain (precision) planter.

CONCLUSIONS

By designing a single-row small grain precision seeder and conducting static seeding and seeding tests on the seeder, the following conclusions are obtained.

1. The core component of the single-row small grain precision seeder is the socket wheel-ring groove type precision metering device. It has the advantages of simple structure, low rate of damage and jam seed, convenient disassembly and assembly, adjustable sowing depth, adjustable sowing rate, adjustable hand-held parts, low cost, etc. Small seeds of different sizes can be sown by changing the seed metering wheel.

2. The results of static seeding test showed that the rotational speed had a significant effect on the sowing quantity of millet and broomcorn millet ($P < 0.001$). The higher the rotational speed, the greater the sowing quantity. With the increase of rotational speed of seed metering wheel, the damage rate of millet and broomcorn millet increased. At the same rotational speed, the damage rate of broomcorn millet is smaller than that of millet.

3. When the seeder is at a marching speed of about 0.5 m/s, the qualified rate of the hill spacing of millet and broomcorn millet is greater than or equal to 90%, and the qualified rate of the number of grains per hole is greater than or equal to 82%. All indicators meet the requirements of the technical conditions of single-grain (precision) seeder.

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