

Design and indoor simulated experiment of pneumatic rice seed metering device

Zhang Guozhong^{1,2,3}, Zang Ying², Luo Xiwen^{2*}, Wang Zaiman²,
Zhang Qiang^{1,3}, Zhang Shasha^{1,3}

(1. College of Engineering, Huazhong Agricultural University, Wuhan 430070, China; 2. Key Laboratory of Key Technology on Agricultural Machine and Equipment, Ministry of Education, South China Agricultural University, Guangzhou 510642, China; 3. Modern Agricultural Equipment Engineering Technology Research Center, Wuhan 430070, China)

Abstract: In order to meet the agronomy demand for hybrid rice direct seeding, a novel precise pneumatic rice seed metering device was designed with groups of sucking holes plate, by which 3-4 seeds could be synchronously sucked and synchronously dropped into the paddy field. The plate was divided into five sections: seed sucking, seed clearing, seed carrying, seed dropping, and blank sections. The seeds were sucked in sucking section by the vacuum, carried and rotated to the dropping section with the plate, blown away in dropping section by the positive pressure air, and thrown into the dropping tube. The influences of the hole diameter, vacuum degree, and clear-up equipment on precision of metering device were discussed. Experiments were conducted to investigate the seeding precision and simulate the field emergence rates on the indoor seeding test-bed. The subjects were pregnant Indic hybrid Peizataifeng under two kinds of moisture content (23.43% and 26.07%). Other experiment conditions included the vacuum degree of 2.60 kPa, the rotation speed of seed sucking plate of 30 r/min, three sucking holes with a diameter of 1.6 mm, and the seed layer thickness of 25 mm. The seeding results showed that, in condition of no more than two seeds per hill, the emergence probabilities under the two moisture contents were 11.82% and 11.95%, respectively, and in condition of 3-4 seeds per hill, the results were 64.81% and 65.84%, respectively. With 2-5 seeds per hill, the results were 92.08% and 92.60%, respectively. If the emergence probability was 80%, under the two moisture contents, the no seed per hill probabilities were 1.33% and 0.80% respectively; the probabilities with 3-4 seeds per hill were 56.13% and 56.40% respectively; the probabilities with 5 or more seeds per hill were 10.67% and 10.13% respectively; the probabilities with 2-5 seeds per hill were 87.60% and 88.13% respectively. The results showed the simulated experiment was an efficient and economic method to assess the capability of pneumatic rice seed drilling metering device, and the precise pneumatic rice seed drilling metering device had a good prospect in practical application.

Keywords: agricultural machinery, seeds, pneumatic seed metering device, precision hill-drop drilling, perpendicularity sucking plate, rice

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1 Introduction

Rice has been the most important grain crop in China

with increasing planted area in recent decades. Direct seeding and transplanting are two main planting modes. Direct seeding by planter is becoming popular in China,

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Biographies: **Zhang Guozhong**, PhD, Associate Professor, Research interests: Agricultural mechanization and automation Email: zhanggz@mail.hzau.edu.cn; **Zang Ying**, PhD, Associate Professor, Research interests: Agricultural mechanization and automation. Email: yingzang@scau.edu.cn; **Wang Zaiman**, Engineer, Research interests: Agricultural mechanization and automation. Email: wangzaiman@scau.edu.cn; **Zhang Qiang**, Graduate student, Research interests: Agricultural mechanization

and automation. Email: 1006082034@qq.com; **Zhang Shasha**, Graduate student, Research interests: Agricultural mechanization and automation. Email: 905674566@qq.com.

***Corresponding author:** **Luo Xiwen**, Professor, Research interests: Agricultural mechanization and automation. South China Agricultural University, Key Laboratory of Key Technology on Agricultural Machine and Equipment, Ministry of Education, Guangzhou 510642, China. Tel: +86-13902277193 Email: xwluo@scau.edu.cn.

India and other countries, with high efficiency and economy, as well as easy operation^[1,2]. Hybrid rice makes up over 50 percent of the growing area in China. According to agronomic requirements, one seedling per hill can simply achieve high productivity with hybrid rice by the high capacity of tilling ability. But in application of direct seeding, with the actual field environment being worse than experimental seeding environment, three seeds per hill can well meet the agronomic demand^[3].

The hybrid rice seed has a slenderness shape and its sphericity index is low. For its irregular shape and poor flow ability, the existing mechanical metering device and technology cannot meet the seeding agronomic requirements. The airflow has little damage on the seeds and well fits their various shapes for its flexible characteristics, thus the technology of airflow seeding has been widely applied in precision seeding. Using corn, peas, onions and cucumber seeds as the subjects, Karayel et al^[4] did experiments with the air suction precision seeding device and established the regression equation for the relationship between vacuum chamber pressure and the following factors include weight, area of sucking hole, sphericity index and the density of seed. Singh et al^[5] conducted experiments with the cotton seed air-suction device on its performance of absorbing single cotton seed. The results of his study showed that when the cone angle of the sucking hole was 120°, the suction effect was the best. Tang et al.^[6] studied the interaction influence on the seeding performance of the factors which include nozzle flow, the relative position between the nozzle and the shaped hole. Yuan et al.^[7] did experiments on the influence of the seeding sucking performance by such parameters as the vacuum degree, the diameter, and the speed. With the assistance of a vibration device, Wang et al.^[8] did research about the influence of seed layer thickness on the sucking performance of the double-hole rolling suction seeding device sucking (2±1) seeds of super hybrid rice. Yazgi et al.^[9] indicated that the vacuum of the suction plate, the diameter of the suction hole and the rotational speed had interacted effect and would influence the seeding variation coefficients. As the rotational speed of the suction plate decreased, the metering performance increased.

In brief, former studies showed that by adopting the

air suction method in metering device, the seed varieties, seed condition and metering structure parameters and motion parameters would all affect the suction process, so did the overall performance of the seed metering device.

At present, the research of rice precise seeding technology mainly focused on the single seed suction technology applied in indoor seedling cultivation, and could not accommodate rice seeding in field^[10,11]. Consequently designing a multi-seed suction seeding technology of the precise drilling seeding for field environment was much more urgent. In order to support the theoretical basis for the field hybrid rice technology research, a simulated field emergence experiment of pneumatic rice seed metering device was conducted on the suction precision.

The objectives of this study include:

(1) Introduction of a novel precise pneumatic metering device which was designed for synchronously sucking multiple seeds and could achieve hill-drop distribution of seeds in the field;

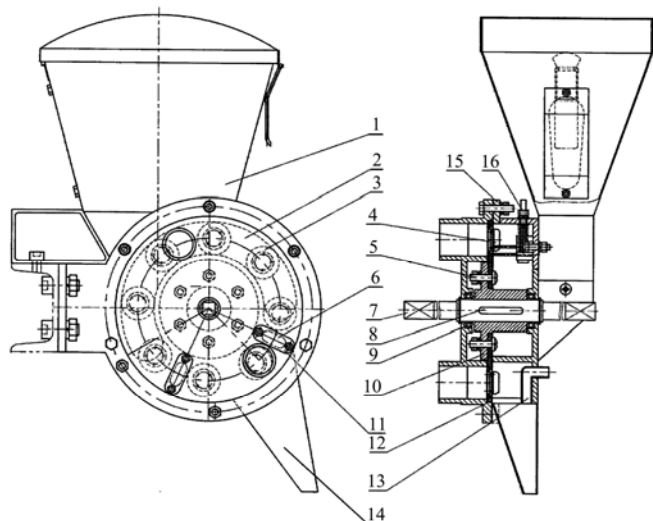
(2) Simulation of field rice direct seeding experiment was conducted on the seeding test-bed in the laboratory and the capability of the rice pneumatic seed metering device was evaluated with pregnant Indic hybrid Peizataifeng. It was hypothesized that germination rate of rice was ensured and knowable; therefore the actual field emergence could be estimated on the metering device in time.

2 Design of the pneumatic metering device

2.1 Configuration and working principle

As shown in Figure 1, the precision pneumatic rice seed metering device mainly consisted of plate, churning tooth, screw, brush, shaft, bearing, sleeve, gas chamber shell, row seed tube, seed chamber shell, and cleaning device. It had a vertical disc pneumatic device with groups of holes uniformly distributed on the plate. In operation, the plate rotated through five sections, namely sucking section, clearing section, carrying section, dropping section, and blank section. Negative pressure air with certain vacuum existed in sucking section, clearing section, carrying section, and the seeds were sucked on surface of the plate by the vacuum air, then the seeds rotated along the plate to dropping section. Positive pressure air was injected to the dropping section.

Seeds fell from the plate with positive pressure air blown off, and then dropped into seed tube. The process realized that several seeds were sucked, transported and dropped synchronously, and met the requirement of precision rice hill-drop drilling. The configuration of the seeds suction plate was shown in Figure 2.



1. Seed box 2. Sucking plate 3. Sucking hole 4. Churning tooth 5. Screw 6. Brush 7. Shaft 8. Flat key 9. Bearing 10. Sleeve 11. Gas chamber shell 12. Gasket 13. Blow gas nozzle pipe 14. Seed tube 15. Seed chamber shell 16. Cleaning device

Figure 1 Configuration of the precision pneumatic rice seed metering device

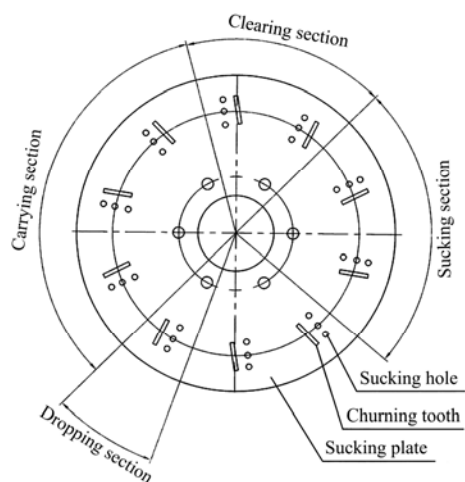
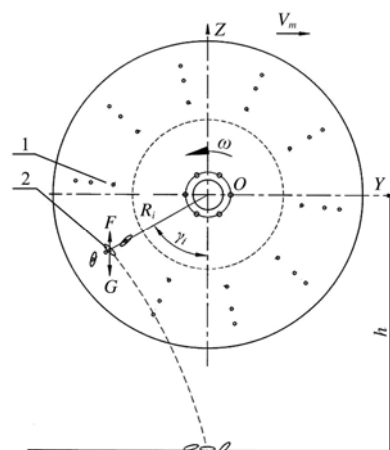


Figure 2 Configuration and principle of seeds suction plate

3 Parameters of the seed metering device

3.1 Distribution of the group suction holes

To achieve synchronously suction, migration, throwing and hill-drop distribution seeds, a vertical plate with group holes was designed and 3 holes with certain interval lined in radius orientation in every group. A model of throwing seeds with group holes was established in Figure 3.



1. Suction plate 2. Seed

Figure 3 Throwing seeds model of group suction holes

A Descartes reference frame was built in the Figure 3 and the upright, right and vertical the paper were Z, Y, X plus direction respectively, and the center of the plate O was the origin. When the seeds are sucked by the group holes on the plate, the location of them could be set as (R_i, γ_i) . Regardless of the collision between seeds and seed tube and air resistance, in dropping section, the seeds are blown off the plate and mainly affected by gravity. The height from the seed-sucking plate to the ground is h , the moving speed of seeding machine is v_m , the time when seeds separated from the suction plate is set as start time $T=0$, then the relative speed of the seeds to the ground could be calculated in the following way with the rotary movement of the suction plate^[12]:

$$\begin{cases} v_x = v_{x_0} \\ v_y = v_{y_0} + \omega R_i \cos \gamma_i + v_m \\ v_z = v_{z_0} + \omega R_i \sin \gamma_i \end{cases} \quad (1)$$

where, $v_{x_0}, v_{y_0}, v_{z_0}$ are the starting speeds of the seeds separated from the plate by positive pressure air blowing in three coordinate directions; v_x, v_y, v_z are three instantaneous velocities, m/s; γ_i is the throwing angle, rad; R_i is the radius, m; ω is the plate rotating velocity, rad. For seeds sucked on the pneumatic suction hole metering device, above factors are influenced by airflow resistance when seeds are expelled, which resulted seeds in position difference in process of falling, thus affected seeds field distribution.

Obviously, in distribution of the group of suction holes, position difference among same group should be as little as possible, and seeds should be discharged by the

same throwing angle. It was desirable to diminish distribution range of seeds, so ideal distribution form of the suckers was radial linear distribution along the plate.

In application of the group suction holes suction, if the interval between the holes was less than the length of seeds, it was likely that one seed was sucked by two suction holes at the same time. Some researchers suggested that following equation be used to determine the interval^[13]:

$$D=(1.2-1.3)L \quad (2)$$

where, D is the distance between the holes, mm; L is the length of the seeds, mm.

In effect, with clearing device and churning tooth, it was not likely that one seed would be sucked by two suction holes at the same time. The interval between two neighboring suction holes could be closer than that shown in above equation. Meanwhile, airflow interference would increase while the interval between holes decreased. In accordance with seed size, clearing device and churning tooth was installed between two holes, the mode with radial linear distribution sucking holes was adopted on the suction plate, and non-equidistant distribution was adopted in groups of 3 suction holes (interval being 11.5 mm and 6.5 mm) to decrease width of negative pressure air chamber. The suction holes were distributed in a circle (radius being 65 mm) with center of the suction plate being its rotary center. Simultaneity a kind of oriented churning device which consisted of two churning teeth was set on the plate, and its configuration and working principle was introduced in reference^[13].

3.2 Throwing angle γ_i

Throwing angle γ_i was the angle between the dropping radius direction and vertical direction. In order to minimize the dropping height of seeds, the document recommended the throwing position was generally set as the lowest position of the plate on precision single seed metering device^[12]. Since the plate adopted group holes in liner distribution, it could achieve throwing the seeds synchronously. To synchronously drop seeds in same hill, and achieve the optimal hill-drop distribution, thus the throwing angle γ_i was set as 45° .

3.3 Diameter of suction hole

In accordance with manufacturing convenience, the shape of sucking hole was round. Its size and shape had critical effect on performance of the suction seed metering device and had a close relationship with the size and shape of the seed. It could be confirmed by the following equation^[12, 14]:

$$d=(0.64-0.66)k \quad (3)$$

where, d is the diameter of the suction hole, mm; k is the thickness of the seed, mm. Being irregular spindle shape, rice seeds were easily sucked deeper when the diameter was too big, based on experiment in literature, the diameter of sucking hole was set as 1.6 mm^[14].

3.4 Shape of the hole section

The process of airflow flowed through the suction hole was similar to a small hole jet^[15]. The chamfered suction hole could reduce the turbulent loss of air around edge of the hole. To prevent the suction hole jam by seeds, the depth of the hole should be minimum. Therefore, the section shape of the suction hole was described in Figure 4. Where, d is the diameter of the suction hole; t is the thickness of the plate, l was the depth of the cylindrical hole, ϕ is the diameter of the taper hole on the back of the plate. On the basis of the suction plate strength requirements and existing data, thickness of the suction plate was fixed as 2 mm, the angle α was 90° , the ϕ was 3 mm.

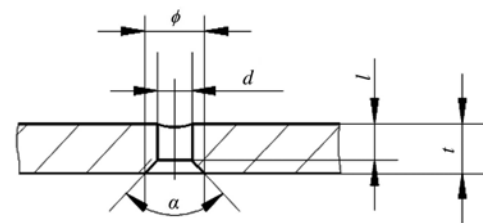


Figure 4 Configuration of the suction hole

3.5 Diameter of the plate

Increasing the diameter of the plate, its rotating speed would decrease and the size of the metering device would increase, thus the pneumatic metering diameter was usually 140-260 mm^[12]. Then the diameter of the pneumatic precise rice seed metering device was set as 165 mm.

3.6 Quantity of group suction holes.

In order to meet agronomic requirements, 3-4 seeds

were appropriate for per hill, three small holes were uniformly distributed on the seed-sucking disk, the quantity of group holes were made by the following equation:

$$n = \frac{2\pi v_m}{\omega S} \quad (4)$$

where, n is the quantity of group holes; v_m is the moving speed, m/s; ω is rotating angular velocity, rad; S is the interval in the adjacent hills, m.

According to the equation, increasing the quantity of group holes was good to rising moving speed, reducing the rotating speed and adjusting to the small hill spacing seed in the same diameter plate. However more groups and holes would increase the interaction and turbulence between the holes for irregular rice seeds hardly covered whole holes, and the air would leak which made the air pressure decreased and power waste, thus affected suction quality. According to agronomic demand, the interval of rice hill was 0.10-0.25 m in china, while moving speed of the seeding machine usually was 0.60-1.0 m/s, pneumatic precise rice seed metering device shaft speed was 20 - 40 r/min, so the quantity of the group holes was set as 10, the total holes number was 30.

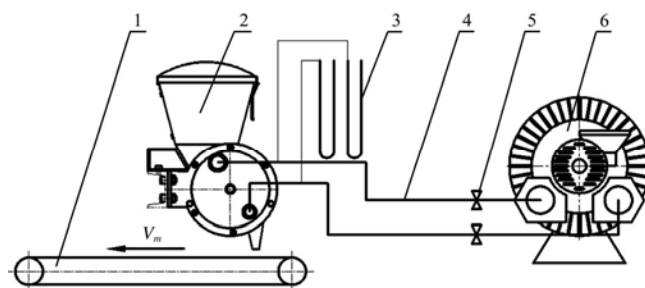
4 Materials and methods

4.1 Experimental materials

Material was the hybrid rice Peizataifeng that widely planted in south China, it was moistened to bud and then filtered out and dried, the overall dimension (length×width×thickness) of Peizataifeng was 9.03 mm×2.25 mm×1.92 mm, and its 1000-grain weight was 24.7 g. Two kinds of moisture content of 23.43% and 26.07% (wet basis) were adopted in the experiment, the sliding friction angle were 28.78°, 37.43°, respectively^[16].

4.2 Experimental equipment

The experimental equipment consisted of a pneumatic rice seed metering device with grouped holes, a U-shaped manometer, a positive and negative pressure air pipeline, a cut-off valve, a vortex pump, and a seeding test-bed. The positive and negative pressure airflow inlets of the feed mechanism were connected to corresponding airflow outlets of the vortex pump. The composition was shown in Figure 5.



1. Seeding test-bed 2. Pneumatic rice seed metering device 3. Manometer
4. Pipeline 5. Globe valve 6. Vortex pump

Figure 5 Composition of the experimental device composition

Clearing device was a plastic stick with diameter of 1.5 mm and length of 38 mm, located in the mesial position of the two adjacent holes which interval was 11.5 mm, and on circumference with diameter of 118 mm, also being 25° with plate vertical axis direction. 10 groups churning teeth were uniformly distributed near the suction hole edge and each group had two oriented churning teeth and the installation angle of inner-churning tooth was 75°, the installation angle of outer-churning tooth was 60°. The shape of the tooth was introduced in reference [13]. According to field seeding, the transportation belt of the seed test-bed was 1 m/s, plate rotary speed was 30 r/min, the suction vacuum was 2.60 kPa and the positive pressure of the air was 0.30 kPa.

4.3 Analytical methods

Seed emergence rate had a crucial influence on field cultivation and it directly affected quantity of seedling in field, eventually affected final yield. Seed emergence rate would be affected by such factors as rice varieties, seed germination rate, weather, plant diseases, insects, water depth in field and it was difficult to predict.

To evaluate seeding effect of the metering device, a simulating field rice direct seeding experiment was conducted on the seeding test-bed in laboratory and evaluated the pneumatic rice seed metering device capability while the subjects were pregnant Indic hybrid Peizataifeng. It was hypothesized that germination rate of rice was ensured and knowable, and therefore achieved actual field emergence which could estimate the effect of the metering device in real time. 20% of total seeds were taken and dried after being marked in red ink until surface color was stable, then mixed with other 80% of seeds to get 80% emergence rate rice (as shown in

Figure 6)^[17]. The mixed seeds were put into the pneumatic precise drilling seed metering device, kept thickness of seeds being 25 mm.



Figure 6 Mixed pregnant hybrid rice of Peizataifeng

The experiment was conducted on seeding test-bed at the Key Laboratory of Key Technology on Agricultural Machine and Equipment, South China Agricultural University, and the DPS software was used for data processing^[18].

4.4 Evaluation and calculation methods

4.4.1 Average seeds per hill

The quantity of total seeds per hill was considered as X_i , and the quantity of red seeds per hill was set as Y_i . Data were successively recorded with 250 hills as one set of data, and 3 sets of the data were obtained. Thus, the average quantity of seeds per hill (\bar{X}_z) could be calculated by the following formula^[19, 20]:

$$\bar{X}_z = \frac{1}{750} \sum_j^3 \left(\sum_i^{250} X_i \right), i=1-250, j=1,2,3 \quad (5)$$

4.4.2 Average not emergence seeds (seedling) per hill

Average not emergence seed (seedling) per hill was \bar{Y}_m , it could be calculated by the following formula:

$$\bar{Y}_m = \frac{1}{750} \sum_j^3 \left(\sum_i^{250} Y_i \right), i=1-250, j=1,2,3 \quad (6)$$

4.4.3 Average emergence seeds per hill (denoting as seedlings per hill)

Therefore, emergence seeds per hill (denoting as seedlings per hill) was $(X_i - Y_i)$, the average emergence \bar{X}_m could be calculated by the following formula:

$$\bar{X}_m = \frac{1}{750} \sum_j^3 \left[\sum_i^{250} (X_i - Y_i) \right], i=1-250, j=1,2,3 \quad (7)$$

4.4.4 Probability of seeds per hill

The probability of seeds per hill was considered as

$p(i)$. Frequency of 0, 1, 2, 3, or more seeds per hill from X_i was investigated as x_i . Thus, sucking probability for different seed quantity per hill could be calculated by using the following formula:

$$p(i) = \frac{\sum_{j=1}^3 x_{ij}}{750}, i=0,1,2,3,\dots; j=1,2,3 \quad (8)$$

4.4.5 Probability of seedlings per hill

It was obvious that $(X_i - Y_i)$ seeds also denoted the seedlings in a hill, thus frequency of 0, 1, 2, 3, or more seedlings per hill from $(X_i - Y_i)$ was investigated and probability of seedlings per hill could be calculated by the following formula:

$$p(i) = \frac{\sum_{j=1}^3 (X_i - Y_i)_j}{750}, i=0,1,2,3,\dots; j=1,2,3 \quad (9)$$

4.4.6 Average simulation field emergence probability

Simulated average emergence probability referred to the probability of seeds growing into seedlings after being laid in field, which could be calculated by the following formula:

$$\bar{M} = \frac{\bar{X}_m - \bar{Y}_m}{\bar{X}_m} \quad (10)$$

5 Results and analysis

The results of seeding capability and emergence of pneumatic rice seed metering device on pregnant Peizataifeng were shown in Table 1.

The results of seeding indicated that under the two kinds of moisture content of 23.43% and 26.07%, ≤ 2 seeds per hill probabilities were 11.82% and 11.95% respectively; 3-4 seeds per hill probabilities were 64.81% and 65.84% respectively; 2-5 seeds per hill probabilities were 92.08% and 92.60% respectively. The leak seeding probability was 0.

Based on the simulated emergence rate of 80%, the emergence results indicated that under the two kinds of moisture content of 23.43% and 26.07%: average seedlings per hill were 3.00 and 2.96 respectively; 0 seedlings per hill probabilities were 1.33% and 0.80% respectively, 1 seedling per hill probabilities were 9.07% and 9.47% respectively, 2 seedlings per hill probabilities were 22.40% and 25.60% respectively; 3-4 seedlings per

hill probabilities were 56.13% and 54.40% respectively, 2-5 seedlings per hill probabilities were 87.60% and

88.13% respectively, average emergence seedling probabilities were 79.80% and 79.10%, respectively.

Table 1 Results of simulated field emergence experiment

Evaluation index	Probability/%		Evaluation index	Probability/%	
	Moisture content 23.43%	Moisture content 26.03%		Moisture content 23.43%	Moisture content 26.03%
0 seed per hill	0	0	0 seedling per hill	1.33	0.80
1 seed per hill	1.17	1.04	1 seedling per hill	9.47	9.07
2 seeds per hill	10.65	10.91	2 seedlings per hill	22.40	25.60
3 seeds per hill	31.43	30.78	3 seedlings per hill	34.00	34.67
4 seeds per hill	33.38	35.07	4 seedlings per hill	22.13	19.73
5 seeds per hill	16.62	15.84	5 seedlings per hill	9.07	8.13
6 seeds per hill	4.94	4.42	6 seedlings per hill	1.20	1.73
7 seeds per hill	1.69	1.82	7 seedlings per hill	0.40	0.27
8 seeds per hill	0.13	0.13	8 seedlings per hill	0	0
≤ 2 seeds per hill	11.82	11.95	≤ 2 seedlings per hill	33.20	35.47
3-4 seeds per hill	64.81	65.84	3-4 seedlings per hill	56.13	54.40
≥ 5 seeds per hill	23.38	22.21	≥ 5 seedlings per hill	10.67	10.13
2-5 seeds per hill	92.08	92.60	2-5 seedlings per hill	87.60	88.13
Average seeds per hill (\bar{X}_z)	3.76	3.74	Average seedlings per hill (\bar{X}_m)	3.00	2.96
Average non-emergence seeds per hill (\bar{Y}_m)	0.76	0.78	Average emergence seedlings per hill probabilities (\bar{M})/%	79.80	79.10



Figure 7 Seeds on the seed-bed belt in simulated field emergence experiment

In former documents the moisture content of seeds were an evidently effect factor on the capability of metering device^[3-6]. The verdict was validated from the above results, thus severe assignable moisture content were necessary qualification for the rice metering device application^[7-11].

The irregular rice seeds have a poor liquidity which influences the performance of the seed metering device. The existing studies showed that optimizing the structure of seed box was a valuable way to improve the liquidity. Luo et al.^[3] designed a rice seed metering device with two filling rooms, Ma et al.^[21] added a seed filling wheel which could push the seed into the filling box, Deng et al.^[22] introduced a crossed diversion seed box, and Xing et al.^[23] adopted a filling seed stratified room. Yang et al.^[24] designed a kind of combing teeth which were installed on the comb shaft, and they could affect the seeds feeding process in the seed metering box. Based

on these novel structures the seeds in the filling box were separated and smoothly filled into the metering device which improved its performance. It showed the accumulation of seed in filling room was an important factor too. Then continued to improve the structure of seed box would be an important and effective way for improving the rice seed metering device performance.

At the same time, the turbulence and vibration of pneumatic metering device had significant impact on the liquidity of seeds. Former literature showed there was an interaction on the thickness of seeds layer at sucking section which influenced the capability of seed metering device, thus it needed further test and research on the pneumatic metering device performance with them.

In the experiment the well cleaning pregnant rice seeds had no more than 3 mm buds, consequently the seeds had a well mechanical strength and the buds hardly broke from the seeds. There were two groups cleaning brushes were mounted on the Gas chamber shell and on the Seed chamber shell respectively, and they were located the same site on both sides of the plate, while brushes were mounted on the downside of sucking section. Meanwhile, a positive airflow was injected into

the dropping section; the suction holes were rarely jammed in the experiment.

With the effect of the weather, injuring seedlings, low efficiency and high cost, it was difficult to accurately detect the emergence in the field. Simulation field emergence probability was a valid method for estimating the capability of metering device on corn and soybean in literature^[4]. In our research, the results indicated that it could be used on rice seed; meanwhile it was a kind of low cost, accurate and convenient method.

6 Conclusions

1) To meet direct seeding requirements, a kind of precise pneumatic rice seeds metering device was designed; the most important component of the metering device was a vertical plate with group suction holes. According to the agronomic requirements and synchronously sucking and synchronously dropping seeds into the paddy field, there were three holes in every group and lined in radius orientation with certain interval.

2) The simulated field emergence experiments of the metering device were carried out on the seeding test-bed. Experiment conditions included: vacuum degree being 2.6 kPa, suction plate rotation speed being 30 r/min, suction diameter was 1.6 mm and seeding thickness was 25 mm, Peizatafeng buds with moisture content of 23.43% and 26.07%. The performance of the metering device was as follows: ≤ 2 seeds per hill probabilities were 11.82% and 11.95% respectively; 3-4 seeds per hill probabilities were 64.81% and 65.84% respectively; 2-5 seeds per hill probabilities were 92.08% and 92.60% respectively. The emergence results showed that average seedling per hill of these two buds were 3.00 and 2.96 respectively; zero seedling per hill probabilities were 1.33% and 0.80% respectively; 2 seeds per hill probabilities were 22.40% and 25.60% respectively, 3-4 seeds per hill probabilities were 56.13% and 54.40% respectively, 2-5 seeds per hill probabilities reached 87.60% and 88.13%, respectively. Research showed the metering device had a well hill-drop distribution characteristic. With the simulated field emergence probabilities; it had a good prospect in application.

There were other influences including vibration of machine and slippage of wheel, varieties of seeds, therefore, subsequent researches on the metering device were significant.

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