DESIGN AND TESTING OF DUAL-STATION HIGH EFFICIENCY WHOLE TRAY AIR-SUCTION SEEDING ASSEMBLY LINE FOR RICE SEEDLING CULTIVATION

整盘气吸式水稻双工位高效育秧播种流水线设计与试验

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ABSTRACT

To address the high efficiency and precision seeding requirements for rice factory seedling cultivation, a whole tray air-suction dual-station high efficiency seedling cultivation and seeding assembly line was designed. Based on the whole-tray air-suction principle, the study focused on the design of a dual-suction seed tray dual-station precision hole-to-hole seeding device, a transverse seedling tray conveying device, and an automatic seed replenishment device. Nan Jing 46, Nan Jing 5055, and Koshihikari rice seeds were used for seeding performance experiments on the assembly line. The impact of workstation configuration and production efficiency on the empty hole rate, reseeding rate, damage rate, and seeding precision was analyzed. Experimental results showed that the dual-station precision seeding method significantly improved seeding efficiency. When the seeding efficiency reached 2000 trays per hour, the seeding rate of 1-3 seeds per hole was 90.1%, while the damage rate, empty hole rate and reseeding rate were 0.38%, 0.84%, 9.06% respectively. This study shows that combining the whole tray air-suction principle with transverse seedling tray conveying device, dual-station precision hole seeding device, and automatic seed addition device can significantly enhance the seeding efficiency while ensuring the seeding accuracy, achieving a seeding efficiency of over 2000 trays per hour. This study provides an important reference for further improving the seeding accuracy and efficiency of precision rice seedling cultivation and seeding assembly line.

摘要

针对水稻工厂化育秧的高效率精量播种需求，本文设计了一种整盘气吸式双工位高效育秧播种流水线。基于整盘气吸式原理，重点设计了双吸种盘双工位精量对穴播种装置、横向秧盘输送装置及自动加种装置。南粳 46、南粳 5055 及越光稻种子被用于流水线播种性能试验，分析了工位配置和生产效率对合格率、损伤率、空穴率和重播率的影响。试验结果表明，双工位精量对穴播种方式显著提高了播种效率。当播种效率达到 2000 盘/h 时，每穴 1-3 粒的合格率为 90.1%，损伤率、空穴率、重播率分别为 0.38%、0.84%、9.06%。该研究表明，将整盘气吸式原理与横向秧盘输送装置、双工位精量对穴播种装置及自动加种装置相结合，能够在保证播种效果的同时显著提升播种效率，达到超过 2000 盘/小时的播种效率。这一研究为进一步提高水稻精量育秧播种流水线的播种精度和效率提供了重要参考。

INTRODUCTION

As one of the world's major food crops, improving rice production efficiency and yield was of great strategic significance for ensuring food security, coping with population growth and other key issues *(Zang et al., 2024)*. Factory-based rice seedling cultivation was a modern agricultural technology that transferred the seedling cultivation process to a controlled factory environment, achieving a high degree of standardization and automation of sowing, growth, and management, thereby effectively improving the survival rate and quality of rice seedlings *(Hou et al., 2020; Zhang et al., 2023; Karayel D., 2022)*. As an important equipment for factory-based rice seedling cultivation, the seeding assembly line for rice seedling cultivation could complete tray feeding, subsoil laying, hole pressing, seeding, watering, topsoil covering, tray stacking all at once (*Singh R.C., 2005*), which could significantly improve the production efficiency and quality of rice seedling cultivation *(Sun et al., 2021; Ding et al., 2021)*.

Currently, scholars and enterprises accomplished a series of research progress in the field of factory-based seeding assembly line for rice seedling cultivation *(Yang et al., 2021)*. The mechanical groove wheel seeding method was applied in Japan's Kubota 2BZP-800 rice seedling cultivation and seeding assembly line *(Cao et al., 2021)*. It is suitable for flat seedling trays and could reach a seeding efficiency of 800 trays per hour. The mechanical drum seeding method was applied in the 2BD-300 and 2BD-600 rice seedling cultivation and seeding assembly line produced by Changzhou Yamike Company *(Yuan et al., 2020)*. It was suitable for bowl seedling trays, and the highest seeding efficiency could reach 600 trays per hour. The radial outer groove wheel seeding method was applied in Zoomlion's 2BP-780C rice seedling cultivation and seeding assembly line *(Ma et al., 2018; Zhang et al., 2015)*. It was suitable for bowl seedling trays and the seeding efficiency could reach 780 trays per hour *(Hou et al., 2015)*. The precision seeding assembly line and automatic stacking device was designed by Ma Xu et al. for rice seedling cultivation, while the seeding efficiency could reach 800 trays per hour *(Ma et al., 2019)*. The air-suction drum rice seed metering device designed by Han Bao et al. had realized the functions of automatic seed filling in the sockets and pneumatic assisted seed suction, which greatly improved the uniformity of seeding and seed integrity *(Han et al., 2009)*.

However, traditional mechanical seeding equipment had problems such as low efficiency, easy seed damage, poor adaptability, and difficulty in accurately controlling the seeding amount and position, which affected the consistency of the seeding effect *(Li et al., 2021; Xing et al., 2020; Li et al., 2009)*. Seed metering device based on the principles of air suction rollers and air suction needles have rarely been applied in rice seedling cultivation and seeding. These methods exhibit low working efficiency and struggle to meet the requirements for large-scale promotion and application *(Li et al., 2008)*.

In view of the above problems, a rice seeding assembly line for rice seedling cultivation based on the whole-tray air suction principle was proposed, and its key components such as the tray sending device, seed metering device and tray stacking device were optimized and improved. Under the premise of ensuring seeding accuracy, the production efficiency of rice seedling cultivation and seeding had been greatly improved, providing a new technical path for the development of precise and high-efficiency rice factory-based seedling cultivation and seeding equipment.

MATERIALS AND METHODS

OVERALL STRUCTURE AND WORKING PRINCIPLE

The whole tray air-suction seeding assembly line for rice precision seedling cultivation was mainly composed of horizontal tray delivery device, bottom soil laying device, dual-station high-efficiency seeding device, sprinkler device, topsoil covering device, horizontal tray stacking device, automatic seed adding device, seed tray high pressure fan, electric control box and frame, as shown in Fig.1.

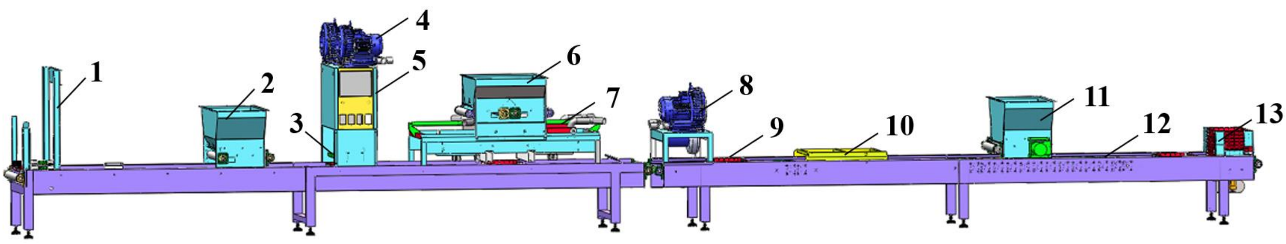


Fig.1 - Schematic diagram of the overall structure of the whole tray air-suction seeding assembly line for rice precision seedling cultivation

1. Horizontal tray delivery device 2. Bottom soil laying device 3. Hole pressing device 4. Left seed tray high pressure fan 5. Electric control box 6. Automatic seed adding device 7. Dual-station high-efficiency seeding device 8. Right seed tray high pressure fan 9. Seedling tray 10. Sprinkler device 11. Topsoil covering device 12. Frame 13. Horizontal tray stacking device

When the seed metering device was working, the power of the seeding assembly line was turned on to ensure that the air compressor and high-pressure fan were in normal working condition. Subsequently, the seedling trays were stacked on the horizontal tray delivery device. The start button on the electric control box was pressed, and then a group of seedling trays (including No. 1 seedling tray and No. 2 seedling tray) were continuously transported through the conveyor belt. When the seedling tray moved to the bottom soil laying device, the conveyor belt driven by the motor spread the nutrient soil evenly on the bottom of the seedling tray. Next, the seedling tray reached the hole pressing device, where it underwent a hole pressing process to form seed holes. Afterwards, when the seedling tray entered the dual-station high-efficiency seeding position, the cross-intermittent seeding method was used for whole-tray precision hole seeding.

Specifically, when the No. 1 seedling tray reached the seeding position, the left suction tray would discharge the seeds, and the right suction tray would suck the seeds. The No. 1 seedling tray moved forward after seeding, while the No. 2 seedling tray reached the seeding position. The right seed suction tray discharged seeds, and the left seed suction tray sucked seeds, thus completing the seeding of a group seedling trays. After the seeding operation, the seedling trays were watered, covered with topsoil and stacked in sequence, and finally the seedling trays that had been sown were removed. The above operation process was repeated to realize the continuous tray delivery - bottom soil laying - hole pressing - seeding - water sprinkling - topsoil covering - trays stacking operation of the seeding assembly line for rice seedling cultivation. The main design parameters of the seeding assembly line for rice seedling cultivation designed in this paper are shown in Table 1.

Table 1

Main design parameters of seeding assembly line

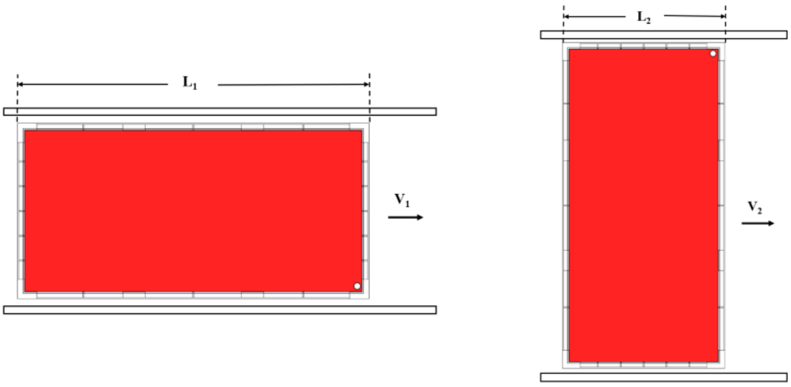
Parameters	Unit	Values
working principle	/	whole tray air-suction
efficiency	tray/h	2000
qualification rate	%	≥85
empty hole rate	%	≤2
reseeding rate	%	≤15
damage rate	%	≤2
delivery method	/	horizontal tray delivery

KEY COMPONENTS DESIGN

Design of horizontal tray delivery and stacking device

（1） Design of horizontal tray delivery device

To ensure the seeding effect of the seed metering device, there was usually a limit to the speed of the seeding tray and the seeding assembly line. The highest efficiency of the traditional seedling cultivation and seeding assembly line could only reach 1000 trays/h. This paper proposed a horizontal tray delivery method, which adjusted the traditional vertical tray delivery method to a horizontal tray delivery method. The seedling tray delivery method is shown in Fig. 2.



a) *b)*

Fig. 2 - Seedling tray delivery method

(a) horizontal delivery; (b) vertical delivery

The time t required for a single seedling tray to move was

$$t = \frac{L}{v} \tag{1}$$

Among them, L was the moving distance of the seedling tray, and v was the moving speed of the seedling tray.

The standard seedling tray size of 300mm*600mm was used in this experiment, that is, $L_1 = 2L_2$, $v_1 = v_2$.

Therefore:

$$t_1 = 2t_2 \tag{2}$$

When the horizontal tray delivery method was applied in the seeding assembly line for rice seedling cultivation, the seeding assembly line efficiency was doubled when the moving speed of the seedling tray remained unchanged.

The horizontal tray delivery device was composed of frame, upper cylinder, lower cylinder and chuck, as shown in Fig. 3. During operation, the upper cylinders on both sides extended out and the chuck was inserted between the two lowest seedling trays. The lower cylinders on both sides retracted, so that the lowest seedling tray automatically fell onto the conveyor belt of the assembly line, completing the automatic tray delivery. Then the lower cylinders on both sides extended out, the upper cylinders on both sides retracted, and the seedling tray fell on the chuck connecting the lower cylinders on both sides. Then the upper cylinders on both sides extended out, and the lower cylinders on both sides retracted to complete the next tray delivery operation.

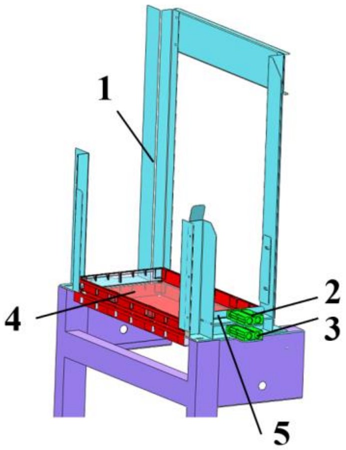


Fig. 3 - Horizontal tray delivery device

1. Frame; 2. Upper cylinder; 3. Lower cylinder; 4. Seedling tray; 5. Chuck

(2) Design of horizontal tray stacking device

The horizontal stacking device was composed of cylinder, frame, tray, and stacking chuck, as shown in Fig. 4. During operation, when the seedling tray reached the stacking position, the two stacking cylinders extended synchronously to move the seedling tray upward, and the stacking chuck was retracted into the through groove driven by the seedling tray. When the seedling tray moved to the upper side of the stacking tray chuck, the stacking tray chuck returned to the initial open state under the action of the spring. Then, the two cylinders retracted at the same time, and the seedling tray moved downward under its own weight and fell on the stacking tray chuck. When the next seedling tray was transported to the tray position, repeated the above process to complete the automatic stacking operation of seedling trays. The horizontal stacking device adjusted the stacking interval time according to the efficiency of the assembly line operation, and completed the automatic stacking operation.

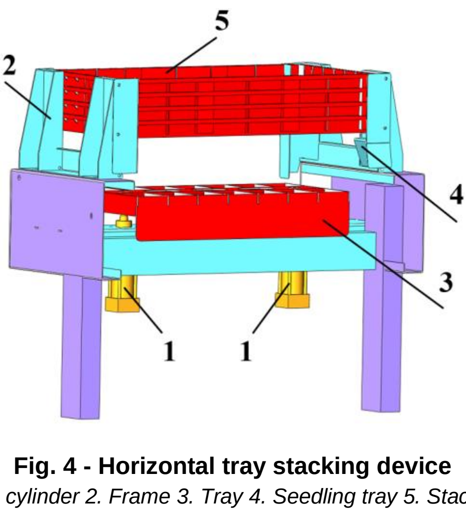


Fig. 4 - Horizontal tray stacking device

1. Stacking cylinder 2. Frame 3. Tray 4. Seedling tray 5. Stacking chuck

Design of dual-station high-efficiency seeding device and automatic seed adding device

Dual-station high-efficiency seeding device and automatic seed adding device are shown in Fig. 5. The dual-station high-efficiency seeding device realized interactive seeding with double suction seed trays, and the automatic seed adding device added seeds to the seed tray according to actual needs.

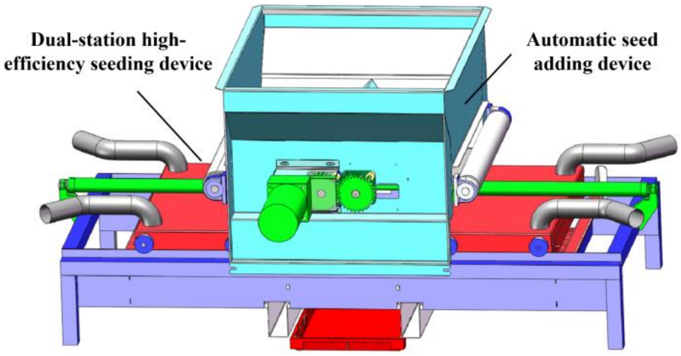


Fig. 5 - Dual-station high-efficiency seeding device and automatic seed adding device

(1) Design of dual-station high-efficiency seeding device

Dual-station high-efficiency seeding device is shown in Fig.6. The dual-station high-efficiency seeding device was mainly composed of seed suction station *1*, seed suction station *2* and seeding station.

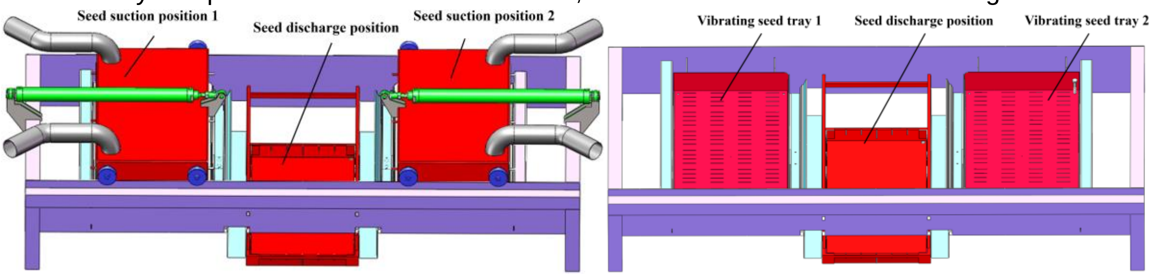


Fig. 6 - Structure diagram of the dual-station high-efficiency seeding device

In the horizontal single-station working mode, seeding work was completed by 1 seed suction tray, 1 seed suction position and 1 seed discharge position. While in the horizontal dual-station working mode, 2 seed suction trays cooperated with 2 seed suction positions and 1 seed discharge position to complete the interactive seeding work. The comparison of operation time under different working modes is shown in Fig.7.

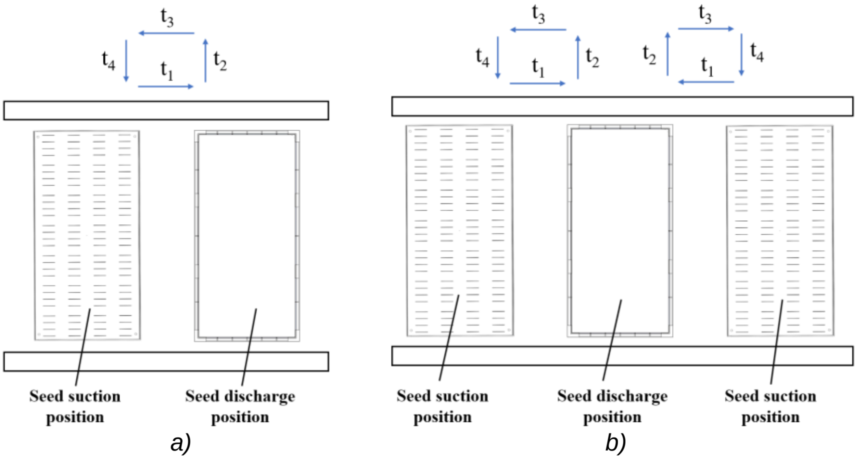


Fig. 7 - Comparison of operation time under different working modes

(a) Horizontal single-station; (b) Horizontal dual-station

In the horizontal single-station working mode, the time required to complete the seeding of one seedling tray is T_s.

$$T_s=t_1+t_2+t_3+t_4 \quad (3)$$

where t_1 is the time required for the seed suction position to move to the seed discharge position, t_2 and t_4 are the time required to complete seed discharge, t_3 is the time required for the seed discharge position to move to the seed suction position.

In the horizontal dual-station working mode, the time to complete the seeding of seedling tray No. 1 and seedling tray No. 2 when working independently was $2T_s$. When working interactively, the seeding position is shared, and only the seeding time t_2 does not overlap. When $t_1+t_3+t_4 \geq t_2$, the time required to complete the seeding for a set of seedling trays (two trays) is $T'_d = T_{d1}+T_{d2}=t_1+t_2+t_3+t_4=T_s$. Therefore, the time T_d required f to complete one seedling tray seeding could be shown as Eq.(4).

$$T_d = T'_d = \frac{1}{2}T_s \tag{4}$$

During operation, the dual-station high-efficiency seeding device worked sequentially in reset state 1→seeding state 1→reset state 2→seeding state 2. This process repeated itself to achieve interactive seeding of seed suction tray 1 and seed suction tray 2. The working principle diagram of dual-station high efficiency seeding is shown in Fig. 8.

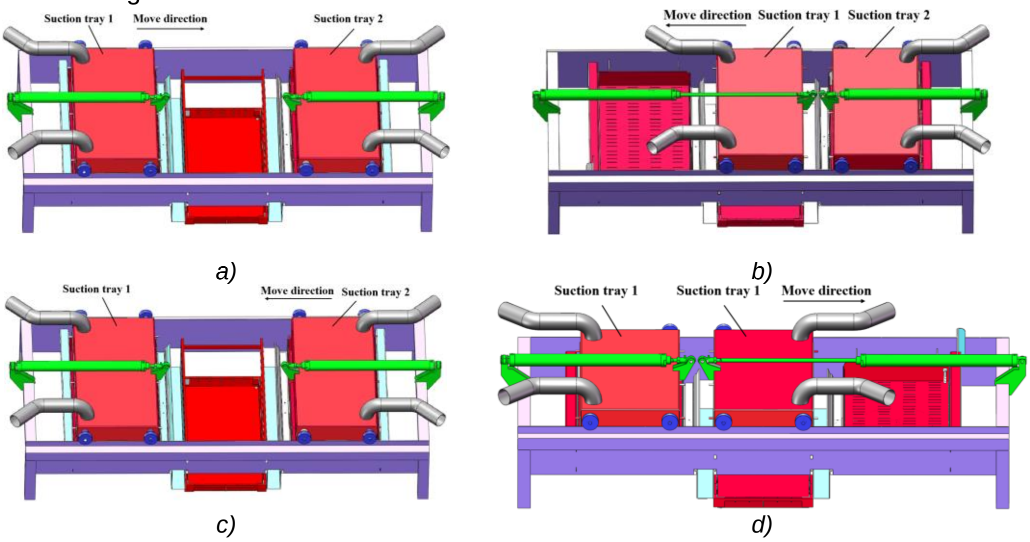


Fig. 8 - Working principle diagram of dual-station high efficiency seeding
(a) Reset state 1; (b) Seeding state 1; (c) Reset state 2; (d) Seeding state 2

The physical object of dual-station high efficiency seeding device is shown in Fig. 9.

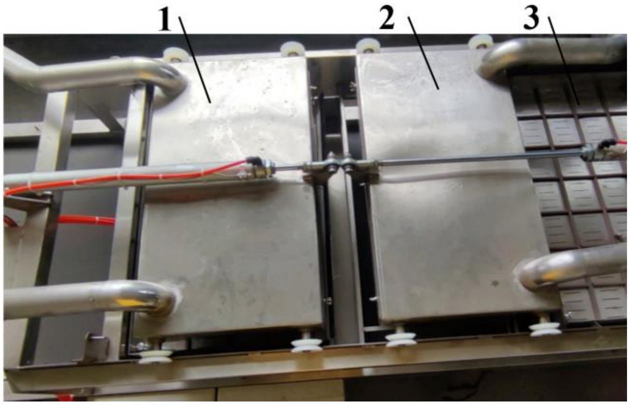


Fig. 9 - Physical object of dual-station high efficiency seeding device
1. Seed suction tray 1; 2. Seed suction tray 2; 3. Vibrating seed tray 1

(2) Design of automatic seed adding device

The automatic seed adding device was located directly above the seeding station of the seeding frame and was connected to the dual-station high efficiency seeding device, as shown in Fig.10.

When the assembly line was working, seeds were manually placed into the seed box in advance *(Liu et al., 2021)*. The seeds in the seed tray were continuously consumed during the operation *(Wang et al., 2021)*. When receiving the seed addition command, the stepper motor drove the conveyor belt to move and deliver the seeds in the seed adding box to the vibrating seed tray at a preset rate, achieving automatic seed replenishment.

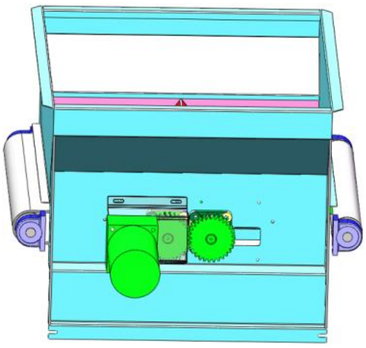


Fig. 10 - Automatic seed adding device

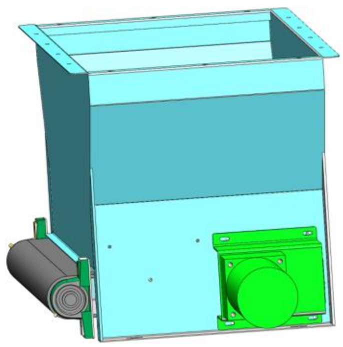


Fig. 11 - Soil laying device

Design of soil laying device

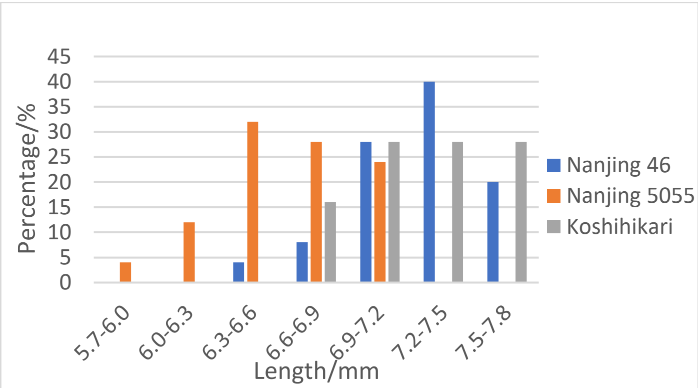
The soil laying device is shown in Fig.11. According to the difference in soil laying type for seedling tray, it could be divided into bottom soil laying device and topsoil covering device. When the seedling tray reached below the soil laying device, the stepper motor drove the conveyor belt on the soil spreading device through the reduction gear. The soil in the soil spreading device was added to the seedling tray along the conveyor belt to achieve uniform soil spreading. The soil thickness was determined by the opening of the outlet baffle and the speed of the stepper motor. According to the actual soil thickness requirements, the relevant parameters were adjusted to achieve uniform soil spreading on the seedling tray.

RESULTS

EXPERIMENT AND ANALYSIS OF SEEDING ASSEMBLY LINE

Experimental Materials

In order to verify the operating effect of this design, seeding performance tests and parameter optimization of the seeding assembly line for rice seedling cultivation were carried out. Three rice seeds varieties, namely Nanjing 46, Nanjing 5055, and Koshihikari, suitable for planting along the Yangtze River in Jiangsu Province, were used as experimental materials. 200 seeds of each variety were randomly selected, and the length, width and thickness of each seed were measured by a vernier caliper with an accuracy of 0.01 mm. The average of three times was taken to obtain the final size of the rice seeds. The rice seed size distribution is shown in Fig.12.



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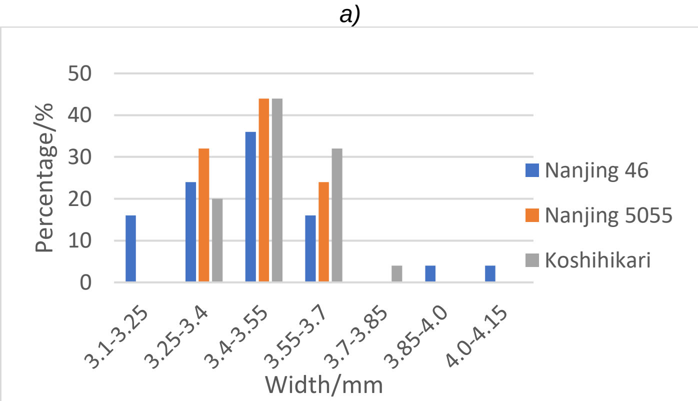

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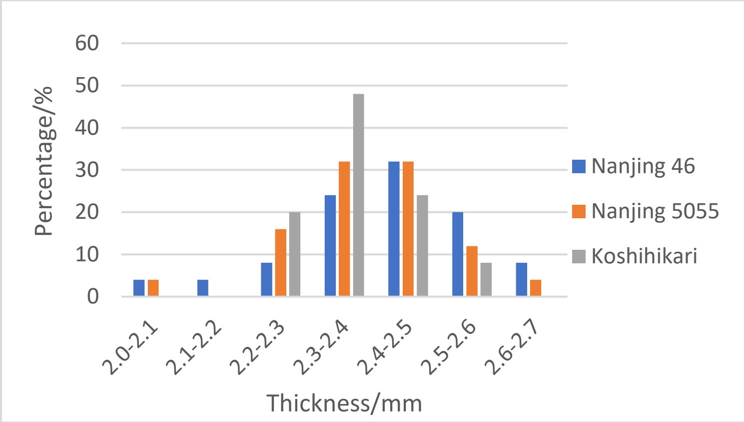


c)

Fig. 12 - Distribution of different rice seed sizes
(a) Length size distribution; (b) Width size distribution; (c) Thickness size distribution

Experimental Equipment

The experiment was carried out on the whole tray air-suction dual-station high efficiency seedling cultivation and seeding assembly line designed in this paper. 434-hole seed suction flat plate, 2-needle suction needle, and 434-hole standard seedling tray were used in this experiment. The physical product of the whole tray air-suction dual-station high efficiency seedling cultivation and seeding assembly line is shown in Fig.13.

Fig. 13 - The physical product of the whole tray air-suction dual-station high efficiency seedling cultivation and seeding assembly line
1. Horizontal tray delivery device 2. Frame 3. Bottom soil laying device 4. High pressure fan 5. Electric control box 6. Dual-station high-efficiency seeding device 7. Sprinkler device 8. Topsoil covering device 9. Horizontal tray stacking device

The main control interface and parameter setting interface are shown in Fig.14 and Fig.15 respectively. The main control interface could realize switching between five interfaces: automatic, manual, query, precision seeding, and setting.

Fig. 14 - Main control interface

Fig. 15 - Parameter setting interface

At the same time, the main control interface could display the cumulative and current completed number of seedling trays. When a failure or emergency occurred, real-time alarm could be realized. Production efficiency could be displayed in real time and adjusted through a visual interface. The setting of vibration times, seeding times, seed scraping times and seed adding times could be realized by the parameter setting interface. At the same time, the functions of tray delivery, bottom soil laying, hole pressing, seeding, topsoil covering, precision seeding, water spraying 1, water spraying 2, automatic subsoil feeding and topsoil feeding could be enabled and disabled.

Test performance evaluation indicators

The production efficiency, qualification rate, reseeding rate and empty hole rate were taken as the main performance evaluation indicators of this equipment. The specific definition and calculation method are as follows:

(1) Production efficiency

Production efficiency refers to the number of seedling trays that can be seeded per hour on a stable seeding assembly line for rice seedling cultivation. During the experiment, seeding assembly line for rice seedling cultivation is started, and the time is measured by a stopwatch with an accuracy of 0.01 s, to obtain the number of seedling trays E_1 within 1 minute *(Wang et al., 2023)*. Thus, the seeding efficiency of the assembly line is calculated from E_q.(5).

$$E=60\,E_1 \tag{5}$$

where the unit of E is trays/h.

(2) Qualification rate

The qualification rate specified in this article is the percentage of holes with 2 ± 1 seeds per hole to the total number of holes in the seedling tray *(Liu et al., 2021)*. Thus, the qualification rate P_1 is calculated from E_q.(6).

$$P_1 = \frac{N_1}{N_0} \times 100\% \tag{6}$$

where N_1 is the number of holes with 2±1 seeds/hole, and N_0 is the total number of holes in the seedling tray.

(3) Reseeding rate

The reseeding rate specified in this article is the percentage of holes with 4 or more seeds per hole to the total number of holes in the seedling tray *(Ni et al., 2022)*. Thus, the reseeding rate P_2 is calculated from E_q.(7)

$$P_2 = \frac{N_2}{N_0} \times 100\% \tag{7}$$

where N_2 is the number of holes with 4 or more seeds.

(4) Empty hole rate

The empty hole rate specified in this article is the percentage of holes with 0 seeds per hole to the total number of holes in the seedling tray *(Hu et al., 2021)*. Thus, the empty hole rate P_2 is calculated from E_q.(8).

$$P_3 = \frac{N_3}{N_0} \times 100\% \tag{8}$$

where N_3 is the number of holes with 0 seeds.

Experiment on the whole tray air-suction seeding assembly line for rice precision seedling cultivation

Considering the similar seed sizes shown in Fig. 12, Nanjing 5055 rice seeds were used to conduct the experiment. Before the experiment, awns, deflated grains, and rice awns were removed from the seeds. The seeds were then soaked one day in advance to allow the buds to emerge. Two hours before the experiment, the seeds were taken out and evenly dried in a cool and dry place to remove moisture from the surface of the seeds. In order to verify that double-station sowing could promote the improvement of work efficiency. The experiment was divided into two groups, namely the single-station seeding mode and the dual-station high-efficiency seeding mode.

(1) Single-station seeding mode

Only part of the equipment of the double-station high-efficiency seeding device was started, which consisted of suction seed tray 1, vibrating seed tray 1 and seeding position *(Liang et al., 2022)*. Before the experiment, preliminary experiments showed that the highest seeding efficiency could reach 1200 trays per hour *(Hu et al., 2021)*. Therefore, seeding experiments were carried out sequentially at production efficiencies of 500, 600, 700, 800, 900, 1000, 1100, and 1200 trays per hour.

During the experiment, the seeds were evenly distributed in the seed boxes, the production efficiency was set, and the assembly line was started. When the assembly line was working stably, the seedling tray was placed on the horizontal tray delivery device to complete the seeding experiment *(Ding et al., 2022)*.

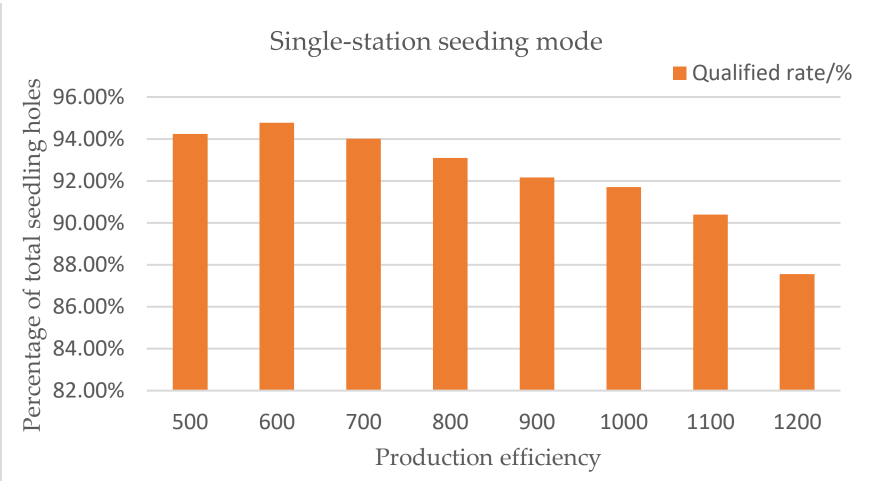
Then, three consecutive seedling trays were randomly selected to obtain seeding effect data. The experimental results of different production efficiencies under the single-station seeding mode are shown in Table 2.

Table 2

Experimental results of different production efficiencies under single-station seeding mode

No.	Production efficiency	Qualified rate (2±1) /%	Reseeding rate / %	Empty hole rate / %	Damage rate / %
1	500	94.24%	5.38%	0.38%	0.15%
2	600	94.78%	4.91%	0.31%	0.23%
3	700	94.01%	5.53%	0.46%	0.31%
4	800	93.09%	6.37%	0.54%	0.23%
5	900	92.16%	7.07%	0.77%	0.31%
6	1000	91.71%	7.45%	0.84%	0.38%
7	1100	90.40%	8.68%	0.92%	0.46%
8	1200	87.56%	9.06%	3.38%	0.54%

The changing trend of the operation effect in the single-station seeding mode is shown in Fig.16.



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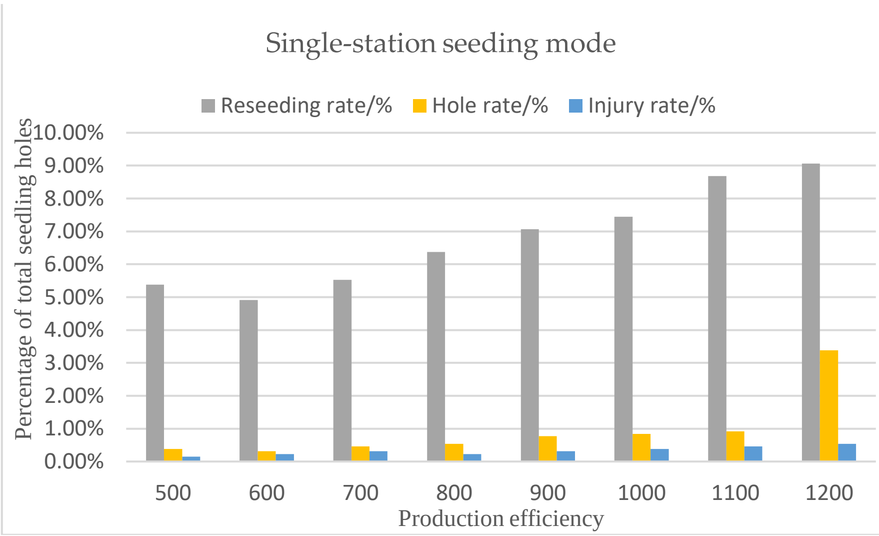


b)

Fig. 16 - The changing trend of the operation effect in the single-station seeding mode

a) Qualified rate; (b) Reseeding rate, empty hole rate, damage rate

(2) Dual-station high-efficiency seeding mode

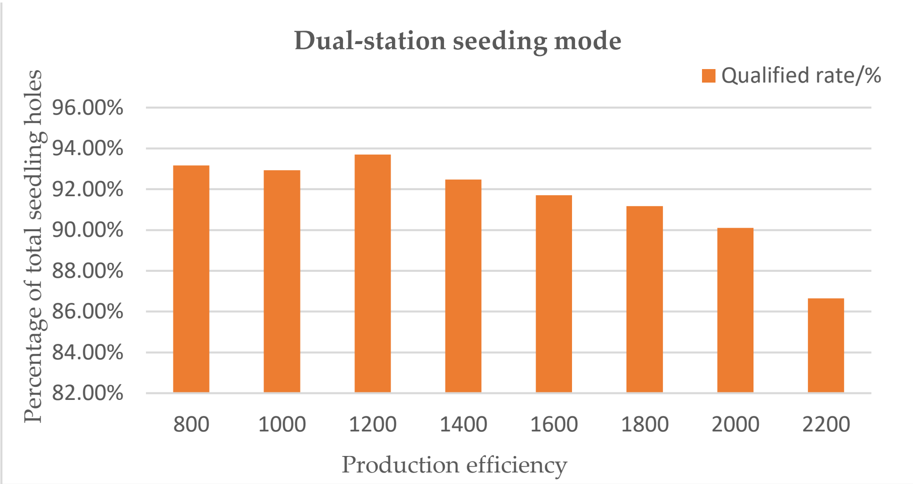
The seed suction tray 1, the vibrating seed tray 1, the seed suction tray 2 and the vibrating seed tray 2 of the dual-station high-efficiency seeding device worked together to realize interactive seeding and complete the entire seeding process *(Khizhnyak V.I., 2021; Ramesh B., 2015)*. Before the experiment, preliminary experiments showed that the highest seeding efficiency could reach 2200 trays per hour. Therefore, seeding experiments were carried out sequentially at production efficiencies of 800, 1000, 1200, 1400, 1600, 600, 1800, 2000 and 2200 trays per hour *(Sial F.S., 1984)*. The experiment was carried out again according to the above method and relevant results were obtained. The experimental results of different production efficiencies under the dual-station seeding mode were shown in Table 3.

Table 3

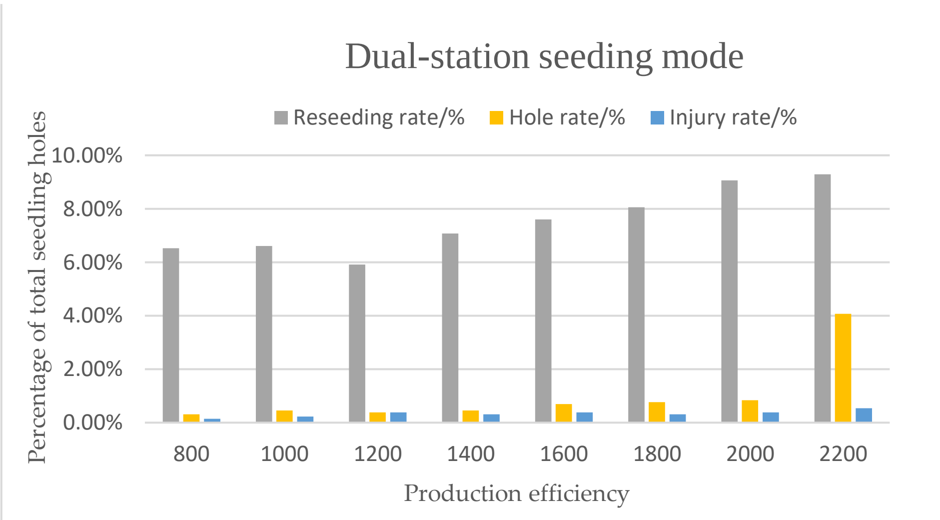
Experimental results of different production efficiencies under dual-station seeding mode

NO.	Production efficiency	Qualified rate（2±1）/%	Reseeding rate /%	Empty hole rate/%	Damage rate/%
1	800	93.16%	6.53%	0.31%	0.15%
2	1000	92.93%	6.61%	0.46%	0.23%
3	1200	93.70%	5.92%	0.38%	0.38%
4	1400	92.47%	7.07%	0.46%	0.31%
5	1600	91.71%	7.60%	0.69%	0.38%
6	1800	91.17%	8.06%	0.77%	0.31%
7	2000	90.10%	9.06%	0.84%	0.38%
8	2200	86.64%	9.29%	4.07%	0.54%

The changing trend of the operation effect in the dual-station seeding mode is shown in Fig.17.



a)



b）

Fig. 17 - The changing trend of the operation effect in the dual-station seeding mode

(a) Qualified rate; (b) Reseeding rate, empty hole rate, damage rate

In the single-station seeding mode and the dual-station seeding mode, the experimental results showed the changing trends of the qualified rate, reseeding rate, empty hole rate and damage rate with the operation efficiency as shown in Table 2, Table 3, Figure 16 and Figure 17. In both working modes, the overall pass rate gradually decreased with the improvement of production efficiency. When the efficiency exceeded 1100 trays per hour (single-station mode) or 2000 trays per hour (dual-station mode), the pass rate would drop significantly. The reseeding rate and empty hole rate showed a gradual upward trend with the improvement of production efficiency, but the changes were not significant. When the number of trays per hour exceeded 1,100 (single-station mode) or 2,000 (double-station mode), the void rate would increase significantly and failed to meet the requirements for rice seedling cultivation and seeding. The principle of air suction seeding ensured that the damage rate did not change significantly with the increase of production efficiency.

Therefore, the dual-station seeding mode could improve operational efficiency while ensuring seeding accuracy. When the seeding efficiency reached 2000 trays per hour, the seeding rate of 1-3 seeds per hole was 90.1%, while the damage rate, empty hole rate and re-seeding rate were 0.38%, 0.84%, 9.06% respectively. It could meet the accuracy requirements of precision rice seedling cultivation and seeding.

CONCLUSIONS

Aiming at the common problems of low qualified rate of precision seeding and limited operation efficiency of rice seeding production line, this paper innovatively proposed the collaborative operation mode of " horizontal tray delivery—dual-station seeding ". A whole tray air suction dual-station high-efficiency seeding device was designed, which adopted two sets of seed suction trays to work alternately with vibrating seed trays, combined with the optimization of the horizontal tray delivery mechanism, to compress the seeding tray movement time by 50%, and successfully achieved a breakthrough in seeding efficiency of 2000 trays/h. The experiment results showed that under the dynamic working condition of 800-2000 trays per hour, the qualified rate of 2±1 seeds/hole was more than 90.1%, and the hole rate and damage rate were kept within 0.84% and 0.38% respectively. Compared with the single-station mode, the dual-station interactive strategy improved efficiency by 81.8% while ensuring seeding accuracy. The integrated assembly line design realized the coordination of the processes of tray feeding, subsoil laying, hole pressing, seeding, watering, topsoil covering, tray stacking. It had been verified by Nanjing 46, Nanjing 5055 and Koshihikari rice seeds that it could meet the agronomic requirements of factory-based seedling cultivation and seeding of different rice varieties.

The research results have significantly improved the efficiency of mechanized rice planting. Through precision seeding, the amount of seeds used per acre will be reduced, and the rice yield per acre is expected to increase, providing technical support for ensuring food security. The proposed horizontal tray delivery mechanism and dual-station dynamic compensation strategy provide a transferable solution for the modular design of dryland seedling equipment for vegetables, flowers, etc. The interactive operation mode provides a new path to solve the problem of improving efficiency in the field of precision seeding, and has important reference significance for promoting the intelligent upgrading of precision agricultural equipment.

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