

DESIGN AND EXPERIMENT OF TRANSPLANTING MACHINE FOR CABBAGE SUBSTRATE BLOCK SEEDLINGS

甘蓝基质块苗移栽机设计与试验

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ABSTRACT

Aiming at the problems of high specificity and low efficiency of vegetable transplanting machine, a substrate block seedling transplanter was designed. Through theoretical calculation and force analysis, the structural parameters of two key components of automatic seedling separation device and planting device are determined. Taking cabbage seedlings with 40 × 40 × 40mm substrate block size as the experimental object, the effects of forward speed, planting frequency, front conveyor belt speed on lodging rate, missing rate and qualified rate were studied by single factor test and three factor three-level orthogonal test. Based on the analysis of the significance and interaction of the experimental data, the best combination of the forward speed of 1.1km/h, the planting frequency of 55 plants / min and the front conveyor belt speed of 0.5km/h was obtained. The verification test of the best combination showed that the average qualified rate of planting was 93.31%, which met the relevant industry standards.

摘要

针对现有蔬菜移栽机专用性强, 低收费工等问题, 设计了一种基质块苗移栽机。通过理论计算、受力分析确定了自动分苗装置和栽植装置两大关键部件的结构参数。以基质块尺寸为40×40×40mm的甘蓝苗为试验对象, 通过单因素试验和三因素三水平正交试验, 研究了前进速度、栽植频率、前输送带速度等因素对倒伏率、漏栽率和合格率的影响, 并进行了显著性和交互作用影响分析, 获得了前进速度为1.1km/h、栽植频率为55株/min、前输送带速度为0.5km/h的最佳参数组合, 对最佳组合进行了验证试验表明, 平均栽植合格率为93.31%, 满足相关行业标准。

INTRODUCTION

Cabbage is one of the most widely planted vegetable varieties in China. The annual planting area is maintained at 900,000 hm² and the annual output is 2.2 million tons. It has a prominent position in vegetable production and supply (Yang *et al.*, 2016). The planting of cabbage mostly adopts the technology of seedling raising and transplanting, which is hard to guarantee the quality of operation due to the high labor intensity and low operation efficiency of manual transplanting. The development of cabbage transplanting machine is of great significance for improving transplanting efficiency, reducing manual labor intensity and improving operation quality (Chen, 2017; Cui *et al.*, 2020; Prasanna, G., 2008). The existing vegetables transplanter has strong specificity and poor adaptability to substrate block seedlings. At present, there is still a lack of transplanter suitable for substrate block seedlings of cabbage in China.

European countries started to study the technology and equipment of substrate block seedling transplanting earlier (RYU K H *et al.*, 1998; Pramod, C. *et al.*, 2017; Yu *et al.*, 2014; Feng *et al.*, 2015; Jin *et al.*, 2015; Zhou *et al.*, 2015; He *et al.*, 2018; Cui *et al.*, 2019). For example, FPC developed by Italy's Ferrari and Tre Matic transplanting machine developed by Hortech have realized automatic transplanting of vegetable substrate block seedlings on film.

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Based on the principle of pneumatic control, French company CM&Regero developed the R2010 substrate block seedling transplanter, which realized the high speed and efficient transplanting of vegetables. A greenhouse fixed channel substrate block seedling transplanter was developed by Chrysant Arcadia, a Dutch company, which can realize the periodic and continuous automatic planting of chrysanthemum substrate block seedlings. The substrate block seedling transplanter developed by European and American countries is mainly developed for the domestic crop planting mode and agronomic requirements. The whole machine tends to be large and functional, and requires higher land conditions, so it is not suitable for the substrate block seedling transplanter of cabbage under the complex terrain environment in China. At present, the research focus of Chinese scholars on the vegetable transplanter is mainly on the hole dish seedling and blanket seedling. For example, Hu Jianping's team based on the pneumatic and PLC control principle developed a vegetable hole plate seedling self-propelled transplanter, which realized the function of multi-row seedling synchronous selection and seedling casting (Hu et al., 2016; Yang et al., 2018). Wu Chongyou's team developed an automatic transplanting machine for rapeseed blanket seedlings, which realized continuous supply and high-speed transplanting of rapeseed seedlings (Wu et al., 2016; Wu, et al., 2020). Mechanized transplanting has been realized in the above two seedling raising methods, but there are also problems of missing transplanting and lodging in the process of taking and throwing seedlings, and there are few reports on the substrate block seedling transplanting machine of cabbage.

In view of the problems of missing and lodging of the existing transplanter affecting the planting quality, a pneumatic substrate block seedling transplanter was developed with the cabbage substrate block seedling as the research object. The whole row of substrate block seedlings were separated by individual plants by the pneumatic stopper structure, and the single plant substrate block seedlings were transplanted into the soil by the directional clamping function of the planter. This transplanter solves the problem that the existing transplanter cannot adapt to the operation of substrate block seedling. Besides, it provides reference for the development of mechanized transplanting technology of Chinese cabbage.

MATERIALS AND METHODS

Design of the test prototype

Overall structure and Working principle

The transplanter is mainly composed of row-based seedling intermittent conveying devices, automatic seedling separating devices, planting devices, transmission systems, trenching and soil covering devices, and racks. Among these, the row-based seedling intermittent conveying devices, automatic seedling separating devices, and planting devices are longitudinally connected sequentially, and are arranged in a modular manner inside the rack. The seedling separating devices and the conveying device, respectively, connect the front conveying belt and the rear conveying belt in the substrate block seedling transportation, and the front conveyor belt extends from the side into the upper circumferential planter of the planting device. The planting device is equipped with a roller in front of the planting device, with a trenching and soil covering device directly below it. The air compressor and hydraulic pump are placed at the forefront of the frame and are connected to the tractor's power output shaft. Ground wheels are positioned at the four corners of the frame. One pass of the transplanter can realize ridge surface smoothing, ditching, transplanting, and soil suppression. The structure of the transplanter is shown in Fig. 1.

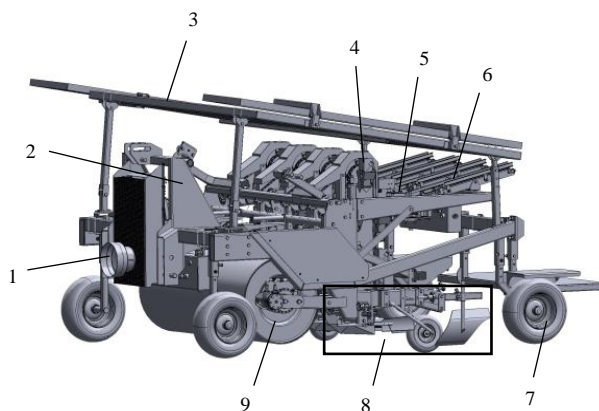


Fig. 1 – Overall structural of the transplanter

1- Power input shaft; 2- Rack; 3- Seedling tray support; 4- Planting device; 5- Automatic seedling separating device; 6- Intermittent conveying device; 7- Ground wheel; 8- Trench covering device; 9- Roller

The entire machine is pulled by a tractor, and the power of the tractor is simultaneously transmitted to the hydraulic pump and the air compressor via the output shaft. The hydraulic motor sequentially transmits power to the drum, row-based seedling intermittent conveying device, automatic seedling separating device, and planting device through a transmission chain to achieve ground leveling, and the operation of the seedling block conveyor belt and transplanting device. Moreover, the air compressor performs work, temporarily stores compressed gas in the gas storage tank, and is connected to the cylinders of the row-based seedling intermittent conveying device and the automatic seedling separating device through the reversing valve to realize the conveyance of substrate block seedlings and automatic seedlings. During operation, rows of substrate block seedlings are removed and fed to the intermittent conveyor. After being distributed by the automatic seedling separating device, there is always a substrate block seedling at the top of the front conveyor belt. Under the action of the parallel four-bar mechanism, the planter on the planting device remains perpendicular to the ground and rotates with the chain. When it crosses the front end of the front conveyor belt, it clamps onto the substrate block seedlings to be removed, and then the planter moves toward the ground. At this time, the planter is forced to open by the opener, and the substrate block seedlings fall into a rectangular trench dug by the opener. Then, the soil-covering device buries the substrate block seedlings to complete the planting.

The technical parameters of the whole machine are shown in Table 1.

Table 1

Technical parameters of the transplanter	
Parameters	Value
Overall dimensions (Length×Width×Height) [mm]	3100×3000×1600
Working rows	4
Row spacing [mm]	270~810
Plant spacing [mm]	200~2600
Substrate block size [mm]	40×40×40
Frequency [plants/min•row]	50~60

Automatic seedling separating device

The automatic seedling separating device distributes the row-based substrate block seedlings one by one at a given speed. The execution part of the device uses a pneumatic transmission for direct power, and it works with the multi-link mechanism to realize compound movement. As shown in Fig. 2, when planter Q_2 reaches point c , the arched rod is lifted to the I state, the reversing valve mechanical arm is constrained by the arched rod, the left circuit is connected, the cylinder B piston rod extends, and the stop pin swings out and releases seedlings. When planter Q_1 leaves point d , and planter Q_2 has not yet reached point c , the arched rod falls back to the II state and releases the restriction on the mechanical arm of the reversing valve, the right circuit is connected, the piston rod of cylinder B returns, and the stop pin swings in and does not release the seedlings. Planter Q_2 then fetches the seedlings. This action cycles in sequence.

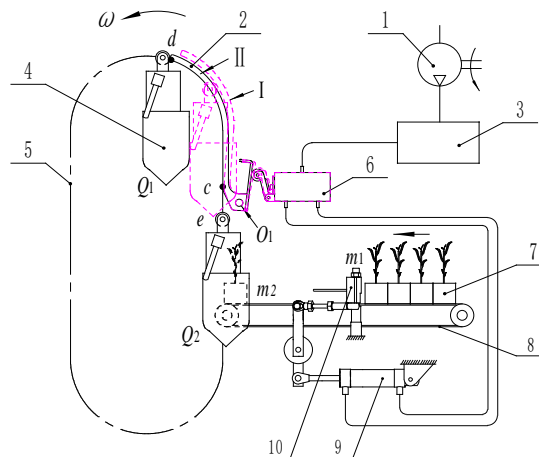


Fig. 2 – Automatic seedling separation process

1- Air compressor; 2- Bow lever; 3- Air storage tank; 4- Planter; 5- Chain; 6- Directional valve;
7- Substrate block seedling; 8- Front conveyor belt; 9- Cylinder B; 10- Stop pin

where:

Q_1 is the front planter; Q_2 is the rear planter; I is the arched rod raised state; II is the arched rod reset state; point c is the starting point of contact between the rear planter and the arch rod; point d is the front planter and arch rod breakaway point; O_1 is the center of rotation of the bow.

The planting rate of this machine is 1 plant/s (60 plants/min), and the time t required for point e of planter Q_2 to reach point c of the bow is 1 s. The following conditions should be met for automatic seedling distribution:

$$0.5 < t_1 \leq t_2 < 1 \tag{1}$$

$$L_{m1m2} = L_{cd} = 210 \tag{2}$$

where:

t_1 is the seedling release time [s], t_2 is the seedling blocking time [s], L_{m1m2} is the distance moved by the substrate block seedling [mm], and L_{cd} is the distance the planter slides through the bow bar [mm].

In order to prevent the sudden stoppage of the substrate block seedlings during transportation, which affects the seedling distribution and planting quality, it is necessary to analyze the force of the blocking pin when it contacts the substrate block to determine the position of the blocking pin. When the substrate block seedling is blocked by the stop pin, it is subject to the thrust of the stop pin, the inertial force of its own motion, the friction of the conveyor belt, its own gravity, and the conveyor belt support force. Under ideal conditions, the substrate block seedling does not stop suddenly. When dumping occurs, it is necessary to ensure that the thrust of the blocking pin against the substrate seedling and the inertial force of its own motion are equal in magnitude, opposite in direction, and act along a straight line, so that the optimal position of the stop pin is equivalent to the position of the center of gravity of the substrate block seedlings.

However, in actual operation, it is difficult to ensure that the size of the substrate block remains the same. Therefore, it is unlikely that the stop pin is aligned with the center of gravity of all the substrate block seedlings. As shown in Fig. 3 (a), when the stop pin is above the center of gravity of the substrate block, the substrate block is momentarily stopped owing to the inertial force. It will turn backward around point f . At this point in time, the thrust force F_t generated by the stop pin on the substrate block is below the horizontal line of the substrate block center of gravity, thereby generating a moment to prevent the substrate block from turning downward, balancing the turning moment, and prompting the substrate block to stop and balance. As shown in Fig. 3 (b), when the stop pin is below the substrate block center of gravity, the substrate block turns forward around point b at the moment it is stopped due to the inertial force. The stop pin exerts an upward thrust on the substrate block, and there is no support above the substrate block to keep it from flipping. Therefore, the substrate block may be overturned.

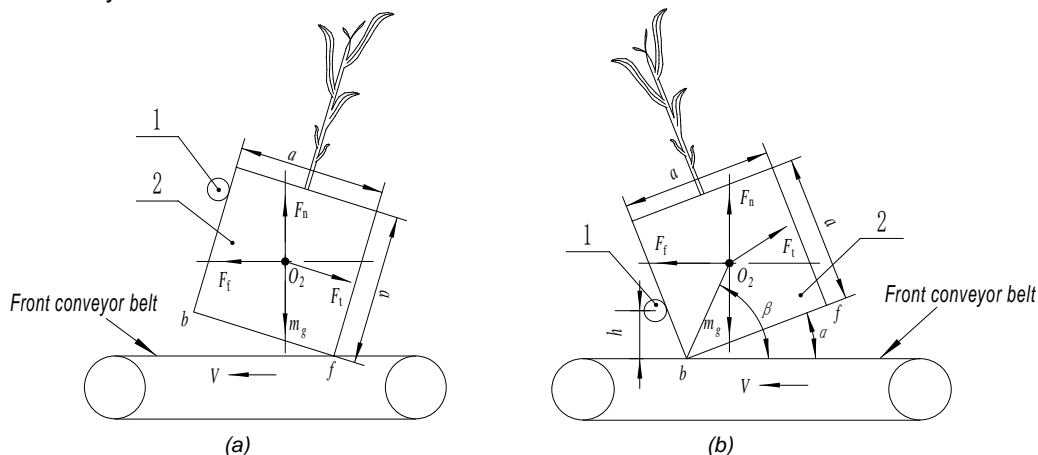


Fig. 3 – The force of the stop pin when it contacts the substrate block

1- Stop pin; 2- Substrate block

2-

where: (a) the stop pin is located above the substrate block center of gravity; (b) the stop pin is located below the substrate block center of gravity; F_n is the supporting force; F_t is the thrust of the stop pin; F_f is the frictional force; G is the gravity; O_2 is the center of gravity of the substrate block seedling; a is the edge length of the substrate block; and h is the vertical distance between the stop pin and the front conveyor belt.

The angle β between the line connecting point b and the center of gravity O_2 with respect to the ground when the substrate block flips is:

$$\beta = \arccos \frac{\sqrt{2}}{2} + \alpha \tag{3}$$

When the substrate block is overturned, the limit height of the stop pin from the front conveyor belt is h , as follows:

$$\frac{m_g \sqrt{2}}{2} a \cos \beta + F_t h \cos \alpha \geq \frac{F_f \sqrt{2}}{2} a \sin \beta + \frac{F_n \sqrt{2}}{2} a \cos \beta \quad (4)$$

$$h \geq \frac{\frac{\sqrt{2}}{2} a [F_f \sin \beta + (F_n - m_g) \cos \beta]}{F_t \cos \alpha} \quad (5)$$

According to the law of conservation of energy, the speed V of the front conveyor belt is as follows:

$$\Delta E_1 = -\Delta E_2 \quad (6)$$

$$\Delta E_1 = m_g \left[\frac{\sqrt{2} a}{2} \cos \beta - \frac{a}{2} \right] \quad (7)$$

$$\Delta E_2 = -\frac{mV^2}{2} \quad (8)$$

$$V = \sqrt{m_g [2a^2 \cos \beta - a]} \quad (9)$$

According to formulas (3)~(9), the probability of the substrate block overturning is directly related to the installation height h of the stop pin and the front conveyor belt speed V . The installation height restricts the speed of the belt; conversely, the speed of the belt determines the maximum installation height.

Planting device

As shown in Fig. 4, the planter is installed on the Z-shaped rod through a fixed sleeve, and the Z-shaped rod is connected to the active chain and the driven chain. The planter keeps the tip vertical to the ground under the action of the Z-shaped bar while it moves with the chain. When the planter rotates to position C, it crosses the front conveyor belt, and the inner plate clamps onto the substrate block to remove it. When the planter moves with the chain to transplanting position E, the planter lever is affected by the opener. The planter overcomes the pretension of the tension spring under the interaction between the convex plate and the concave plate, so that the inner plate and the outer plate open symmetrically around their respective rotation axes, and the substrate block seedlings fall into the planting trench under their own weight. When the planter moves to position D, the roller releases the constraint of the opener. The inner and outer plates of the planter close around the rotating shaft under the force of the tension spring, and a certain pretension is maintained to process the next round of seedlings.

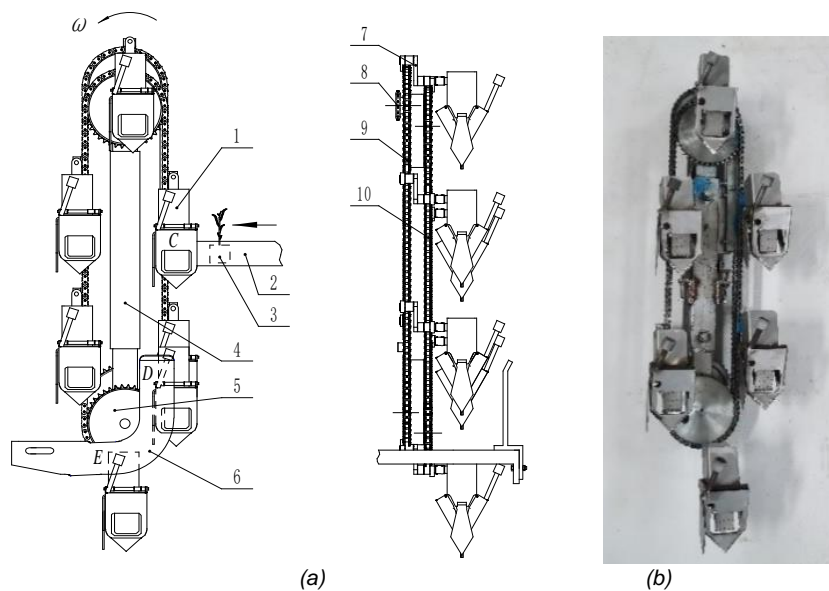


Fig. 4 – Planting device
(a) Structure diagram; (b) Real diagram

1- Transplanter; 2- Front conveyor belt; 3- Substrate-block seedling; 4- Support frame; 5- Sprocket; 6- Opener; 7- Z-shaped rod; 8- Transmission sprocket; 9- Active chain; 10- Follower chain

The structure of the planter is designed in pairs, as shown in Fig. 5. It is composed of an external beak, a pair of inner tongues, mutually meshing concave-convex plates, fixing frame, tension spring, dial rod, guide plate, etc. The outer beak is used for breaking the membrane into the soil, and the inner tongue is used for clamping the seedlings. The dial rod and the outer beak are fixedly connected. the planter can be opened and closed under the joint action of the concave and convex plate and the tension spring. In order to ensure that

the opening of the planter does not affect the free fall of the substrate block seedlings, the opening size of the substrate block should be ≥ 40 mm according to the design requirements. In the design of the inner tongue, it is necessary to increase the success rate of clamping and greatly reduce the clamping force applied on the substrate block to reduce the rate of breakage. The test on the failure resistance of 30 days old cabbage substrate block seedlings showed that the reliable clamping force of tongue in the planter should be between 89.95 and 119.29 N, which should be less than 89.95 N for safety (Guan et al., 2020).

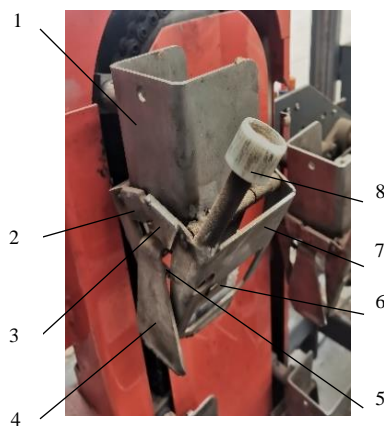


Fig. 5 – Structure of the planter

1- Fixing frame; 2- Convex plate; 3- Concave plate; 4- Guide plate; 5- Tension spring; 6- Inner tongue; 7- Outer beak; 8- Lever

Test conditions

As shown in Fig. 6, field performance tests were conducted at the Changshu Hengtang Vegetable Professional Cooperative in December 2019. Before the test, a double-type ridger was used to rotate and ridge the test field to ensure that the soil on the ridge surface was fine and smooth, and the soil moisture content was 15%–25%. The soil type was loam. The test object was a 40 × 40 × 40 mm cubic cabbage seedling substrate block with seedlings aged 30 days. The average seedling height was 82.74 mm, and there was no adhesion or rooting between the substrate blocks. During transplanting, the moment generated by the seedling tilt on the substrate block did not affect the planting state.

The matching power was John Deere 1204 wheeled tractor. The test instruments mainly included the DM6235P tachometer produced by Shenzhen Shengli High Electronic Technology Co., Ltd, ECA-SW1 soil moisture rapid tester produced by Beijing Yikangnong Technology Development Co., Ltd, and 05 series fiber tape measure produced by Ningbo Baofeng Tools Co., Ltd.



Fig. 6 – Field test

Test factors and indexes

According to the preliminary research on the cabbage substrate seedling transplanter, the main factors affecting the planting quality were the forward speed of the transplanter, the planting frequency and the speed of the conveyor belt. Therefore, the forward speed, planting frequency and conveyor speed of the vegetable substrate block seedling transplanter were used as the test factors, and the lodging rate and the missing rate were used as the test indicators to conduct single factor test and three-factor three-level orthogonal test.

In the test, the speed of the transplanter was changed by changing the tractor gear position, and the frequency of the transplanter and the speed of the front conveyor belt were adjusted by simultaneous interpreting the number of sprocket teeth with different transmission ratios. After the transplanting operation under each group of parameters was completed, three transplanting areas were randomly selected. One line

was taken from each transplanting area, and 120 planting points were continuously measured. The number of lodged and missing seedlings was counted, and the lodging rate, missing planting rate, and planting qualified rate were calculated. Referring to the industry standard of Ministry of Agriculture (NY/T 3486-2019) and the dry land planting machinery industry standard (JB/T 1029-2013), the lodging rate T , missing planting rate E , and planting qualified rate Q are calculated by formulas (10)~(12).

$$T = \frac{N_{DF}}{N} \times 100\% \tag{10}$$

$$E = \frac{N_{LM}}{N} \times 100\% \tag{11}$$

$$Q = (1 - T - E) \times 100\% \tag{12}$$

where: T is the lodging rate, [%]; N_{DF} is the number of lodged plants; N is the number of plants measured in the test section; E is the missing planting rate, [%]; N_{LM} is the number of missed planting plants; Q is the planting qualified rate, [%].

RESULTS AND ANALYSIS

Test result of single factor

Fig. 7 shows that the forward speed and conveyor belt speed have little influence on the lodging rate fluctuation, which was basically stable between 3.5% and 5.5%. With the increase of advance speed, planting frequency and front conveyor belt speed, the rate of missing rate decreased first and then increased.

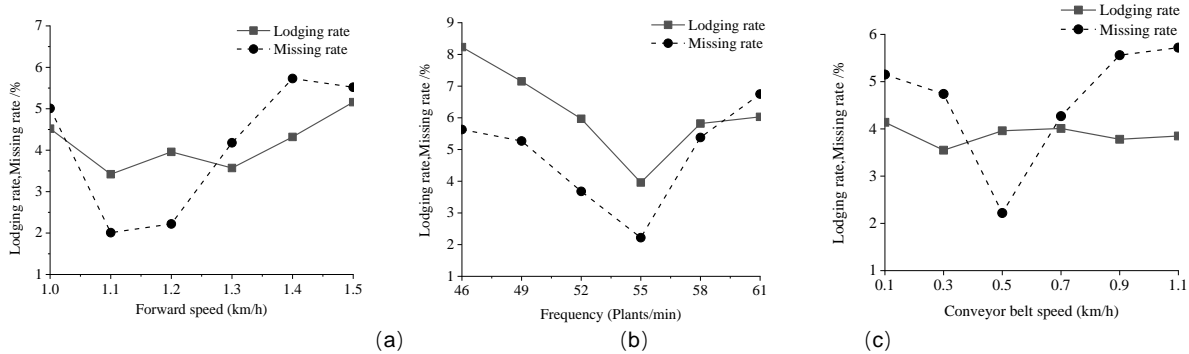


Fig. 7 – Single factor test results

Results of orthogonal test

Based on the single factor test results, the actual working conditions of the prototype, and the operational requirements of the transplanter, the forward speed A range was 1.1~1.3 km/h, the frequency B range of the planter was 52~58 plants/min, and the speed of the front conveyor belt C was 0.3~0.7 km/h. The test factors and level codes are listed in Table 2.

Table 2

Factors and levels			
Code	Factors		
	A [km/h]	B [Plants/min]	C [km/h]
1	1.1	52	0.3
2	1.2	55	0.5
3	1.3	58	0.7

Significance analysis

A three-factor three-level orthogonal test is used for experimental research and taking the average value of three measurements for each test as the test data, the total number of tests was 9, each experiment was repeated three times. The test results and analysis are shown in Table 3. The results of the variance analysis for lodging rate and missing planting rate are shown in Table 4.

Table 3

Test results					
Test number	A	B	C	Lodging rate T [%]	Missing rate E [%]
1	1	1	1	4.26	4.81
2	1	2	2	3.42	2.01
3	1	3	3	7.16	8.37
4	2	1	2	5.97	3.68
5	2	2	3	4.01	4.27
6	2	3	1	8.33	12.74

Table 3
(continuation)

Test number	A	B	C	Lodging rate T [%]	Missing rate E [%]
7	3	1	3	8.71	10.46
8	3	2	1	5.06	7.04
9	3	3	2	9.74	6.45
Lodging rate / T	K ₁	17.84		21.94	18.65
	K ₂	18.31		10.49	19.13
	K ₃	21.51		25.23	19.88
	R	3.67		14.74	1.23
Better scheme		A ₁ B ₂ C ₁			
Missing rate / E	K ₁	15.19		18.95	24.59
	K ₂	20.69		13.32	12.14
	K ₃	23.95		27.56	23.1
	R	8.76		14.24	12.45
Better scheme		A ₁ B ₂ C ₂			

Table 4

Source	T [%]						E [%]					
	Sum of squares	d	Mean square	F-value	P-value	Significance	Sum of squares	d	Mean square	F-value	P-value	Significance
A	6.126	2	3.063	5.095	0.028	*	0.580	2	0.290	0.192	0.828	
B	12.113	2	6.057	31.824	0.000	**	7.044	2	3.522	7.044	0.032	*
C	1.190	2	0.595	3.125	0.081		3.2014	2	1.6007	6.6859	0.0226	*
AB	4.478	4	1.119	11.764	0.001	**	0.201	4	0.050	0.066	0.936	
AC	0.084	4	0.021	3.50	0.062		7.208	4	1.802	3.25	0.093	
BC	0.303	4	0.076	0.796	0.474		11.190	4	5.595	20.125	0.000	**
Pure Error	2.284	17	0.190				18.137	17	1.511			
Correlation total	26.578	35					47.561	35				

According to the analysis of variance for the orthogonal test in Table 4, for a given significance level $\alpha = 0.05$, factor A had a significant influence on the lodging rate, and factor B and the interaction $A \times B$ had a high significant influence on lodging rate. Factors B and C had significant effects on the rate of missing planting, and the interaction $B \times C$ had a high significant effect on the rate of missing planting. As the test indexes were the lodging rate and the missing planting rate, the smaller the better. Considering the range analysis in Table 2 without considering the interaction, the combination with the lowest lodging rate was $A_1B_2C_1$, and the combination with the lowest missing planting rate was $A_1B_2C_2$.

Analysis of interaction factors

Because the interaction $A \times B$ had a high significant effect on the lodging rate, and the interaction of $B \times C$ had a high significant impact on the rate of missing planting, the selection of the three factor levels cannot be considered alone. In order to further analyze the influence of the interaction between forward speed and planting frequency on the lodging rate, and the interaction between planting frequency and front conveyor belt speed on the missing planting rate, the contour map was drawn by using origin 9.0 software according to the results of Orthogonal test, as shown in Fig. 8.

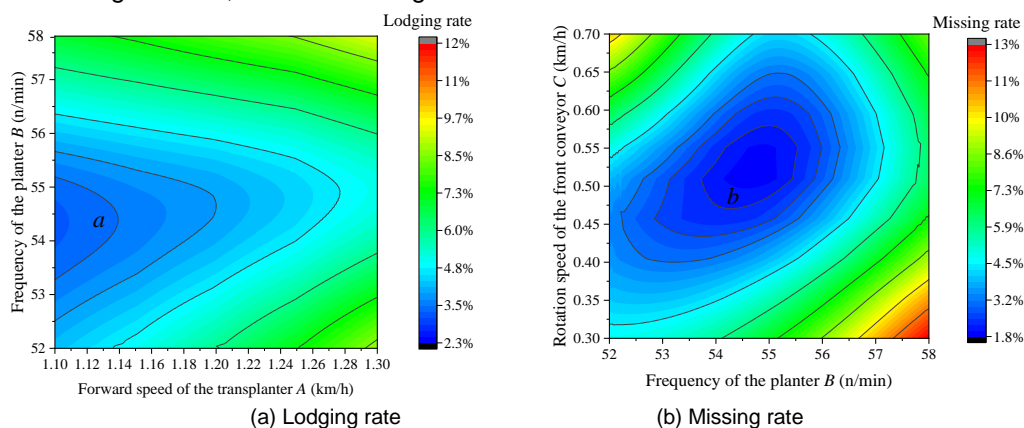


Fig. 8 – Contour map of the influence of multiple factors on the planting effect

It can be seen from Fig. 8 (a) that under the interaction of forward speed and planting frequency, the lowest lodging rate appeared in the curve *a* area when the forward speed was 1.1 km/h and the planting frequency was 53.3~55.7 plants/min. In Fig. 8 (b), the area in curve *b* had a low rate of missing planting, that was, when the planting frequency was 53.7~55.5 plants/min and the conveyor belt speed was 0.475~0.575 km/h. According to the analysis of orthogonal test results, the combination of the factors with the lowest lodging rate and the lowest missing rate and the highest qualified rate can choose the forward speed of 1.1km/h, the planting frequency of 55 plants/min, the speed of conveyor belt being 0.5 km/h, namely $A_1B_2C_2$, the lodging rate was 3.42%, the missing rate was 2.01%, and the qualified rate of planting calculated by formula (14) was 94.57%.

Verification test result

In order to verify the accuracy of orthogonal test results, the optimal combination $A_1B_2C_2$ was validated. The forward speed was set to be 1.1km/h, the planting frequency was 55 plants/min, and the conveyor belt speed was 0.5 km/h. Three repeated tests were conducted to take the mean value, and 120 substrate block seedlings were selected for testing in each group. The test verification results are shown in Table 5. The average qualified rate of the substrate block seedlings was 93.31%. The test results meet the industry standard of vegetable transplanting machine operation quality (NY / T3486-2019) and the industry standard of dryland planting machinery (JB / T 1029-2013) (Lodging rate \leq 7%, Missing rate \leq 5%, Pass rate \geq 90%).

Table 5

Verification test result			
Project	Lodging rate [%]	Missing rate [%]	Pass rate [%]
1	3.58	4.25	92.17
2	2.37	2.91	94.72
3	2.83	4.15	93.02
Average	2.92	3.77	93.31

CONCLUSIONS

In this paper, a transplanting machine of cabbage substrate block seedling was designed, which adopted pneumatic control technology. According to the characteristics of independent seedling raising and high standing stability of substrate block, a transplanting scheme of whole row seedling collection — intermittent transportation — pneumatic seedling separation — clip transplanting was created, which realized the rapid transplanting of cabbage substrate block seedlings and broke the situation of inorganic availability of mechanized transplanting of substrate block seedlings.

Through theoretical calculation and stress analysis, the structural parameters of the key components affecting the planting quality were determined. Taking cabbage seedlings with 40 × 40 × 40mm substrate block size as the experimental object, the effects of forward speed *A*, planting frequency *B*, front conveyor belt speed *C* on lodging rate *T* and missing rate *E* were studied by single factor experiment and three factor three level orthogonal experiment. By means of range significance analysis, the parameter combinations $A_1B_2C_1$ and $A_1B_2C_2$ with the lowest lodging rate *T* and missing planting rate *E* were obtained respectively. On this basis, the effects of the interaction between forward speed *A* and planting frequency *B* on lodging rate *T*, the interaction between planting frequency *B* and front conveyor belt speed *C* on missing rate *E* were further analyzed. The parameter combination of the lowest lodging rate *T*, missing rate *E* and the highest pass rate *Q* was as follows: the forward speed *A* was 1.1km/h, the planting frequency *B* was 55 plants/min, and the front conveyor belt speed *C* was 0.5km/h. The verification test showed that the average planting qualified rate *Q* was 93.31%, and the test results met the relevant indexes of "industry standard for operation quality of vegetable transplanter" (NY / T 3486-2019) and "industry standard for dryland planting machinery" (JB / T 1029-2013).

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