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DEVOLPMENT OF A ROTARY DIBBLE-TYPE CASSAVA PLANTER

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KEYWORDS

cassava, planter, precut stalk, rotary dibble, design.

ABSTRACT

In this study, to meet the requirements of mechanized planting of the wide and narrow double-row ridging cassava cultivation mode, solve the problem of the real-time cutting cassava planter in which cassava stalk cutting length has poor uniformity, and improve the operation performance of the existing precut cassava planters, a rotary dibble-type cassava planter was designed. With its rotary dibble-type stalk metering device, transmission system and other components, the planter can complete the sowing, ditching, soil covering and suppression operations simultaneously. The results of a performance evaluation and an analysis of field trials showed that the variation coefficient of the planting distance was less than 30%, and the planting qualification rate was greater than 95%. The order of factors affecting the variation coefficient of the planting distance was determined to be transmission ratio followed by the forward speed. The order of factors affecting the planting qualification rate was determined to be transmission ratio followed by the forward speed. The results of the variance analysis showed that the influences of the transmission ratio and forward speed on the accuracy of planting distance and the planting qualified rate were significant. The forward speed of the planter operation was recommended to be 0.56 m/s.

INTRODUCTION

Cassava is one of the three major tuber crops in the world, and its roots are the main food for one billion people worldwide. Cassava is the second most important food crop in Africa and a raw material for animal feed, industry and energy in Asia (Bobobee et al., 2019; Duan et al., 2019; Liang et al., 2016). The development of cassava planters has become increasingly important due to the sharp increase in agricultural production costs, the serious population aging problem and the shortage of agricultural production labor.

Some countries have developed machines that can be applied to cassava planting. These cassava planting machines were mainly real-time cutting types with good operating performance and could meet production needs. Odigboh & Ahmed (1982) developed a two-row cassava planter through design and optimization improvements, and the planter performed well at planting speeds up to 8 km/h. A single-row semiautomatic transplanter was refitted by Ladeinde (1995) into a cassava planter, and it could operate at an average speed of 4.39 km/h with a field capacity of 0.39 ha/h and field capacity of over 60%. The Latin American and Caribbean Consortium to Support Cassava Research and Development, by comparing the operating performance of two-row and three-row cassava planters, determined that a two-row cassava planter was the best choice because it could adjust the row spacing, plant spacing, stalk length and planting depth (Ospina et al., 2007). Lungkapin (2007, 2009) designed a cassava planter suitable for use in field conditions in Thailand, with an average field capacity and field efficiency of 0.135 ha/h and 65.3%, respectively, and an average fuel consumption of 21.7 L/ha. The Nigerian National Center for Agricultural Mechanization developed a single-row tractor-drawn mechanical cassava planter that required only one operator to feed the cassava stalks. When the planter was running at a speed of 3.7 km/h, the field capacity was 2.7 ha/h, and the planting distance and planting depth were 1000 mm and 120 mm when the hill rate was 3.3%, respectively (Hariharan et al., 2015; Kamal et al., 2009; James & Faleye, 2015). The Federal University of Science and Technology in

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Akure also developed a cassava planter that achieved field productivity and field productivity of 0.28 ha/h and 73.1%, respectively, at a forward speed of 4.24 km/h (Oyedeji et al., 2011). The 2CMS-2 type cassava planter, which could complete ditching, cassava stalk cutting, planting, fertilization, and covering soil at one time, was designed. Its stalk-injuring rate and qualified rate of stem length were 4.9% and 91.7%, respectively, the average planting distance was 807 mm, and the productivity was 0.32 ha/h (Yang et al., 2015; Zeng et al., 2011). In addition, more research has focused on the overall design of cassava planters (Chen et al., 2022; He et al., 2019; Shi et al., 2022) and the optimal design of cutting mechanisms (Cui et al., 2017; Li et al., 2021; Ren et al., 2020).

However, when the real-time cutting type cassava planter continuously feeds the cassava stalks, the cutting length of the head and tail ends of the cassava stalks are prone to poor stability, and repeated planting of two stalks may occur as a problem. Therefore, the precut type cassava planter, which can ensure the uniformity of cassava stalk length by precutting and screening, was proposed. For example, Zhang (2021) designed a precut cassava planter, and the planting accuracy, missed seed rate and reseeding rate of this planting machine were 81%, 12% and 14%, respectively. Chen et al. (2022) designed a stepped vibration stalk dispersal mechanism for a precut cassava planter in which the success rates of lateral attitude adjustment and scattered stalk transportation reached 85.7% and 88.2%, respectively. In general, few studies on precut cassava planters exist, and the performance of the existing machines needs to be improved.

At the same time, cassava harvesters, which were developed in recent years, have not adapted to the equal row spacing cultivation method. As a consequence, the tractor walking wheel of the traction harvester crushes the cassava roots, causing a cassava root harvest loss rate of up to 17%. Therefore, the wide and narrow double-row ridging cultivation mode, which is an agronomic model suitable for mechanized cassava cultivation, was proposed. This cultivation mode effectively prevents the tractor from crushing the cassava rows and significantly reduces the root damage rate during mechanized harvesting, and the loss rate is less than 5% (Deng et al., 2018, 2019). However, none of the existing cassava planters are suitable for this cultivation mode, and a new cassava planter must be developed.

Therefore, to meet the needs of mechanized planting in wide and narrow double-row ridging cultivation modes, the objective of this study was to design a precut cassava planter based on the wide and narrow double-row ridging cultivation mode and to analyze the operating performance of this planter. The research is important to the development of mechanized planting technology for cassava and the wide and narrow double-row ridging cultivation mode.

MATERIAL AND METHODS

The wide and narrow double-row ridging cultivation mode

The ridge technical parameters of the wide and narrow double-row ridging cultivation mode (Figure 1) are an important basis for the design of the cassava planter. Before starting the design of the cassava planter, the structural characteristics of this cultivation mode must be understood and analyzed. The ridge technical parameters of this mode require that the width of the ridge top be approximately 1100 mm, the width of the ridge bottom be approximately 1200 mm, the width of the furrow be approximately 500 mm, and the height of the ridge be 250 mm to 300 mm.

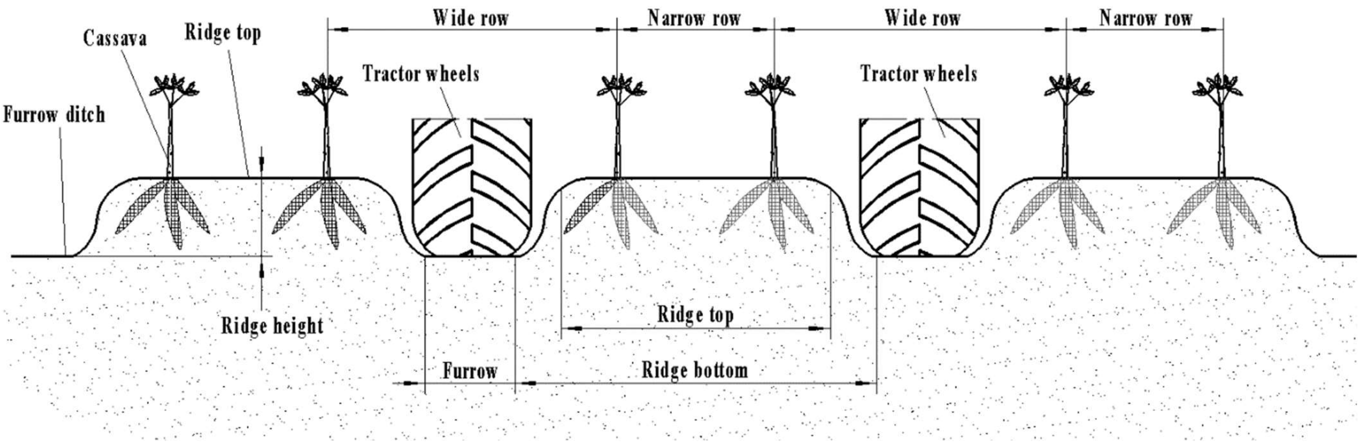


FIGURE 1. Structural diagram of the wide and narrow double-row ridging cultivation mode.

Characteristics of cassava stalks

In previous studies on the storage root configuration of cassava and the influence of mechanical harvesting, Huanan 205 (SC205) and Nanzhi 199 (NZ199) had lower loss rates and potato injury rates during mechanized harvesting (Su et al., 2019), and these two varieties of cassava have relatively large areas in China. Therefore, this study selected Huanan 205 (SC205) and Nanzhi 199 (NZ199) as the research reference objects of cassava planters. The cassava stalk material was selected from the cassava straw when the cassava root was mature. The stem diameter ranges for these two varieties were 10 mm to 50 mm, and the length range was 150 mm to 200 mm, as shown in Figure 2. The characteristic values of cassava stalks were used as a reference basis for the design of the parts of the planter.

FIGURE 2. Cassava stalks.

Main frame of the cassava planter

The rotary dibble-type cassava planter comprises a cassava stalk box, transmission system, ground wheel, three-point hitch, frame, ridge plate, stalk groove, furrow opener, soil-covering system, seat and rotary dibble-type stalk metering device. The overall structure is shown in Figure 3. The planter measurements are 1800 mm in width, 1600 mm in length, and 2050 mm in height. The planter has two sets of metering devices that can plant two rows of cassava at the same time.

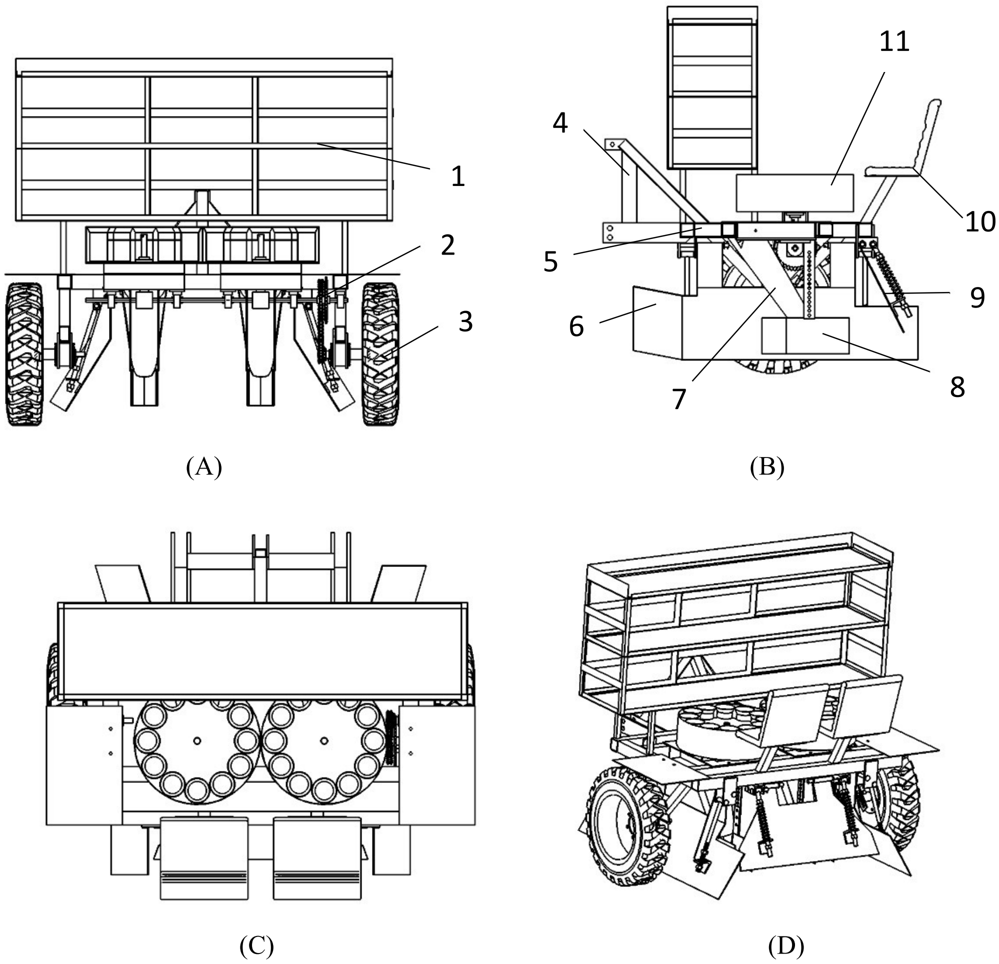


FIGURE 3. Structural diagram of a rotary dibble-type cassava planter: 1) cassava stalk box; 2) transmission system; 3) ground wheel; 4) three-point hitch; 5) frame; 6) ridge plate; 7) stalk groove; 8) furrow opener; 9) soil-covering system; 10) seat; and 11) rotary dibble-type stalk metering device. (A) Front view. (B) Right view. (C) Top view. (D) Isometric view.

Metering mechanism

The cassava planter is connected to a tractor using a three-point hitching method. Before starting the work of the planter, the cassava stems were cut into 150 mm to 200 mm stalks. After sifting the cassava stalks, the high-quality stalks are placed in a box, and then the box, which is full of stalks, is placed on the stalk box of the planter. When the cassava planter is in operation, the tractor pulls the planter forward. The ground wheel turns and drives the rotary dibble-type stalk metering device. The stalk cups on the stalk metering device perform a circular motion. The two operators remove the cassava stalks from the box and put the cassava stalks into the stalk cups, and only one cassava stalk is placed in each stalk cup. The cassava stalk rotates in a circle with the stalk cup and moves all the way to the stalk outlet. Under the effect of gravity, the cassava stalks fall onto the stalk guide groove and are discharged into the planting ditch by the stalk guide groove.

Design of the rotary dibble-type stalk metering device

The metering device is the core component of a cassava planter. It comprises 12 stalk cups, a protective cover, two bearing housings, transmission shaft I and other components, as shown in Figure 4. The 12 cups are fixed on the connecting plate and turned with transmission shaft I. To ensure the smooth discharge of cassava stalk, the cassava stalk is placed in the stalk cup; according to the length of the cassava stalk, the height of the stalk cup is designed to be 200 mm. When the cassava stalk is discharged from the stalk cup, it not only moves downward due to gravity but also rotates with the stalk cup. Therefore, to ensure that the cassava stalk can completely leave the stalk cup, the diameter of the stalk orifice needs to be larger than the rotational displacement of the cassava stalk. Thus, according to eqs (1) and (2), the falling time and rotational displacement of the stalk can be calculated as follows:

$$H=\frac{1}{2}gt^2 \quad (1)$$

$$s=v_0t+\frac{1}{2}at^2 \quad (2)$$

in which:

h - falling height of the stalk, m;

g - gravity acceleration, m s^{-2};

t - falling time of the stalk, s;

s - rotational displacement of the stalk, m;

v_0 - initial speed of the stalk, m s^{-1},

a - motion acceleration, m s^{-2}.

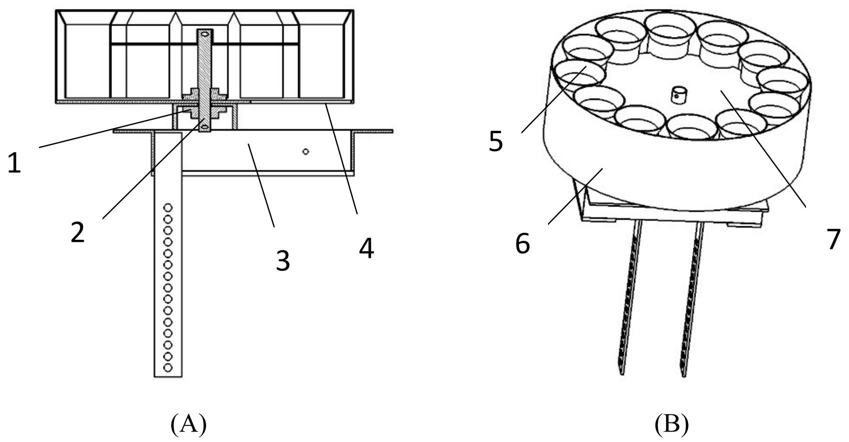


FIGURE 4. Structural diagram of the metering device: 1) bearing housing; 2) transmission shaft I; 3) clamping frame; 4) stalk orifice; 5) stalk cup; 6) protective cover; and 7) connecting plate of the stalk cup. (A) Front view. (B) Isometric view.

According to the length of the stalk, the minimum falling height of the stalk is 200 mm. Therefore, the minimum falling time of the stalk is 0.2 seconds. Under ideal conditions, the stalk cup is considered to rotate at a constant speed; thus, the movement acceleration of the stalk is considered to be 9.8 m/s^2. Therefore, the displacement of the stalk is determined by the length of the cassava stem and the initial speed of the stalk. The initial speed of the stalk is determined by the rotating speed of the metering device.

$$S_F=v_s\times t_s=(N-1)\times L \quad (3)$$

$$N=M\times n_0\times t_s \quad (4)$$

in which:

S_F - forward displacement of the metering device, mm;

v_s - forward speed of the metering device, m s^{-1};

t_s - forward time of the metering device, s;

N - number of cassava stalks;

L - plant spacing of cassava stalk, mm;

M - number of cassava stalks of stalks per revolution of the metering device;

n_0 - rotating speed of the metering device, rpm.

By solving eqs (3) and (4), the relational expression of the rotating speed of the metering device is obtained.

$$n_0 = \frac{v_s}{M \times L} + \frac{1}{M \times t_s} \quad (5)$$

With reference to the forward speed of the metering device (He et al., 2020) and the ideal plant spacing of cassava stalks, the forward speed is 1 m/s, and the plant spacing is 650 mm. Therefore, the rotating speed of the metering device is determined to be 11.66 rpm. Assuming that the ideal state of the cassava stalk is on the axis of the stalk cup (Figure 5), the distance between the cassava stalk and the centerline of the metering device is designed to be 160 mm. Based on the above results, the initial speed of the stalk is 0.2 m/s, and the diameters of the stalk orifice should be greater than 40 mm. To adapt the metering device to different sizes of cassava stalks and alleviate clogging problems, the diameter of the stalk orifice was designed to be 120 mm.

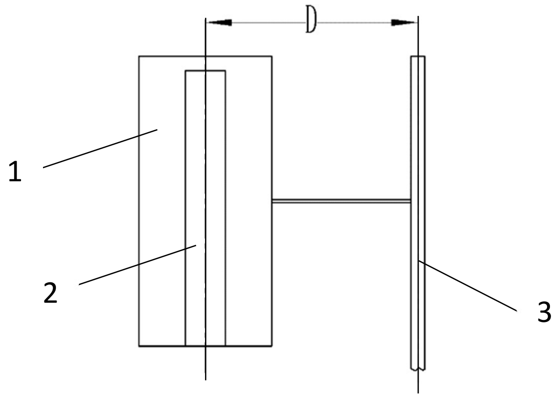


FIGURE 5. Schematic diagram of cassava stalk position: 1) stalk cup; 2) cassava stalk; 3) transmission shaft I; and D) the distance between the cassava stalk and the centerline of the metering device.

To test the rationality of the diameters of the stalk orifice, Unigraphics NX 10.0 software, which was developed by Siemens PLM Software, Plano, TX, USA, was used to perform a movement simulation analysis of the cassava stems, and the movement trajectory of the cassava stems was tracked. In the process of motion simulation, the rotating speed of the metering device was set to 11.66 rpm, and the diameter and length of the cassava stalks were designed to be 30 mm and 180 mm, respectively. The movement of the cassava stems is shown in Figure 6.

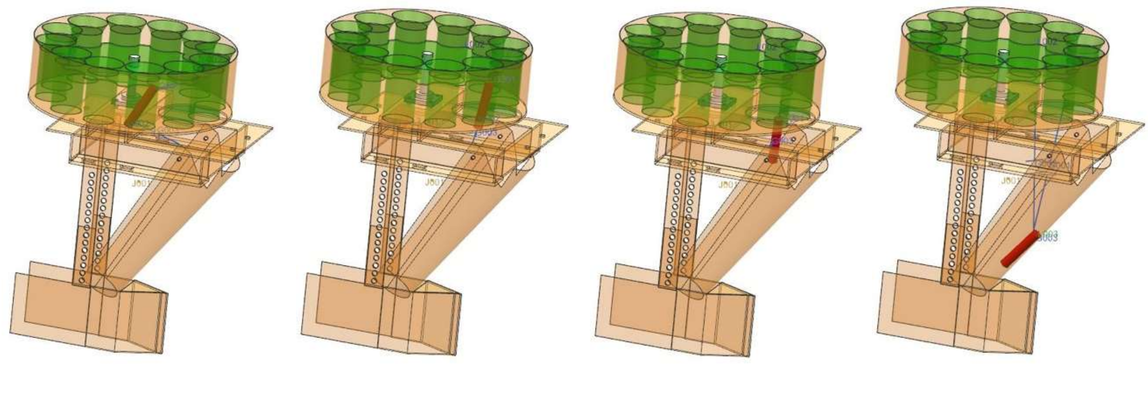


FIGURE 6. The trajectory of cassava stalks in the seeding process. (A) Stalk transfer process. (B) Entering the stalk orifice. (C) Stalk expulsion process. (D) Entering the stalk groove.

According to the above pictures, the trajectory of the cassava stalk was analyzed. A cassava stalk was transported to the stalk orifice by the stalk cup, and then the cassava stalk was discharged from the stalk orifice in a specific direction. During the whole seeding process, the cassava stalk moved smoothly, and no jamming occurred, indicating that the design of the stalk orifice size was reasonable and met the seeding requirements of cassava stalks.

Design of the transmission system

The transmission system comprises a ground wheel, a chain transmission mechanism, three transmission shafts, a commutator and other components, as shown in Figure 7. The ground wheel is the power source of the transmission system. The power is transmitted to the metering device through the chain transmission mechanism and the commutator to provide power for the stalk metering device. The maximum diameter of the ground wheel is designed to be 850 mm. The transmission ratio of the commutator is designed to be 1:1. The driving sprocket and driven sprocket are each provided with two sprockets with different numbers of teeth. The number of teeth of the driving sprocket is 10 teeth and 13 teeth, and the number of teeth of the driven sprocket is 36 teeth and 41 teeth. Thus, four transmission ratios of 10:36, 10:41, 13:36 and 13:41 are formed, which can meet the requirements of 4 types of planting spacing. According to the diameter of the ground wheel and the transmission ratio of the sprocket, the theoretical planting distance of the cassava stem can be calculated as follows:

$$\frac{\pi D}{12x}=\frac{T_1}{T_2} \tag{6}$$

in which:

D - diameter of the ground wheel, mm;

x - theoretical planting distance, mm;

T_1 - number of driving sprocket teeth,

T_2 - number of driven sprocket teeth.

By evaluating the above formula, the theoretical planting spacing of cassava stems can be obtained as 61.59 cm, 70.15 cm, 80.07 cm and 91.19 cm. Therefore, by changing the installation position of the chain, the planting spacing of different varieties of cassava stems can be satisfied, and the versatility of the planting machine is improved. Furthermore, this method of changing the planting spacing is convenient.

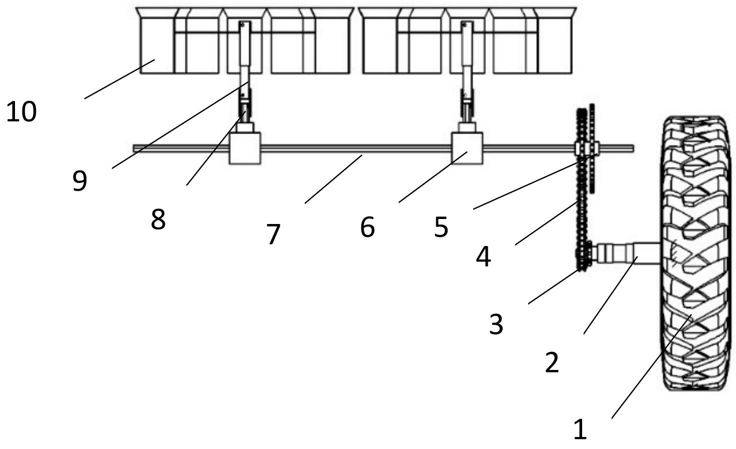


FIGURE 7. Structural diagram of the transmission system: 1) ground wheel; 2) transmission shaft III; 3) driving sprocket; 4) chain; 5) driven sprocket; 6) commutator; 7) transmission shaft II; 8) transmission connection sleeve; 9) transmission shaft I; and 10) stalk cup.

Design of the frame

The frame (Figure 8) is welded rectangular pipe profiles and steel plates, including 4 longitudinal beams, 4 transverse beams, 2 trapezoidal support beams, 2 connecting beams, and 8 connecting plates. It is divided into three parts: the upper and lower frames and a three-point hitch. The upper frame carries key components such as the transmission system, metering device, stalk groove, ridge plate, covering plate, seat, furrow opener, and stalk box. The lower frame carries the ground wheels. The three-point hitch is connected to the tractor. The material used for the rectangular pipe profiles and steel plates is Q235-type carbon structural steel. To adjust the planting row spacing of cassava stalks, the 16 holes designed at the position of the planter unit can be installed according to the planting needs. Therefore, the adjustment range of the planting row spacing is 500 mm to 700 mm.

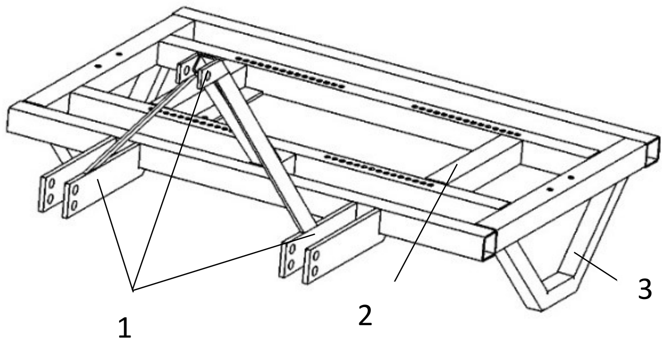


FIGURE 8. Structure of the frame: 1) three-point hitch; 2) upper frame; and 3) lower frame.

To verify the rationality of the frame design, Unigraphics NX 10.0 software was used to perform finite element analysis on the force of the frame. By analyzing the stress and strain distribution of the frame, information on the structural force was obtained, the design of the frame's structural parameters was judged to be reasonable, and the basis for the modification of the structural parameters was provided. When the cassava planter is operating, the weight of the stalk box and stalks is approximately 200 kg, the weight of a metering device is approximately 36 kg, the total weight of the seats and the operators is approximately 150 kg, the total weight of the two ridge plates is approximately 10 kg, and the weight of the ground wheel mechanism is approximately 15 kg. Therefore, the frame is subjected to 2000 N, 720 N, 1500 N, and 100 N pressure on the stalk box, metering devices, seats and ridge plates, respectively, and the total pulling force of the two ground wheel mechanisms is 300 N. According to the loads, material properties, and fixed constraints of the frame, the static dynamic characteristics of the frame were analyzed, and the result shows that the maximum stress is 210.19 MPa, as shown in Figure 9.

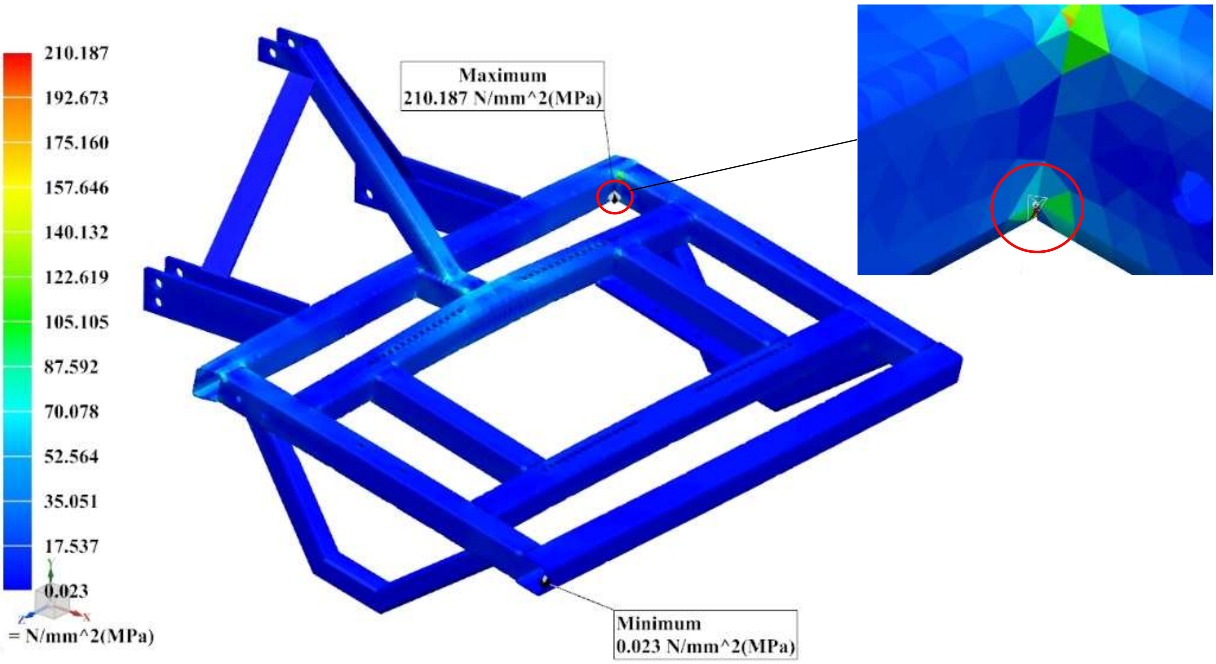


FIGURE 9. Stress cloud of the frame.

Design of the gatherer and furrow opener system

The gatherer and furrow opener system (Figure 10) consists of a positioning frame, a gatherer, two height-adjusting plates and a furrow opener. The positioning frame, which comprises angle steel, steel plate and channel steel welding, is designed with bolt holes for positioning and installation with the frame and the gatherer. The gatherer is formed by bending stainless steel with a length of 600 mm, and it is fixed in position using bolts. The height-adjusting plate is a steel plate with a length of 540 mm and is designed with 15 holes for fixed installation of the furrow opener. The furrow opener can be fixedly installed on the hole that meets the needs of the seeding depth. The furrow opener, with a length and height of 490 mm and 200 mm, respectively, comprises a triangular plowshare and two retaining plates welded together. Two gatherer and furrow opener systems are installed on each planting machine with bolts, and the installation distance of the two systems is the row spacing of the cassava stems.

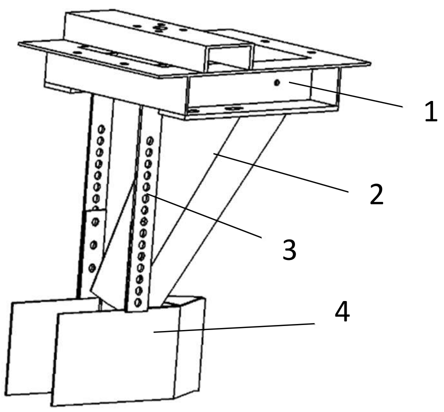


FIGURE 10. Schematic of the gatherer and furrow opener system: 1) positioning frame; 2) gatherer; 3) height adjusting plate; and 4) furrow opener.

Design of the soil-covering system

The soil-covering system consists of two mounting bases, two coil springs, two support rods, a cover board, two location bases, two support rod positioning dowels and two cover board positioning dowels (Figure 11). The function of the soil-covering board is to cover the planting ditch with the cassava stems. According to the width of the ridge top of the wide and narrow double-row ridging cultivation mode, the maximum width of the soil-covering board is designed to be 1100 mm. The coil springs provide pressure for the soil-covering board to compact the soil such that the cassava stems are in full contact with the soil. The position of the bolt nut on the support rod can be adjusted to adjust the coil spring pressure, which can meet the needs of different degrees of soil compaction.

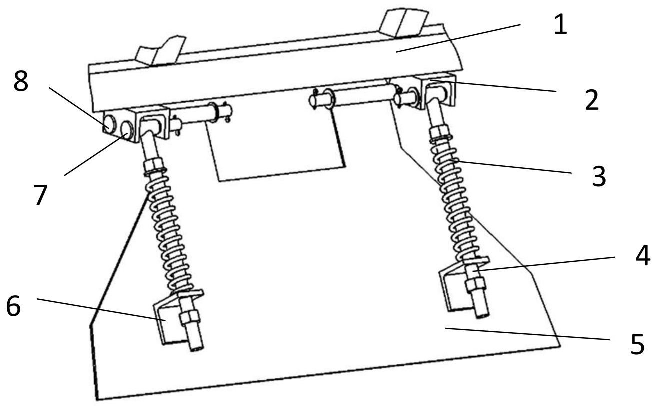


FIGURE 11. Schematic of the soil-covering system: 1) frame; 2) mounting base; 3) coil spring; 4) support rod; 5) soil cover board; 6) location base; 7) support rod positioning dowel; and 8) cover board positioning dowel.

Field trials

Trials for the rotary dibble-type cassava planter were performed at an experimental demonstration base for complete cassava production mechanization at the Agro-Machinery Research Institute of the Chinese Academy of Tropical Agricultural Sciences in Zhanjiang city, Guangdong Province (Figure 12). The area of this experimental demonstration base is 2 hectares. To conduct the field test of the plant spacing accuracy of the planter, the experimental demonstration base was divided into four plots, and four different operating speeds were used for planting operations on each plot. The cassava varieties used in the experiment were all Nanzhi 199, and the length of the cassava stems was approximately 150 mm. The tractor used was a YTO-X904 wheeled tractor produced by the China YTO Group. The technical parameters of the YTO-X904 wheeled tractor are shown in Table 1. During the experiment, the cassava stems were placed in the stalk cups of the planting machine by two skilled workers, the forward displacement of the planting machine was above 100 m, and the sample data were collected in the middle 70 m. After the planting machine was completed, a high-precision ruler was used to measure the distance between the middle positions of two adjacent cassava stems, and the planting distance of the cassava stems was obtained.

FIGURE 12. Trials for the rotary dibble-type cassava planter.

TABLE 1. Technical parameters of the YTO-X904 wheeled tractor.

Index	Technical parameter
Overall dimensions (length × width × height) (mm)	4350 × 2300 × 2765
Wheelbase (mm)	2314
Min. ground clearance (mm)	440
Min. operating mass (with safety stand) (kg)	3920
Tire specifications of front wheel	13.6-24
Wheel tread of front wheel	1562-2000
Tire specifications of rear wheel	16.9-34
Wheel tread of rear wheel	1520-2120
Rated power (kw)	66.5
Forward speed range (km/h)	≤27.17
Backward speed range (km/h)	≤12.85

Field analysis

Planting distance accuracy

The planting distance test of the planter was performed under four forward speed conditions, and the stalk metering device adopted four theoretical plant spacing transmission ratios for the test. By measuring the distance between two adjacent cassava stems planted by the planter, the actual planting distance of the planter was obtained. The coefficient of variation of the test sample was used to reflect the planting distance accuracy of the planter. The coefficient of variation is given by the formula below:

$$CV=\frac{\sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}}}{\bar{x}}\times 100\% \tag{7}$$

in which:

CV - variation coefficient of cassava stalk spacing, %;

x_i - actual planting distance, mm,

$\bar{x}$ - average value of actual planting distance, mm.

Optimal operating speed (m/s)

To obtain the best operating forward speeds for the four planting distances, based on the positions commonly used in actual tractor operations and under the condition of an engine speed of 1500 rpm, through pretests, 0.29 m/s, 0.46 m/s, 0.56 m/s and 0.7 m/s were selected as the test conditions of forward speed. By analyzing the eligible rate of the four theoretical planting distances under the conditions of three forward speeds, the forward speed with the best eligible rate was selected as the optimal working speed corresponding to the four theoretical planting distances of the planter. The qualification rate of metering was given by the formula below:

$$y=\frac{q}{Q}\times 100\% \tag{8}$$

in which:

y - qualification rate, %;

q - qualification sample size;

Q - total sample size.

Statistical analysis

Through statistical analysis of the average plant spacing evaluation of 100 actual plant spacing samples, the plant spacing of each operating condition was obtained. According to the evaluation method of operation quality of ridge-type cassava planters (Qin et al., 2021), when the seed spacing was less than half of the theoretical spacing, it was repeated. When the seed spacing was greater than 1.5 times the theoretical spacing, it was an omission. The double planting spacing and omission planting spacing of the four theoretical planting distances are shown in Table 2. As the planting qualification rate is not clearly specified in the evaluation method of operation quality of ridge-type cassava planter, the planting qualification rate of the rotary dibble-type cassava planter cannot be evaluated. Therefore, this study selected the planting qualification rate index in "Potato planters – operating quality" (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2018), which stipulates that the planting pass rate of qualified planters be greater than 80% and the variation coefficient of planting spacing be less than 33% as the evaluation standard for the planting qualification rate of the rotary dibble-type cassava planter. The software used in the analysis was Origin Pro. The test scheme was designed based on the orthogonal test method with two factors and four levels, and the factor level of the orthogonal test with two factors and four levels is shown in Table 3. To reduce the test error, each group of tests was repeated twice, and the test results were determined using the average of the two test results.

TABLE 2. Double planting distance and omission planting distance.

Theoretical planting distance (cm)	Double planting distance (cm)	Omission planting distance (cm)
61.59	＜30.795	＞92.385
70.15	＜35.075	＞105.225
80.07	＜40.035	＞120.105
91.19	＜45.595	＞136.785

TABLE 3. Factor level of the orthogonal test with two factors and four levels.

Levels	Factors	
	Transmission ratio (A)	Forward speed (B) (m/s)
1	10:36	0.29
2	10:41	0.46
3	13:36	0.56
4	13:41	0.70

RESULTS AND DISCUSSION

According to the test method and plan, a field test was performed. To reduce the test error, each group of tests was repeated twice. The test results and range analysis of the orthogonal test with two factors and four levels are shown in Table 4. The variance analysis of the test results is shown in Table 5.

TABLE 4. Test results and range analysis of the orthogonal test with two factors and four levels.

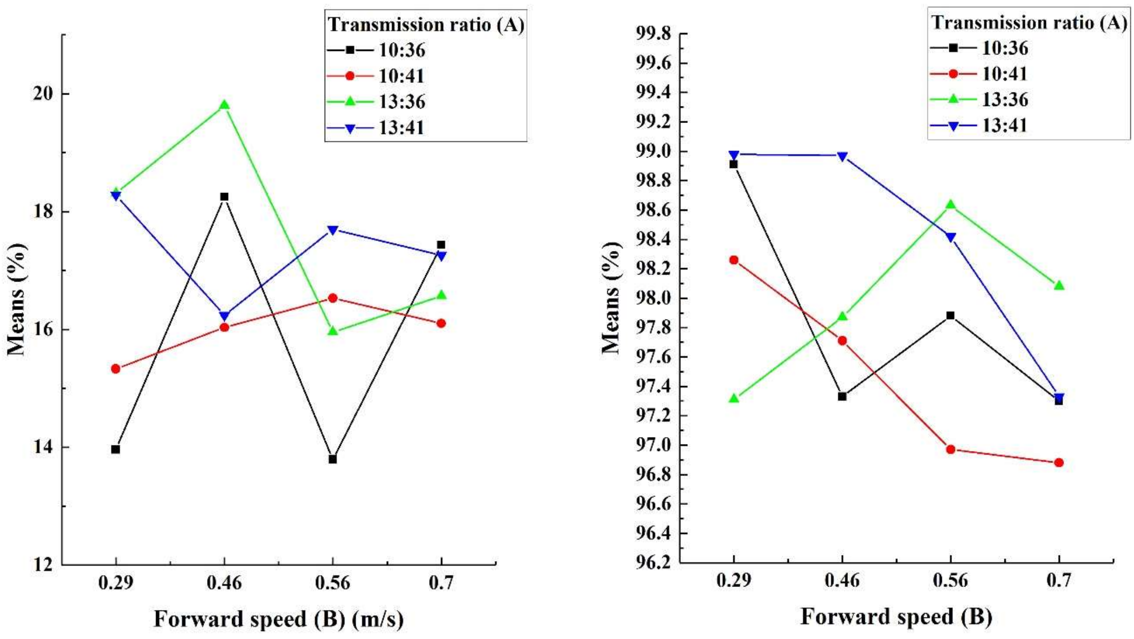
Index	No.	Transmission ratio (A)	Forward speed (B) (m/s)	Variation coefficient (*VC*) (%)	Qualification rate (*y*) (%)
	1	10:36	0.29	13.96	98.91
	2		0.46	18.25	97.33
	3		0.56	13.79	97.88
	4		0.70	17.43	97.30
	5	10:41	0.29	15.33	98.26
	6		0.46	16.03	97.71
	7		0.56	16.53	96.97
	8		0.70	16.10	96.88
	9	13:36	0.29	18.31	97.31
	10		0.46	19.80	97.87
	11		0.56	15.95	98.63
	12		0.70	16.57	98.08
	13	13:41	0.29	18.28	98.98
	14		0.46	16.24	98.97
	15		0.56	17.70	98.42
	16		0.70	17.26	97.33
Variation coefficient (*VC*) (%)	Sum of test results at level 1	63.43	65.88		
	Sum of test results at level 2	63.99	70.32		
	Sum of test results at level 3	70.63	63.97		
	Sum of test results at level 4	69.48	67.36		
	Range	7.2	6.35		
	Primary and secondary factor	Transmission ratio (A), Forward speed (B)			
	Optimum scheme	Transmission ratio (A) = 10:36, Forward speed (B) = 0.56 m/s			
Qualification rate (*y*) (%)	Sum of test results at level 1	391.42	393.46		
	Sum of test results at level 2	389.82	391.88		
	Sum of test results at level 3	391.89	391.90		
	Sum of test results at level 4	393.7	389.59		
	Range	3.88	3.87		
	Primary and secondary factor	Transmission ratio (A), forward speed (B)			
	Optimum scheme	Transmission ratio (A) = 13:41, forward speed (B) = 0.29 m/s			

TABLE 5. Variance analysis results of the orthogonal test with two factors and four levels.

Index	Source of variance	Sum of squared	Degree of freedom	Mean squares	F test	P value
Variation coefficient (*VC*)	Transmission ratio (A)	10.737	3	3.579	5089.901	4.809×10^{-24}
	Forward speed (B)	20.709	3	6.903	9817.676	2.520×10^{-26}
	Interaction	46.159	9	5.1290	7294.254	3.623×10^{-27}
	Error	0.011	16	0.001		
	Summation	77.616	31			
Qualification rate (*y*)	Transmission ratio (A)	3.790	3	1.263	2807.130	5.578×10^{-22}
	Forward speed (B)	3.686	3	1.229	2730.481	6.958×10^{-22}
	Interaction	7.432	9	0.826	1835.019	2.240×10^{-24}
	Error	0.007	16	0.000		
	Summation	14.915	31			

Planting distance accuracy

Through the range analysis results (Table 4), the average coefficients of variation coefficients of the four transmission ratios were 15.86% (10:36), 16.00% (10:41), 17.66% (13:36) and 17.37% (13:41). All variation coefficients of cassava stalk spacing were less than 33%, which met the requirements of operational quality of the planter (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2018). The primary and secondary factors for planting distance were A (transmission ratio) and B (forward speed). According to the variance analysis results (Table 5), the influence of the transmission ratio on planting distance was significant, the influence of the forward speed on planting distance was significant, and the influence of the interaction on planting distance was significant. Due to the significance of the interaction, Tukey's test was used to compare the means. The results of the mean comparison analysis are shown in Figure 13.



(A) (B)

FIGURE 13. Trend plot for interaction mean comparison. (A) Mean comparison of the variation coefficient. (B) Mean comparison of the qualification rate.

Through the results of the mean comparison analysis of the variation coefficient (Figure 13), when the transmission ratio (A) was 10:36 and the forward speed (B) was 0.56 m/s, the mean of the variation coefficient was the smallest, and the planting distance accuracy was the highest at this time. Therefore, the transmission ratio (A) and the forward speed (B) could be determined. The optimal combination scheme was 10:36 and 0.56 m/s, and the planting distance accuracy was 86.21%. The results of the optimal combination scheme obtained by means of interaction comparison were consistent with those obtained by range analysis.

Few precut cassava planters have been developed at present, and few examples compare the planting distance accuracy of precut cassava planters. In previous research, the planting accuracy of the precut cassava planter developed by Zhang was 81% (Zhang, 2021). The planting distance accuracy of the rotary dibble-type cassava planter was 5.12% higher than that of the planter developed by Zhang. Compared with other cassava planters, the rotary dibble-type cassava planter had great advantages in planting distance accuracy and met the operation quality requirements of planting machinery.

Optimal operating speed (m/s)

Through the range analysis results (Table 4), the qualified planting rates of the four transmission ratios were 97.86% (10:36), 97.46% (10:41), 97.97% (13:36), and 98.43% (13:41). All of the qualified planting rates of the rotary dibble-type cassava planter were greater than 80%, which met the requirements of the operational quality of the planter (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2018). The primary and secondary factors for the qualified planting rate were A (transmission ratio) and B (Forward speed). According to the variance analysis results (Table 5), the influence of the transmission ratio on the qualified rate was significant, the influence of forward speed on the qualified rate was significant, and the influence of the interaction on the qualified rate was significant. Due to the significance of the interaction, Tukey's test was used to compare the means. The results of the mean comparison analysis are shown in Figure 13.

Through the results of the mean comparison analysis of the qualification rate (Figure 13), when the transmission ratio (A) was 13:41 and the forward speed (B) was 0.29 m/s, the mean of the variation coefficient was the best, and the qualification rate was the highest at this time. Therefore, the transmission ratio (A) and the forward speed (B) could be determined. The optimal combination scheme was 13:41 and 0.29 m/s, and the planting qualification rate was 98.98%. The results of the optimal combination scheme obtained by means of interaction comparison were consistent with those obtained by range analysis.

In previous research, the planting qualification rate of the precut cassava planter developed by Zhang was 74% (Zhang, 2021), and the planting qualification rate of the five-bar single-row cassava planter developed by Peng was 92.9% (Peng et al., 2022). The planting qualification rate of the rotary dibble-type cassava planter was at least 6.08% higher than that of the planters developed by Zhang and Peng. Compared with other cassava planters, the rotary dibble-type cassava planter had great advantages in planting qualification rate and met the operational quality requirements of planting machinery.

Therefore, if pursuing a higher planting distance accuracy, the recommended forward speed is 0.56 m/s because under the condition of slower operation, the cassava stalks were often turned over when they fell into the stalk ditch. If pursuing a higher qualified planting rate, the recommended forward speed is 0.29 m/s because under the condition of a slower operating speed, the time for workers to send stalks was relatively sufficient, less leakage of cassava stalks occurred, and the inertial displacement of the cassava stem was also relatively small. However, according to the needs of production efficiency, the forward speed should be 0.56 m/s. In this way, the planting distance accuracy can be guaranteed, and better operation efficiency can be obtained.

The germination rate of the cassava stalks planted by the rotary dibble-type cassava planter reached 100%, indicating that the damage rate of the cassava stalks during the planting process of the planter was 0.

CONCLUSIONS

A rotary dibble-type cassava planter was designed to meet the agronomic requirements of the wide and narrow double-row ridging cultivation mode of cassava. Through field analysis, the order of factors affecting the variation coefficient planting distance was determined to be the transmission ratio followed by the forward speed. The variation coefficient of the planting distance was less than 30%. The order of determining the factors affecting the planting qualified rate was the transmission ratio followed by the forward speed. The planting qualification rate was greater than 95%. The influences of the transmission ratio, forward speed and their interaction on the variation coefficient planting distance and planting qualified rate were significant. During the operation of the rotary dibble-type cassava planter, its forward speed should be 0.56 m/s such that a relatively high operation efficiency can be obtained to maintain a good planting quality. The work quality of the rotary dibble-type cassava planter meets the requirement of technical specifications of quality evaluation for planting machinery, and its operating performance is better than that of the existing precut cassava planter. The rotary dibble-type cassava planter can be promoted and applied to production.

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