Design of pneumatic-type red jujube picker

Junbing Pan[1], Jiazhong Xu[2], Chenliang Zhang[3], Hengming Zhang[4], Lin Li, Xuyan Cao[5]

[1,2,3,4,5]*Shaanxi institute of technology, Xi'an, China*

Abstract- In order to solve the problems of low harvesting efficiency, high cost and low mechanized harvesting degree of red jujube, the artificial harvesting of red jujube in harvest period is very intensive. In this paper, a pneumatic-type red jujube picker was developed using the air-blowing principle, and a bench test was carried out. The test results show that the uniformity of the outlet speed of the nozzles is good, the pick-up rate of the whole machine can reach 80.2%, and the injury rate is 0. The machine can reduce the loss of ground red jujube and reduce the labor intensity, and provides a theoretical basis for the development of the air-blown red jujube harvester.

Keywords – CFD, Ground jujube harvesting, jujube harvest

I. INTRODUCTION

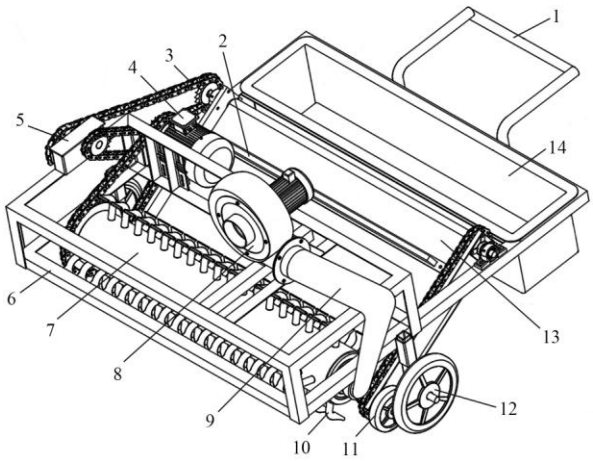
Xinjiang, China has a unique geographical location and climatic conditions, suitable for planting high-quality red jujube, and its cultivation is mainly based on dwarf dense planting mode [1~4]. The planting area in Xinjiang Province has reached 476,000 hm2 [5~8], and its yield has exceeded 34,700 t. Production practice shows that the dwarf dense planting mode has high yield and the value of promoting planting. At present, the harvesting of ground jujube, which is mainly realized by manual picking, accounts for 30%~50% of the total production during harvest season [9]. Manual picking up work is labor intensive, high cost and low efficient, which can hardly meet the ground jujube picking demand in Xinjiang. Therefore, it is urgent to research and develop a new jujube picking device to solve the current problem.

In recent years, Chinese researchers have already carried out relevant research on the ground jujube pickup machine. In 2014, Shi & Ma developed an air-suction jujube picking machine. This machine is simply structured. But the picking efficiency is 5.2 times of that by manual picking [10]. However, it consumes more energy and produces too much noise; in 2017, Lu, et al. developed a new ground jujube harvester combining Mechanical collection in a row and air suction picking based on the characteristics of dwarf dense planting mode. However, the pickup rate is going down with the increase of the advancement speed of the machine [11]; Dang, et al. also designed an air-suction jujube harvester, which adopts a double airflow separation device, and has good separation effect and low impurity content of the harvested jujube. Because manual hand-held suction duct is needed for harvesting operation, the labor intensity is high [12]; In 2019, Zhang, et al developed a kind of air suction type jujube picking machine. which mainly uses air suction type to pick up red jujube with high power consumption [9]. The above research mainly focuses on the research of air-suction red jujube picker, which has the advantages of good picking effect, low jujube injury rate, and the disadvantages of low picking efficiency and large power consumption. Therefore, based on the advantages of low jujube injury rate and the previous research foundation, this paper develops a kind of red jujube picker by using the principle of air blowing, and carries out bench test, which provides a theoretical basis for the development of the red jujube picker.

II. MACHINE STRUCTURE AND WORKING PRINCIPLE

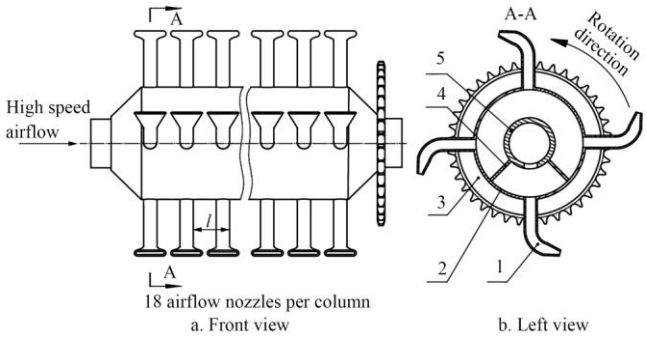
2.1 Machine structure

In Figure 1，The jujube picker is mainly composed of a frame, a blower, an electric motor, a gearbox, an airflow distribution device, a conveying device, a ground wheel and a profiling wheel. The conveying device is obliquely hinged in the middle of the picker, with the bottom contacted with the profiling wheel and ground; the airflow distribution device mainly consists of an airflow inlet duct, a rotating airflow duct and a shelter plate, etc.; one side of the inlet duct is connected to the blower through a duct and the other side is sealed; the airflow inlet duct and the shelter plate together formed an "Ω" shape shelter. The included angle between two shelter plates is 90°; four rows of nozzles are evenly placed around the rotating duct, 18 nozzles in each row. The distance between two nozzles is 71 mm, as shown in Figure 2. The operating breadth of the picker is 1.3 m, and other structural parameters are shown in Table 1.



1.Handle 2. Brush 3. Chain 4. Electric motor 5. Gearbox 6. Frame 7. Air distribution device 8. Blower 9. Duct 10. Airflow spray tube 11. Profiling wheel 12. Ground wheel 13. Conveying device 14. Collecting box

Figure 1 Pneumatic-type red jujube picker



1. Nozzle 2. Rotating airflow duct 3. Chain 4. Shelter plate 5. Airflow inlet duct

Figure 2 Structure of airflow distribution device

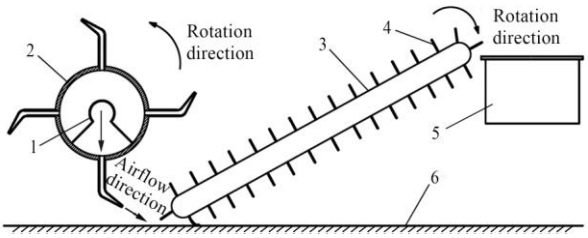
Table -1 Experiment Result

Parameters	Value
Total length (mm)	1520
Airflow inlet duct (d/mm)	80
rotating airflow duct （R/mm）	210
Diameter of airflow spray tube (d1/mm)	20
Nozzle distance (l/mm)	71

2.2. Working principle

The picker is pushed manually to walk among jujube trees. The drive system is powered by a motor. The power produced by the motor is distributed to the conveying device and the airflow distribution device separately through chain transmission. When the picker is working, the high-speed airflow from the blower will enter the airflow inlet duct along the duct to form a high-pressure flow field at the shelter area. Meanwhile, the rotating airflow duct will rotate anticlockwise around its central axis (as shown in Figure 2 and 3). When the airflow spray tube above the rotating airflow duct enter the high-pressure flow field, the high-speed airflow will erupt from the outlet surface and blow the ground jujube to the transporter. With the joint effect of the high-speed airflow and brush, the ground jujube will be “picked” to the transporter. Then the transporter will deliver the jujube to the collector and thus the picking is finished. This device can carry out ground jujube picking continuously.

When the device is working, the profiling wheel will contact with the ground and realize the ground profiling effect. When the rotating duct is working, the current row of airflow spray tubes will leave the high-pressure flow field and the next row of airflow spray tubes will enter the high-pressure flow field. The area of the first row and the second row is the same. In this process, it is regarded that only one full row of nozzles is working.

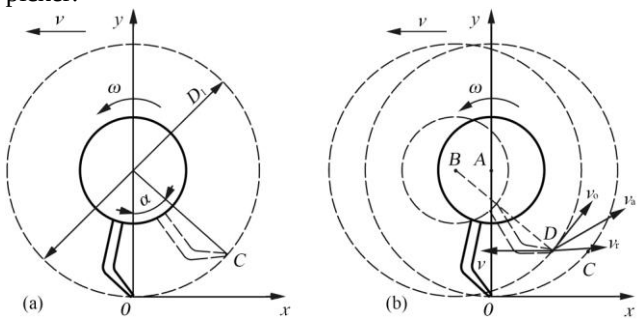


1. Airflow inlet duct 2. Rotating airflow duct 3. Conveying device 4. Brush 5. Collecting box 6. Ground
Figure 3 Working principle diagram of the pneumatic-type red jujube picker

III. KEY COMPONENT DESIGN

3.1. Airflow distribution device

The airflow distribution device is an important part of the pneumatic jujube picker and mainly used for airflow distribution to ensure that the air pressure of the nozzles in the working state is stable, which directly affects the working performance of the picker.



Note: v - Moving velocity along the working direction, m/s; ω - Rotating duct rotation angular velocity, rad/s; α - Rotation Angle of rotating airflow duct, rad; R - Rotating airflow duct radius, mm; D1- Rotating airflow duct diameter, mm.
Figure 4. Kinematics analysis of nozzle

During operation, the rotating airflow duct rotates about its central axis while moving horizontally in the working direction. Establish a cartesian coordinate system for the rotating duct, as shown in Figure 4. Any nozzle rotated to the origin of the coordinate is the initial position. The rotating airflow duct rotates through the angle α during the time t; when the speed of the rotating airflow duct is 0, the nozzle rotates from the origin of the coordinate to the point C, as shown in Figure 4(a); When the velocity in the working direction of the rotating airflow duct is any value v, the nozzle rotates from the origin to the point D. This process can be regarded as the horizontal movement of the vt distance along the working direction in Figure 4(a), as shown in Figure 4(b), and its displacement equation is equation (1). The movement track is a spinning wheel line, that is, the movement track of the nozzle during the working process is a spinning wheel line, which is beneficial for the airflow to blow up the red jujube.

$$y = R - \sqrt{R^2 - \frac{\pi^2 v^2}{4\omega^2} - x^2 - \frac{\pi v}{\omega} x} \tag{1}$$

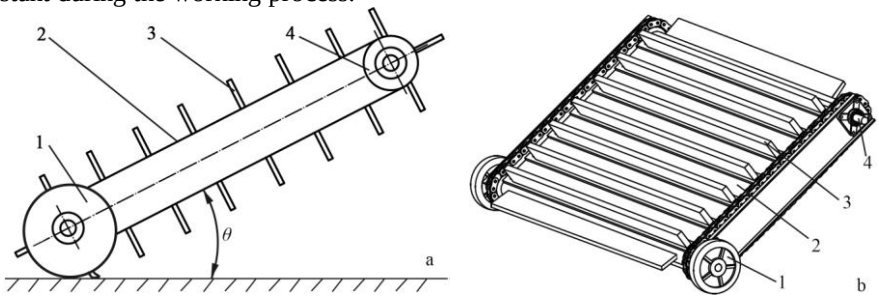
$$R = \frac{D_1}{2}$$

In the equation: v - Moving velocity along the working direction, m/s; ω - Rotating duct rotation angular velocity, rad/s; t - time quantum, s; α - Rotation Angle of rotating airflow duct, rad; R - Radius of rotating airflow duct, mm; D1- Diameter of rotating airflow duct, mm.

3.2. Conveying device

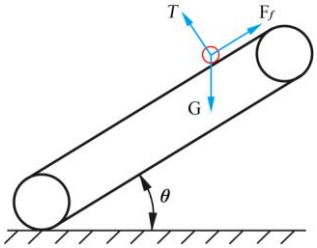
The conveying device cooperates with the airflow to pick up the red jujubes and transport them to the collecting box, and uses chain transmission to ensure continuous and stable operation during the working process. It is mainly composed of a profiling wheel, a conveyor belt, a brush and a sprocket shaft, as shown in Figure 5. Among them, the chain is a roller chain with a curved plate (model 08As); the brush is bolted to the roller chain; the upper end of the conveying device is hinged to the sprocket shaft through the bearing seat, which is fixed on the frame, and the lower sprocket shaft is equipped with a profiling wheel. During the working process, the profiling wheel adjusts the

conveying device with the ground undulation, thereby ensuring that the distance between the conveying device and the ground is constant during the working process.



1. Profiling wheel 2. conveyor belt 3. brush 4. sprocket shaft
Note: θ is the angle between the conveyor and the ground.
Figure 5. The conveying device

In the working process, the angle between the conveying device and the ground is θ, which is mainly for the purpose of blowing the red jujubes to the conveyor belt. If the angle is too small, the length of the picker needs to be lengthened to ensure that the conveying device can be installed on the frame smoothly and connected with the collection box; if the angle is too large, the red jujubes are not easy to blow on the conveying device, which is easy to miss. Kinematic analysis of the red jujubes on the conveying device to study a reasonable angle, as shown in Figure 6.



1. Profiling wheel 2. conveyor belt 3. brush 4. sprocket shaft
Note: θ is the angle between the conveyor and the ground.
Figure 6. Analysis of force analysis of red jujube in conveying device

the angle between the conveyor and the ground

$$\theta = \arctan\frac{1}{\mu_n} \tag{2}$$

In the equation: θ is the angle between the conveying device and the ground, °; μn is the friction coefficient between jujube and conveyor belt.

In order to ensure that the red jujubes do not fall during the conveying process and meet the size requirements of the whole machine, it is determined that the installation angle between the conveying device and the ground is 18°. The profiling wheel is installed at the lower end of the conveying device, and is formed integrally with the conveying device, and is mainly used for adjusting the distance between the conveying device and the ground to avoid falling of the red jujube. According to the ground flatness (the maximum difference of the ground height of the jujube garden is 92.5 mm) and the size requirements of the picker, the diameter of the profiling wheel is determined to be 150 mm.

IV. PICKER PERFORMANCE TEST

4.1. Test materials and methods

In order to verify the rationality of the whole structure design. The bench test was carried out in Tianli Xin Agricultural Machinery Co., Ltd., Wugongcun, Shihezi City, Xinjiang, China. on March 25th, 2019. The test site is shown in Figure 7. The bench test was carried out as follows. Adjust the blower rpm with a frequency converter at first; when the outlet airflow velocity reached 30 m/s, the blower was turned off and connected to the airflow distribution device; then kept the adjusting parameter of the frequency converter, and the blower was restarted; when the blower worked stably, the outlet airflow velocity of 18 nozzles was tested successively, three times for each nozzle; the average of the velocities was taken as the nozzle outlet airflow velocity. The test results are shown in

Figure 8. SMART SENSOR AS8336 hand-held anemometer was used for the test. The range of the anemometer is 0~45 m/s with the accuracy of 0.001 m/s.

The pick-up rate and jujube injury rate of ground jujube are the important index for the evaluation of the picker. The pick-up rate refers to the ratio of the number of red jujubes in the collecting box to the number of ground jujubes, as shown in equation (3); jujube injury rate refers to the number of damaged jujubes and all the red jujubes in the collecting box. The ratio of numbers is as shown in equation (4). the red jujube was counted as damaged red jujube, when the surface of the jujube was obviously damaged or more than 1/4 of the area appears concave in the test. Putted 500 jujubes on the ground to simulate the ground red jujubes, carried out the pick-up test, counted the pick-up rate, repeated the test 3 times (500 jujubes each time), and took the average value as the statistical result.

Figure 7. Test site

$$P = \frac{n_1}{n} \tag{3}$$

In the equation: P is the pick-up rate, %; n1 is the number of jujubes picked up to the collecting box, n is the total number of test jujube samples.

$$Q = \frac{n_2}{n_1} \tag{4}$$

In the equation: Q is the injury jujube rate, n2 is the injury jujube number in the collecting box, n1 is the number of jujubes picked up to the collecting box.

4.2. Test results and analysis

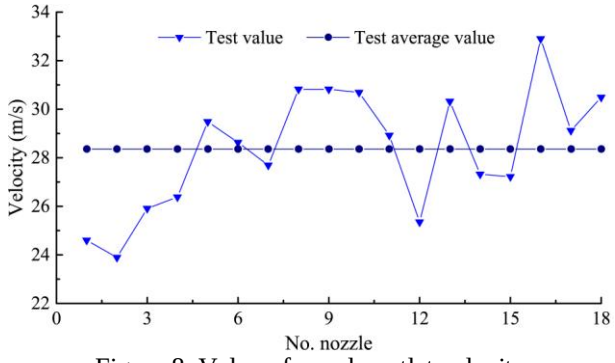


Figure 8. Value of nozzle outlet velocity

The test results show that the minimum outlet airflow speed of the nozzles is 23.58 m/s, which is greater than 18.50 m/s (this value is the minimum value of the ground jujube movement in the previous jujube garden test), and the average outlet airflow velocity of nozzles is 28.36 m/s, the coefficient of variation is 8.5%, and the nozzle outlet airflow velocity is uniform. The pick-up rate of the picker is 80.2%, and the injury rate is 0. It can pick up ground red jujubes, reduce the loss of red jujubes and increase the income of farmer.

V. DISCUSSION AND CONCLUSION

Use the dwarf dense planting mode of red jujube, this paper designed the jujube picker based on the advantages of pneumatic picking, and carried out the bench test on the machine. The test results show that the pick-up rate of the machine is 80.2%, and the injury rate is 0. It can pick up ground red jujubes, which can reduce the loss of red jujubes and increase the income of farmers. The machine picks up ground red jujubes through the airflow, and does not damage any red jujubes; in the case of skimmers, the conveying device passes over ground red jujubes. At this time, the brush on the conveying device is bent, bifurcated and scratched over the red jujube, which has the advantage of low injury rate.

In the harvest period of Xinjiang jujube in China (generally in early November, it has been frosted), the ground leaves have dried up, and the quality is much smaller than the ground red jujubes. During the operation, the dead leaves are blown up before the red jujubes, which had little effect picking up the ground red jujubes. Therefore, the bench test did not simulate the effect of fallen leaves on the pick-up rate. It is difficult for to avoid dead leaves falling on the conveying device or directly into the collection box, but this paper has not been studied for the separation of red jujube impurities. When the jujube picker is working under the ground, the electric motor can't be used, so the picker can be connected with the tractor, and the power output from the tractor is transmitted to the picker by the reducer to solve the power problem; or it can also be connected to the front end of the self-propelled jujube harvester, Powered by a hydraulic motor.

VI. ACKNOWLEDGMENT

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